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SOIL MEMOIR 2

THE SOILS OF CENTRAL SARAWAK LOWLANDS, EAST MALAYSIA

by

I.M. SCOTT
M.A., PhD

VOLUME 1 — TEXT

SOILS DIVISION, RESEARCH BRANCH

DEPARTMENT OF AGRICULTURE – SARAWAK
EAST MALAYSIA

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SUMMARY

Approximately 6,200 square miles (16,000 square kilometres) of Sarawak, Malaysia, were mapped at 1:125,000 scale, the Area including portions of the coastal swamp plain, the interior highlands, and the intervening lower upland zone in which population and development are largely concentrated. Red-Yellow Podzolic Soils (mainly Dystropepts or Cambisols, and their shallow associates) are dominant in the uplands and are mainly derived from sedimentary rocks. Terrace Podzols (Humods; Podzols) are important in many swamp fringe tracts. Deep Organic Soils (Fibrists; Dystric Histosols) mantle much of the coastal swamp zone with Gley Soils (Aquents; Fluvisols) in estuarine and delta tracts.

Silication and loss of clay from the upper subsoil are among the prosesses evident in upland soils but clay illuviation is slight in most profiles examined. Other soil processes involved in upland areas include layering of subsoil materials through slope creep and homogenisation through faunal disturbance. The difficulties of applying quantitative classifications to such soils is discussed and the continued use of traditional genetic groupings is supported. Correlations are made with the USDA and FAO classifications and with others regional systems. A proposed classification is developed for the Area's soils, using Groups based on the Thorp and Smith divisions (with some redefinition) and employing Families and Series defined with the requirements of a practical operational classification in mind. These requirements are discussed.

The study is supported by soil and other maps, by data on sample profiles representing the main Soil Series of the Area, and by discussions of the soil pattern in relation to landform history and to the agricultural landscape now developed on it.

ACKNOWLEDGEMENTS

The writer is indebted to the Drawing Office staff of the Soil Survey Division, Sarawak Department of Agriculture, for the preparation of Maps and Figures, and to Dr. Iqbal Ahmad, Soil Chemist, Sarawak Department of Agriculture, for analytical data quoted in Appendix IV and elsewhere in the text;

to the Royal Tropical Institute, Amsterdam, for clay mineral analysis, and to Dr. E.A. FitzPatrick, Soil Science Department, University of Aberdeen, for preparation of thin sections;

to the Statistics Department, Sarawak, for access to unpublished data from the 1970 census of Sarawak used for tabulations quoted in Appendix II and Figs. 52 – 54; and to the Director of Lands and Surveys, Sarawak, for permission to use air photographs included as Plates 1 and 8 – 17;

and to a large number of Soil Survey Assistants in the Sarawak Department of Agriculture, who shared the burden of field work in the Area over a number of years.

GLOSSARY

Vernacular terms have been avoided as far as possible but some Iban and Malay terms for natural or other features also occur as proper names. These have not been translated. In the following list, the translations given are those which apply to the usage in the present text. Other meanings may also exist.

Batang	(Btg.)	—	main river; trunk stream;
Bukit	(Bt.)	—	hill;
Kampong	(Kg.)	—	village (Malay or Melanau);
Kuala	(K.)	—	river estuary (Malay);
Nanga	(Ng.)	—	river mouth (Iban)
Pulau	(P.)	—	island;
Rumah	(R.)	—	longhouse (Iban village);
Sungei	(S.)	—	river; small stream;
Tanjong	(Tg.)	—	coastal headland; river bend;
Ulu		—	upper reaches of river or drainage basin; headwaters.

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Part I

THE ENVIRONMENT

CHAPTER 1

THE SCOPE OF THE STUDY

The study comprises a survey of the soils in the central Sarawak lowlands, East Malaysia. The Area, which covers approximately 6,200 square miles (16,000 square kilometres) is located in Fig. 1. It is bounded by the coast in the north and west, and extends in the south and east to sheet lines appropriate for mapping convenience.

The title 'Central Sarawak Lowlands' was chosen for brevity rather than exactness. The Area does not form a natural region but rather comprises portions of a number of physiographic units which form a succession from the coast to the interior in a pattern which repeats itself through much of Sarawak. The main components are a coastal plain which largely comprises basin peat swamps, a dissected lowland belt in which population and agriculture are mainly concentrated, and portions of sparsely populated highlands which extend eastward outwith the Area and are dominant in interior Sarawak. The Area conforms quite closely to a tract chosen for geological mapping (Wolfenden, 1960) to which the title 'the Lower Rajang valley and adjoining areas' was applied.

The study was undertaken for the Sarawak Department of Agriculture. The identification of areas with scope for agricultural development underlay the exercise and dictated to some extent the intensity of field investigations in each locality. There was a particular concentrations of work in the dissected lowland belt and in the mineral and shallow peat soils of riverain tracts on the coastal plain and near the coast itself. Relatively little work was undertaken in the steep-land zone. In the larger basin peat swamp tracts interest was largely confined to establishing the depth of the peat mantle (to 10 feet or 3 metres) on the swamp margins and did not extent into the interior, which was mapped from aerial photograph interpretation.

The general level of survey was of reconnaissance intensity, with some areas being mapped at semi-detailed level and a few sample tracts receiving detailed coverage. The methods of survey are explained in Chapter 6 and the intensity of ground observations indicated in Map 2. Some tracts had been surveyed by other workers prior to the start of this study (in the period 1960-1962). These investigations were undertaken before a formal soil classification had been established in Sarawak and only general reports were prepared. Although survey records are incomplete in some cases these data have, as far as possible, been incorporated in the present mapping, supplemented by further survey where necessary.

The study is presented in two main parts, which consider the environment of the Area and the soil mantle developed in it. In discussing the environmental setting particular emphasis is given to the climate and the development of the present landscape. A considerable amount of climatic data have been gathered in the Area but this has not previously been discussed in any detail. A number of geologists working in adjacent areas have reviewed the evidence for the erosional history of nothern Broneo. It was only while the present study was in progress, however, that basic contour mapping coverage was completed for the Area (1:50,000 scale, 100-foot contour interval). Some localities have also been covered by more detailed mapping (1:10,000-1:25,000 scale, mainly 25-foot contour interval). The opportunity is therefore taken to relate previous reconstructions of erosional history to the Area's landforms. The later stages of landform development, which have had a direct influence on the present soil pattern, are discussed in Chapter 4. Evidence for earlier denudation history is detailed in Appendix I.

Vegetation and land-use are considered in Chapter 5. There are some obvious relationships between specific soils and the natural vegetation cover on them, and these are noted. The areas on which the study has concentrated have, however, largely been colonised by farmers and are mainly under secondary covers or under crop. The opportunities for exploring soil-vegetation relationships are less in the Area than in other more sparsely-populated parts of Sarawak, and this subject is therefore not pursued in detail. The forms of agriculture are briefly mentioned in Chapter 5, where the erosion effects of the main land-use types are also discussed. The historical geography of the Area is outlined in Appendix II, where a particular emphasis is given to the development of the present agricultural landscape and the distribution of the present agricultural population.

The soils of the Area are described and classified in Chapters 7–10. A major aspect of the study is the development of a soil classification for the Area. In classification at higher levels there is a broad division between traditional systems with a strongly genctic bias and those currently in vogue for international correlation which, while also partly genetic in basic strategy, attempt to adopt a framework of precisely quantified parameters to identify hierarchical divisions. For reasons discussed in the text, a classification is

proposed which follows the former approach but which incorporates features of the latter where they are useful in a Sarawak context. At lower levels the classification emphasises parameters which can be recognised in the field as, to be of value, it must be an operational classification capable of consistent application by workers with varied level of training and experience. The classification strategy and higher-level divisions are discussed in Chapter 7. Families and Series are briefly described in Chapter 8 and their distribution in the Area in Chapter 9.

Aspects of soil formation in the Area are discussed in Chapter 10, the emphasis here being on the development of residual profile forms which are best expressed in the dissected lowland belt. This and the previous three Chapters are supported by selected profiles which are described in detail in Appendix IV, together with available analytical and other data. These data have been supplied by the Analytical Chemist, Department of Agriculture, Sarawak, and from other sources detailed in that Appendix.

The application of established soil classifications to the soils of the Area, and the difficulties of correlating the proposed classification in a regional or international context are discussed in Chapter 11. Correlations at Series or profile level with systems used elsewhere in the region are given in Appendix V and Appendix VIII. More general considerations with regard to soil classification which arise from the study of the Area's soils are discussed in Chapter 12.

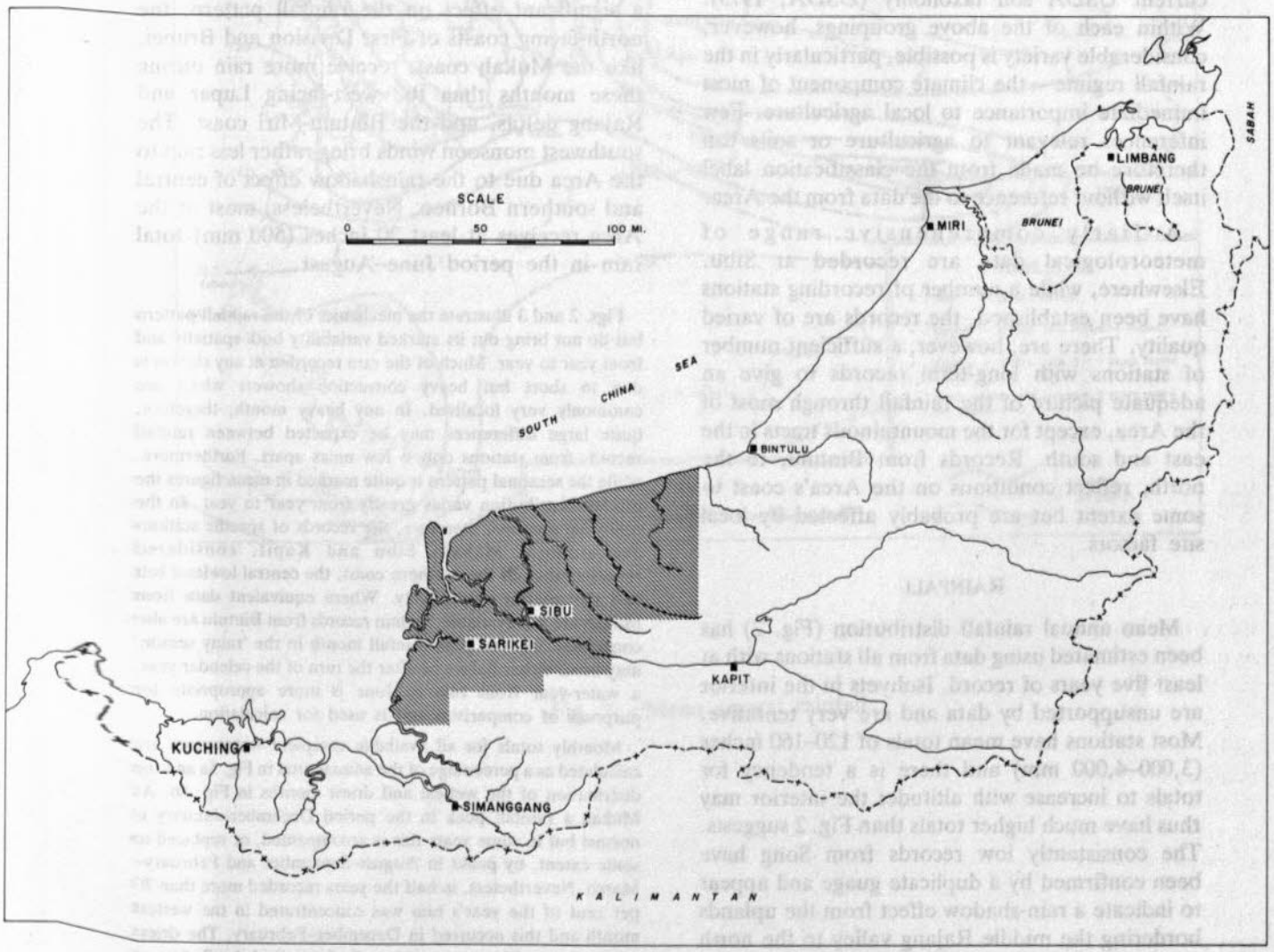


Fig. 1: Location of the Area

CHAPTER 2

CLIMATE

Mean annual rainfall is above 100 inches (2,500 mm) almost throughout the Area and all months average more than 4 inches (100 mm) of rain. Mean monthly temperatures are in the range 24-27°C. The climate therefore qualifies for the hot and wet extreme of most classification systems: the 'Afa – tropical rainy climate, continuously moist' of Koppen (1916, in Miller, 1953: 81), the 'Group I Climate' of Mohr and Van Baren (1954), the 'Type A Climate' of Schmidt and Fergusen (1951) and the 'Equatorial Monsoon Climate' of Miller (1953). The soil moisture and temperature regimes are classed as 'perudic' and 'isohyperthemic' respectively in the current USDA soil taxonomy (USDA, 1975). Within each of the above groupings, however, considerable variety is possible, particularly in the rainfall regime – the climate component of most immediate importance to local agriculture. Few inferences relevant to agriculture or soils can therefore be made from the classification label itself without reference to the data from the Area.

A fiarly comprehensive range of meteorological data are recorded at Sibu. Elsewhere, while a number of recording stations have been established, the records are of varied quality. There are, however, a sufficient number of stations with long-term records to give an adequate picture of the rainfall through most of the Area, except for the mountainous tracts in the east and south. Records from Bintulu, to the north, reflect conditions on the Area's coast to some extent but are probably affected by local site factors.

RAINFALL

Mean annual rainfall distribution (Fig. 2) has been estimated using data from all stations with at least five years of record. Isohyets in the interior are unsupported by data and are very tentative. Most stations have mean totals of 120–160 inches (3,000–4,000 mm) and there is a tendency for totals to increase with altitude: the interior may thus have much higher totals than Fig. 2 suggests. The consistently low records from Song have been confirmed by a duplicate guage and appear to indicate a rain-shadow effect from the uplands bordering the middle Rajang valley to the north and south. To a lesser degree this effect is also suggested by records from Kanowit but not by those from Kapit. A closer network of rainfall stations in the interior might show similar 'dry' pockets in other major river valleys.

Seasonal variation (Fig. 3) is great and reflects the monsoonal air-stream patterns. Heaviest rainfall totals through the Area as a whole are experienced during the northeast monsoon. Particularly high totals are recorded on the exposed northern coast. It has been suggested (Beckinsdale, 1957: 83) that, even in the absence of hill masses backing the coast, the turbulence resulting from on-shore rain-bearing winds meeting the seaward fringe of a high forest area is sufficient to trigger heavy precipitation. This may explain the high figures for Mukah at this season. It does not explain why noticeably lower totals are recorded farther west at Matu and Kut, unless the effect is confined to a very narrow coastal belt, but generalised monthly isohyet plots for the State as a whole (Anon, 1961: 6-18) show that the coast alignment and degree of exposure to onshore winds during January and February have a significant effect on the rainfall pattern: the north-facing coasts of First Division and Brunei, like the Mukah coast, receive more rain during these months than the west-facing Lupar and Rajang deltas, and the Bintulu-Miri coast. The southwest monsoon winds bring rather less rain to the Area due to the rainshadow effect of central and southern Borneo. Nevertheless, most of the Area receives at least 20 inches (500 mm) total rain in the period June–August.

Figs. 2 and 3 illustrate the mechanics of the rainfall pattern but do not bring out its marked variability both spatially and from year to year. Much of the rain recorded at any station is due to short but heavy convection showers which are commonly very localised. In any heavy month, therefore, quite large differences may be expected between rainfall records from stations only a few miles apart. Furthermore, while the seasonal pattern is quite marked in mean figures the rainfall distribution varies greatly from year to year. In the following sections, therefore, the records of specific stations are studied: Mukah, Sibu and Kapit, considered representative of the northern coast, the central lowland belt and the interior respectively. Where equivalent data from Mukah are not available, certain records from Bintulu are also considered. As the peak rainfall month in the 'rainy season' may occur either before or after the turn of the calendar year, a water-year from July to June is more appropriate for purposes of comparison and is used for calculation.

Monthly totals for all available complete water-years are calculated as a percentage of the annual total in Fig. 5a and the distribution of the wettest and driest months in Fig. 5b. At Mukah a rainfall peak in the period December–January is normal but in some years this is accompanied, or replaced to some extent, by peaks in August–September and February–March. Nevertheless, in half the years recorded more than 20 per cent of the year's rain was concentrated in the wettest month and this occurred in December–February. The driest month was, with one exception, in the period April–August and in more than half the years recorded the driest month had less than 2.5 per cent of the year's rain. The seasonal pattern and contrast is therefore quite marked at this station.

At the interior stations the year's rain is somewhat more evenly distributed and no month has more than 20 per cent of

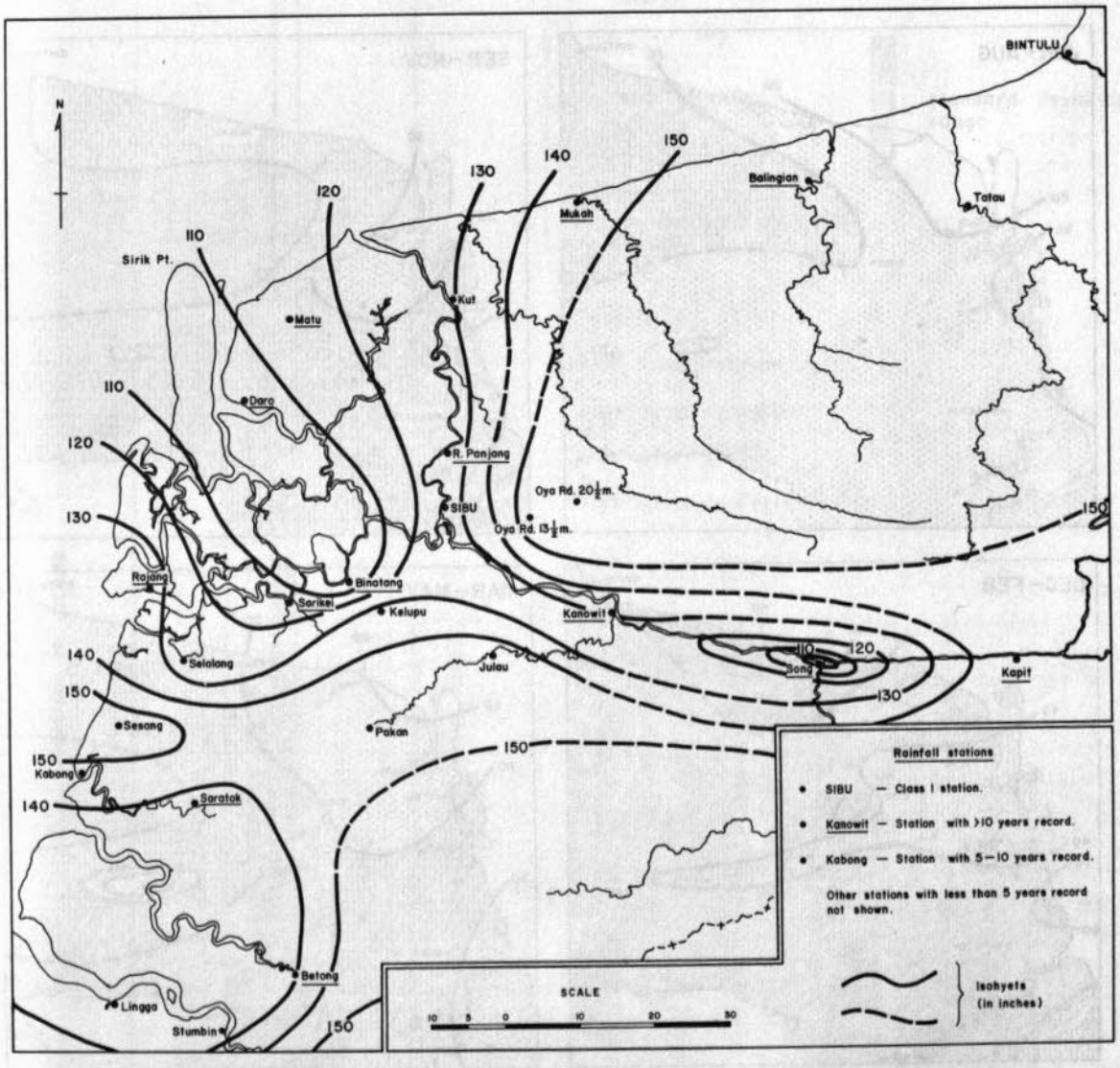


Fig. 2: Mean annual rainfall

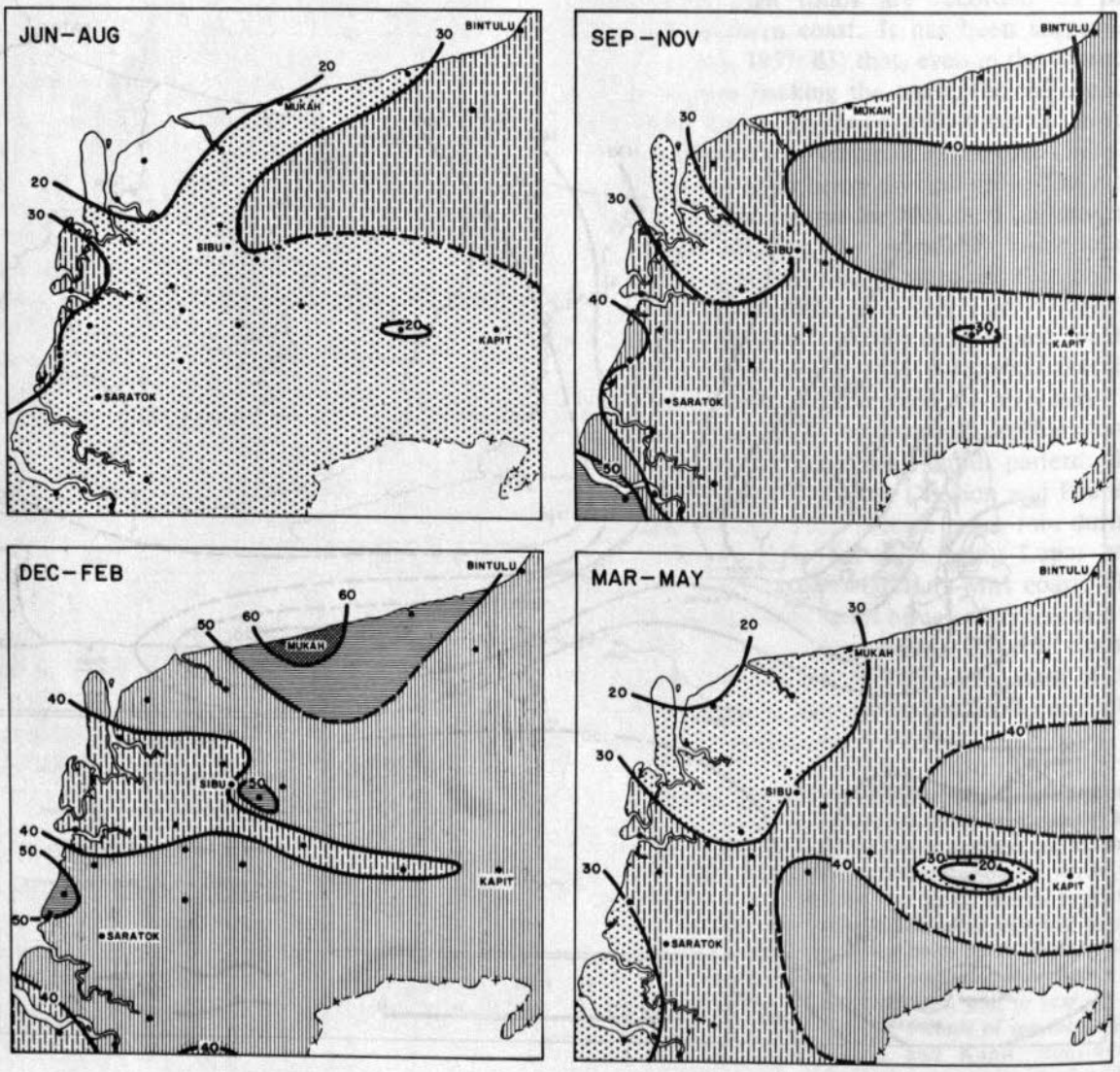


Fig. 3: Seasonal rainfall distribution as quarterly totals (isohyets in inches)

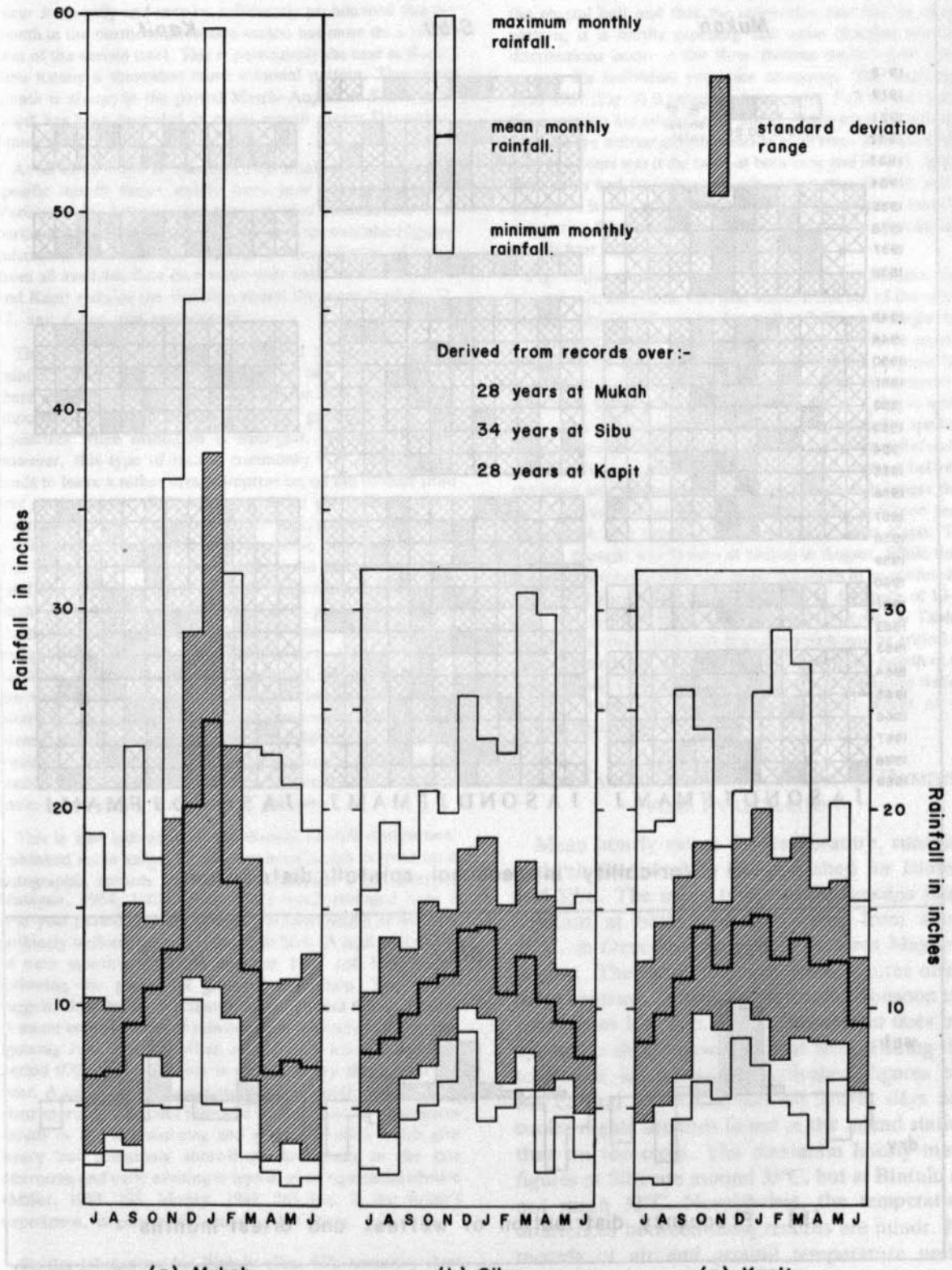


Fig. 4: Variability of monthly rainfall totals at three Stations

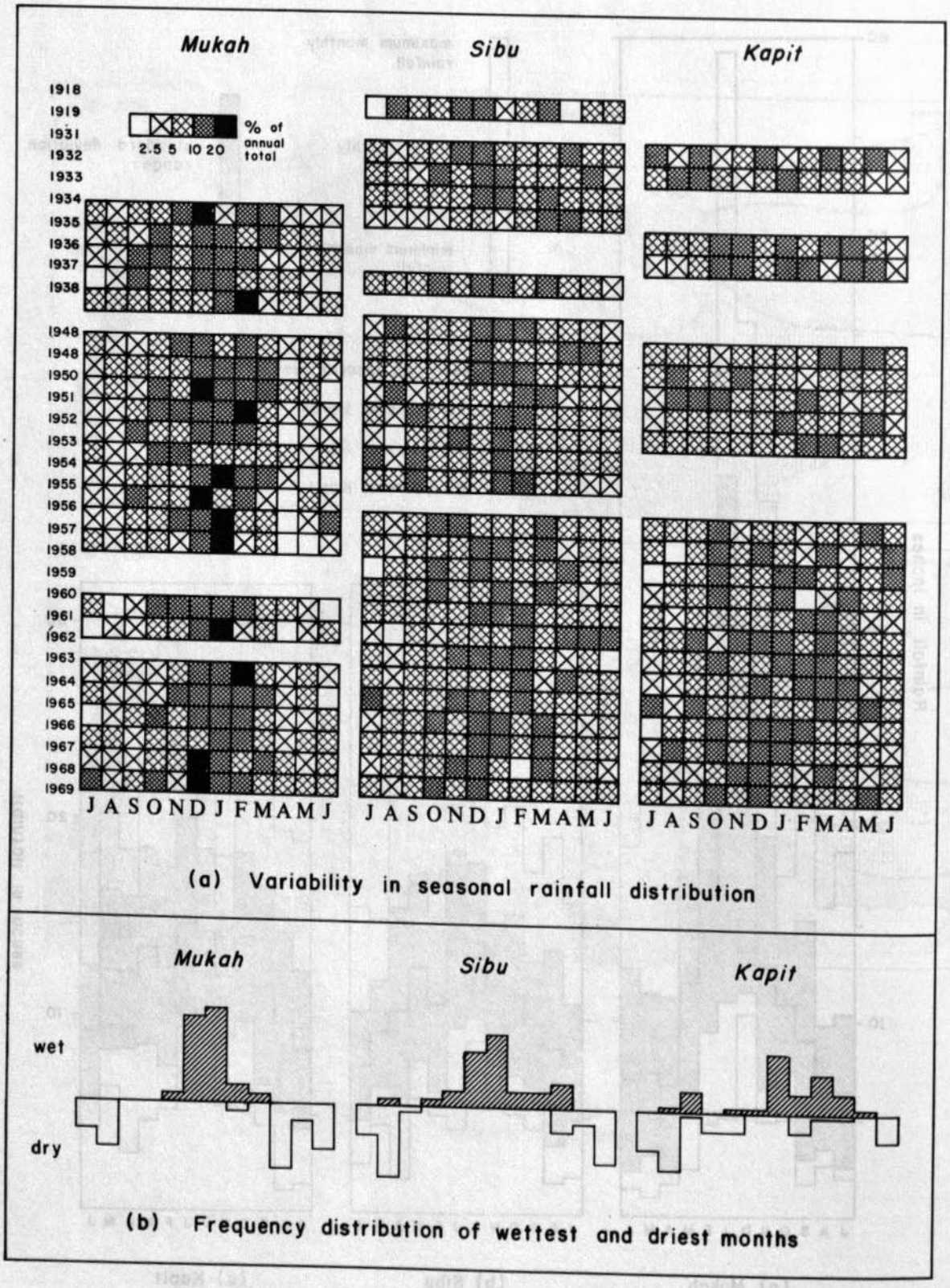


Fig. 5: Variability of seasonal rainfall patterns at three stations, based on monthly totals.

the annual total. A peak in December or January is common but any month between August and April can be the wettest month in individual years. Rainfall peaks about the equinoxes occur frequently and may be sufficiently pronounced that no month in the northeast monsoon season has more than 10 per cent of the annual total. This is particularly the case at Kapit, Sibu having a somewhat more seasonal pattern. The driest month is always in the period March–August at Sibu but at Kapit has been recorded in every month except December, January and May.

At all three stations, therefore, the total rain received in a specific month varies widely from year to year (Fig. 4). Variations in the annual totals are also considerable but, particularly near the coast, are inflated in the published figures calculated on a calendar-year basis. Recalculation of totals from all available data on a water-year basis for Mukah, Sibu and Kapit reduces the variation round the mean total by 22, 12, and 4 per cent respectively.

The data summarized in Figs. 4 and 5 suggest that the rainfall pattern is largely controlled by two factors. Firstly, there is a high proportion of convection rain which, while important at all times, is generally greatest about the equinoxes when insolation is strongest. As stated above, however, this type of rain is commonly very localised and tends to leave a rather erratic impression on the records from any particular site. Rainfall peaks about the spring equinox are rather stronger than those in autumn, possibly due to the continuing effect of rain-bearing monsoon winds at this time. The monsoon rains comprise the second factor and give a rainfall peak which usually occurs in December or January. Such rain varies in amount from year to year, however, and the period of the monsoon rains may be early or late and thus merge with the convection peaks about the appropriate equinox. Judging from the Mukah record, the monsoon rains are most effective on the coast, and are less important in the interior – to the extent that they cannot be recognised in records for certain years at Kapit. Rainfall peaks around the equinoxes are most evident from the records at the interior stations and it is inferred that the convection effect is more pronounced inland than close to the sea.

This is also indicated by the diurnal rainfall distribution. Published mean values of rain per hour/month derived from autographic records for Sibu and Bintulu (Met. Service, Malaysia, 1964; 1965; 1966; 1967) were averaged over a four-year period (Fig. 6). Despite the short length of record a strikingly uniform pattern is found at Sibu. A high proportion of each month's rain falls between 1300 and 1900 hours, following the period of greatest convection. The record suggests that this is particularly the case about the equinoxes. A minor concentration of rain occurs in the early morning but, ignoring June and July when rainfall as a whole is low, the period 0700 to 1200 hours is relatively dry throughout the year. A cycle of early morning mist or drizzle dissipating to clear morning skies and followed by the build up of cumulus clouds in the late morning and early afternoon which give heavy but commonly short-lived downpours in the late afternoon and early evening is typical of an equatorial climate (Miller, 1953: 105; Money, 1965: 96) and, in the writer's experience, is general for most of the Area.

Similar tabulations for Bintulu (Fig. 6b), however, show that on the coast all hours of daylight are relatively dry, most of the rain falling between 2000 and 0500 hours. This pattern is probably common to most sites close to the sea: Seal (1958: 501) states that at Miri during the southwest monsoon 'the heaviest rainfall is from thunderstorms of sharp intensity during the early hours after midnight'. The data tabulated in Fig. 6 tends to support the view that the coastal belt has a rainfall regime differing in many respects from that of interior areas.

Given that the northeast monsoon rain has most effect on the coastal belt and that the convection rain has an erratic pattern, it is hardly suprising that quite different seasonal distributions occur at the three stations studied even when records for individual years are compared. The water-year 1956–1957 (Fig. 7) is typical in this respect. Full records for all three stations are available for fifteen water-years. In only one year did the wettest month coincide at all three stations and in only five years was it the same at both Sibu and Mukah. In five years Sibu had its wettest month earlier than Mukah and in five years it was later. A similar random pattern is found in comparing Sibu and Kapit, where the wettest month coincided in only four years out of fifteen.

Fig. 7 also shows both that ten or more consecutive days without rain may occur and that much, if not all, of the rain in any five-day period may be due to that falling in a single day. The total number of extended dry periods over fifteen years at these stations are tabulated in Table 1. For this purpose days in which less than 0.2 inches (5 mm) rain fell are considered dry. As a lengthy dry spell interrupted by one day in which more than 0.2 inches rain fell is recorded as two dry spells of shorter duration, the actual drought hazard is somewhat under estimated by this method. Nevertheless the contrast between the coast and the interior is marked. Dry periods longer than 19 days occurred ten times at Mukah during th fifteen years considered, five times at Sibu and not at all at Kapit. The longest drought was 33 days at Mukah in August. While there is a general tendency for the longer dry spells to be confined to the period April-August this is not true of dry spells of 10–19 days duration and the general distribution shown by Table 1 suggest that even the longer droughts which may be critical for agriculture can, on occasion, occur in almost any month of the year. Brunig (1971) considers that periodic moisture deficits are also important in modifying the development of the natural forest cover.

Temperature, Sunshine, Relative Humdity and Evaporation

Mean hourly values for temperature, sunshine and relative humidity are published for Bintulu and Sibu. The mean temperature remains fairly constant at both stations, varying from about 25°C. in December to 26.5°C. between May and August. The range in hourly mean figures offers more contrast. During the northeast monsoon the range is as low as 6.3°C. at Bintulu but does not appear to drop below 7.3°C. at Sibu. During the southwest monsoon the equivalent figures are 8.8°C. and 13.4°C. Somewhat hotter days and cooler nights are thus found at the inland station than on the coast. The maximum hourly mean figures at Sibu are around 33°C. but at Bintulu do not reach 31°C. Nevertheless, the temperature differences between these records are minor. No records of air and ground temperature under natural conditions are available from the Area but records from sites near Kuching are probably relevant. These have been discussed in detail by Andriesse (1972). Maximum temperatures over grass were found to be some 3°C. higher than those under a forest canopy; manimum

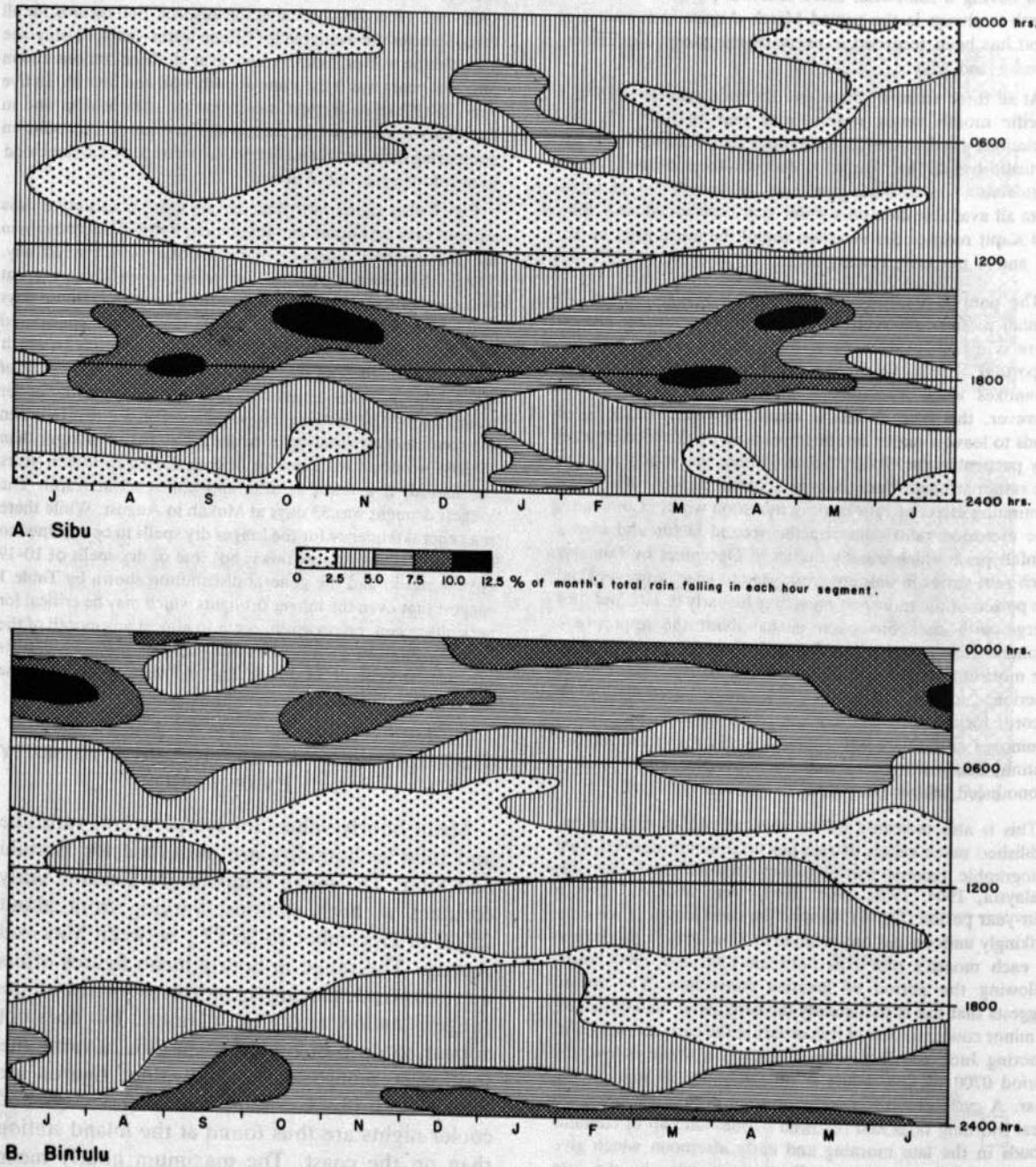


Fig. 6 Diurnal distribution of rainfall at Sibu and Bintulu (generalised average 1964-1967)

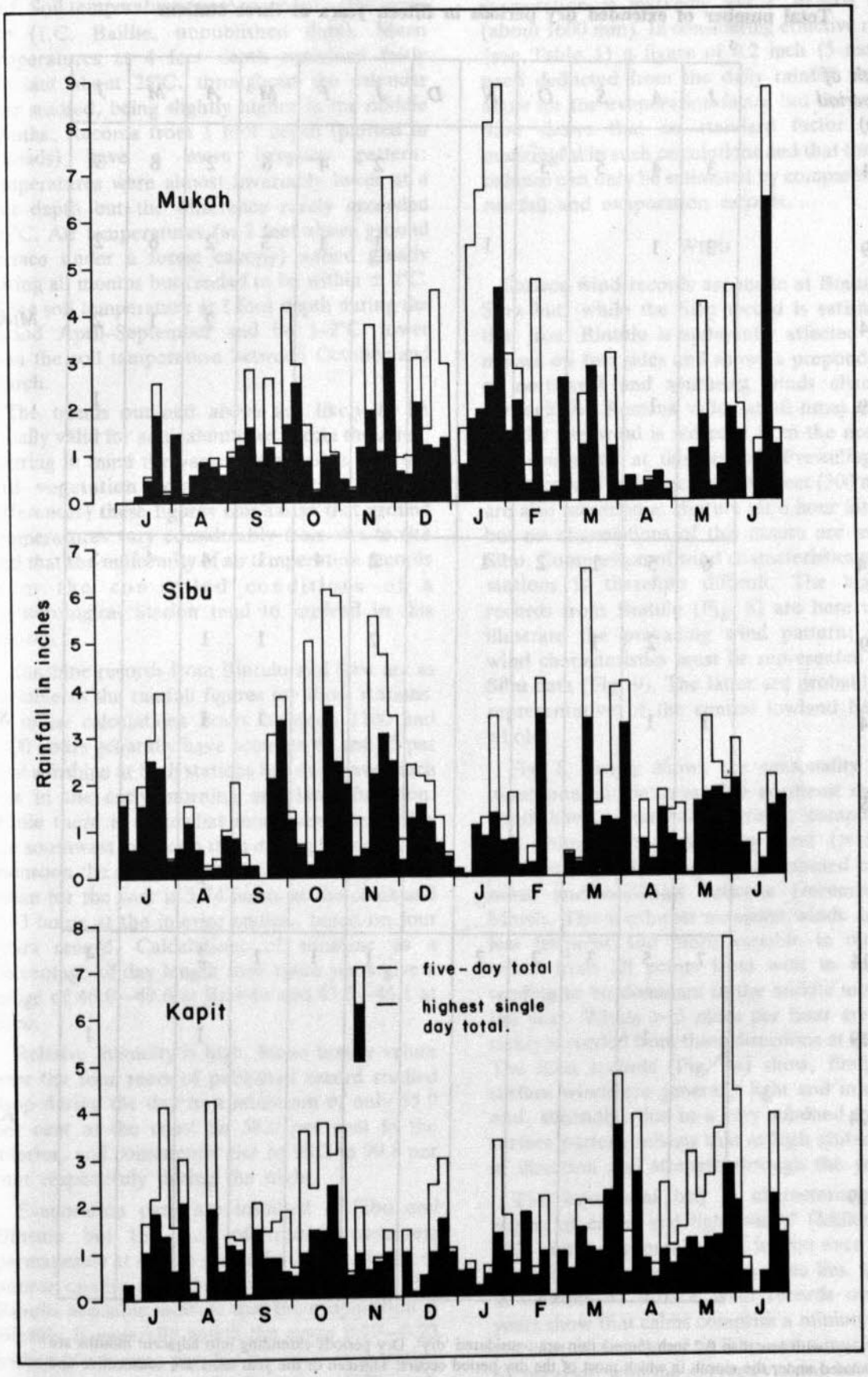


Fig. 7 Rainfall as pentads for the water-year 1956—1957 at three stations

Table 1

Total number of extended dry periods in fifteen years at three stations

Length of dry period (days)	*J*	*A*	*S*	*O*	*N*	*D*	*J*	*F*	*M*	*A*	*M*	*J*	
10–14	3	4	5	3			2	4	6	2	8	3	
15–19	3	1			1		1	1	3	2	6	2	
20–24	2									2	1	2	*Mukah*
25–29		1										1	
30–		1											
10–14	6	5	1	2	1		2	4	1	4	4	5	
15-19		2	1				2		1	1			
20-24	1	1							1	1			*Sibu*
25-29													
30–										1			
10–14	7	5	3	2	2		1	1	1	2		4	
15–19		1								1		1	
20–24													*Kapit*
25–29													
30–													

(Days with less than 0.2 inch (5mm) rain are considered 'dry'. Dry periods extending into adjacent months are tabulated under the month in which most of the dry period occurs. Thirteen of the year used are consecutive and comparable).

temperatures were up to 5°C. lower; a forest cover reduced the diurnal range by approximately half. Soil temperatures were recorded at the same site (I.C. Baillie, unpublished data). Mean temperatures at 4 feet depth remained fairly constant about 25°C. throughout the calendar year studied, being slightly higher in the middle months. Records from 1 foot depth (plotted in pentads) gave a more irregular pattern: temperatures were almost invariably lower at 4 feet depth but the difference rarely exceeded 0.5°C. Air temperatures (at 2 feet above ground surface under a forest canopy) varied greatly during all months but tended to be within ± 2°C. of the soil temperature at 1 foot depth during the period April–September and be 1–2°C. lower than the soil temperature between October and March.

The trends outlined above are likely to be equally valid for equivalent sites within the Area. Bearing in mind the variety of possible land use and vegetation cover (in addition to soil differences) these figures emphasise that ground temperatures vary considerably from site to site and that the uniformity of air temperature records from the controlled conditions of a Meteorological Station tend to mislead in this respect.

Sunshine records from Bintulu and Sibu are as variable as the rainfall figures for these stations. In mean calculations hours between 1100 and 1400 hours generally have between 60 and 85 per cent sunshine at both stations but they have much less in the early morning and late afternoon. While there is somewhat more sunshine during the southwest monsoon than during the northeast monsoon the difference is not marked. The daily mean for the year is 5.74 hours at the coast and 5.43 hours at the interior station, based on four years record. Calculations of sunshine as a percentage of day length over these years give a range of 46.0—49.6 at Bintulu and 43.5—46.1 at Sibu.

Relative humidity is high. Mean hourly values over the four years of published record studied drop during the day to a minimum of only 55.9 per cent at the coast an 58.0 per cent in the interior, and consistently rise to 95.2 to 99.8 per cent respectively during the night.

Evaporation pans are installed at Sibu and Bintulu but the lack of trained observers permanently at station results in the data being of poorer quality than desirable (DID, 1968: 16). Results available indicate that the evaporation at Bintulu is generally within the range 0.17—0.23 inches (4—6 mm) per day the total evaporation per year is approximately 70 inches (1800 mm). The range at Sibu is rather greater—0.02—0.43 inch (0.5—11 mm) per day—but the total annual evaporation is markedly less at 62—64 inches (about 1600 mm). In considering effective rainfall (see Table 1) a figure of 0.2 inch (5 mm) has been deducted from the daily rainfall totals to allow for the evaporation factor but the range at Sibu shows that no standard factor is very meaningful in such calculations and that the water balance can only be estimated by comparing daily rainfall and evaporation records.

Wind

Surface wind records are made at Bintulu and Sibu but, while the Sibu record is satisfactory, that from Bintulu is apparently affected by hill masses on two sides and shows a preponderence of northwest and southeast winds channelled through the Kemena valley at all times of year. Hardly any wind is recorded from the northeast and southwest at this station. Prevailing wind direction and frequency at 1,000 feet (300 metres) are also recorded at Bintulu (at 6 hour intervals) but no observations of this nature are made at Sibu. Comparison of wind characteristics at these stations is therefore difficult. The high-level records from Bintulu (Fig. 8) are here used to illustrate the prevailing wind pattern; ground wind characteristics must be represented by the Sibu data (Fig. 9). The latter are probably fairly representative of the central lowland belt as a whole.

Fig. 8 clearly shows the seasonality of the monsoonal air patterns. The northeast monsoon winds have a dominant northerly component in this altitude although strong wind (>15 miles per hour) are about equally distributed between north and northeast between December and March. The southwest monsoon winds are both less frequent and more variable in direction, winds from all points from west to southeast tending to be dominant in the middle months of the year. Winds >15 miles per hour are rather rarely recorded from these directions at any time. The Sibu records (Fig. 9a) show, firstly, that surface winds are generally light and infrequent and, secondly, that in a very subdued form the surface pattern reflects that at high altitude both in direction and strength through the year.

The equatorial belt is characteristically 'a region of calms and light winds' (Miller, 1953: 102) and this generalisation is true even for the monsoonal zone in which the Area lies. Monthly tabulations of surface wind records over four years show that calms comprise a minimum of 34 per cent of the record at Sibu and a maximum of 57 per cent, with the average varying between 43

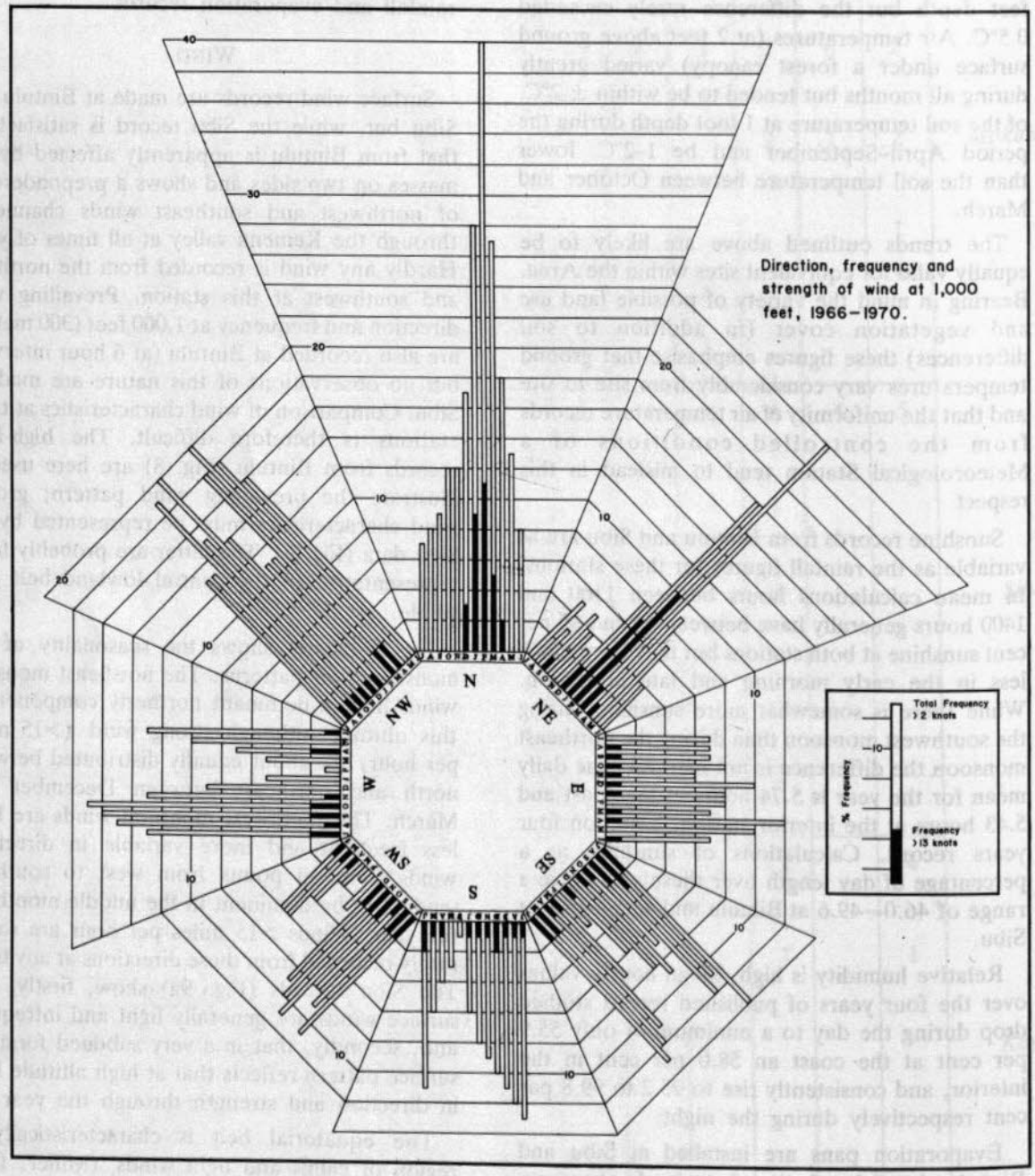


Fig. 8: High-level wind at Bintulu

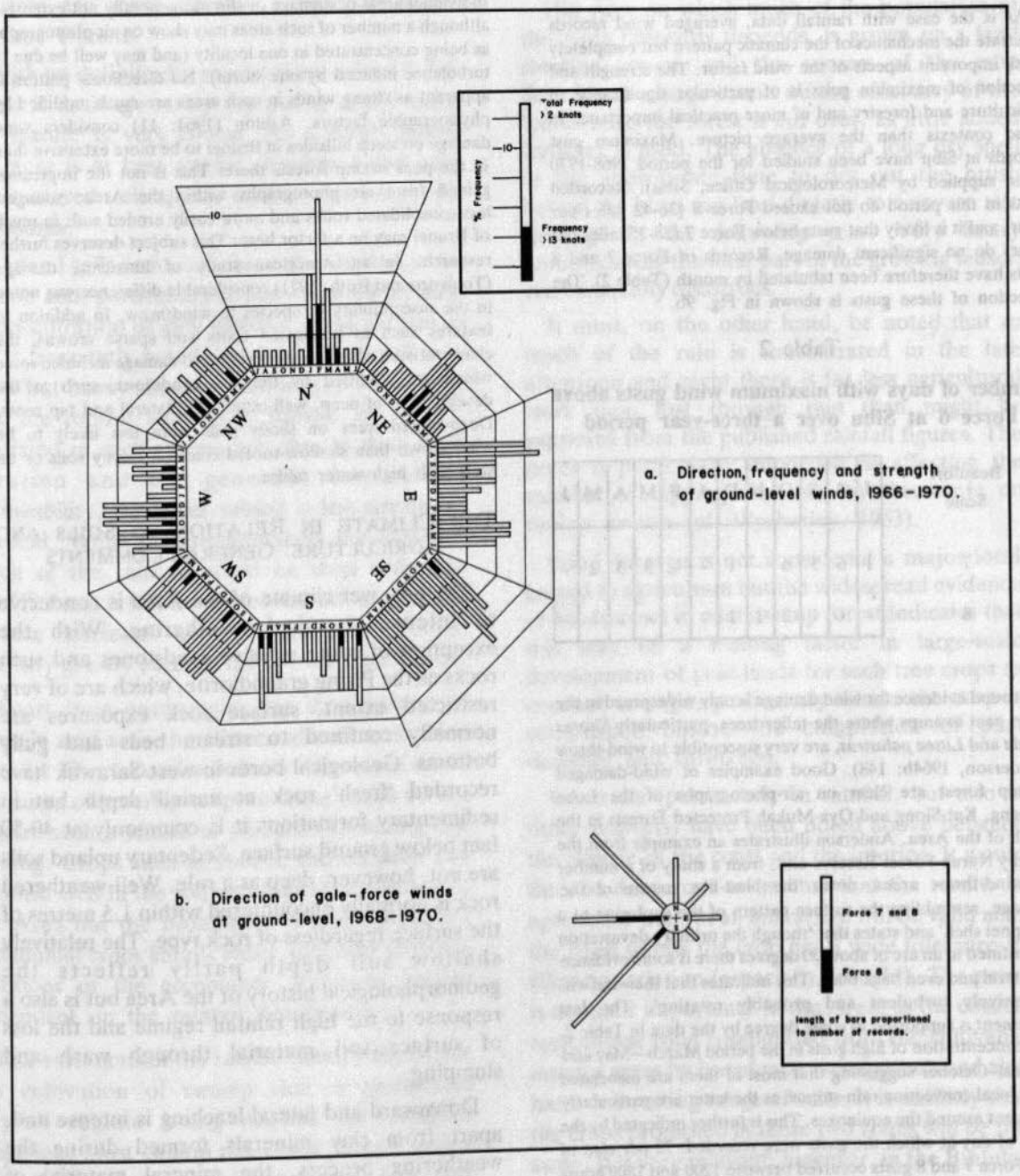


Fig. 9: Ground-level wind at Sibu

and 50 per cent. Over the same years the equivalent figures from Bintulu are 11 and 40 per cent calms, with an average between 14 and 29 per cent. The coast is therefore windier than the interior but at both stations the mean monthly wind velocity is low, maximum monthly figures during these years being only 5.9 miles per hour at Bintulu and 5.2 miles per hour at Sibu.

As is the case with rainfall data, averaged wind records illustrate the mechanics of the climatic pattern but completely mask important aspects of the wind factor. The strength and direction of maximum gusts is of particular significance to agriculture and forestry and of more practical importance in these contexts than the average picture. Maximum gust records at Sibu have been studied for the period 1968-1970 (data supplied by Meteorological Office, Sibu). Recorded gusts in this period do not exceed Force 8 (36-42 miles per hour) and it is likely that gusts below Force 7 (28-35 miles per hour) do no significant damage. Records of Force 7 and 8 gusts have therefore been tabulated by month (Table 2). The direction of these gusts is shown in Fig. 9b.

Table 2

Number of days with maximum wind gusts above Force 6 at Sibu over a three-year period

Beaufort Scale	J	A	S	O	N	D	J	F	M	A	M	J
7	1	6	5	6	-	1	-	-	3	3	2	-
8	-	-	-	2	1	1	-	-	-	-	-	-

Ground evidence for wind damage is only widespread in the basin peat swamps where the taller trees, particularly *Shorea albida* and *Litsea palustrus*, are very susceptible to wind-throw (Anderson, 1964b: 148). Good examples of wind-damaged swamp forest are clear on air-photographs of the Loba Kabang, Kut-Siong and Oya-Mukah Protected Forests in the north of the Area. Anderson illustrates an example from the nearby Narub Forest Reserve and, from a study of a number of wind-throw areas, notes 'the blast-like nature of the damage, resembling the surface pattern of the explosion of a shrapnel shell' and states that 'though the primary devastation is confined to an arc of about 30 degrees there is some evidence of lateral and even back blast. This indicates that the wind was excessively turbulent and probably rotating'. The last statement is supported to some degree by the data in Table 2, the concentration of high gusts in the period March—May and August–October suggesting that most of them are associated with local convection rain-storms, as the latter are particularly frequent around the equinoxes. This is further indicated by the time of day at which the gusts were recorded: 72 per cent of the Force 7 and 8 gusts occurred between 1200 and 1800 hours —a concentration similar to that of rainfall at this station (Fig. 6a).

The above evidence suggests that wind damage is likely to come from any direction. But while throws in all directions are shown on air photographs, there is a general tendency in the large examples for the main throw to be towards the northeast, north or, as in the case of Anderson's Narub example, to the northwest. This partially—but only partially—correlates with wind direction, Fig. 9b showing that maximum gusts above Force 6 in the period studied were dominantly from the northwest, west and southwest. If winds generated in local convection storms are primarily responsible for the existing wind gaps a more erratic pattern would be expected both on the ground and in the wind-direction record. It would appear that a more complex explanation must be sought for these features.

Forested interior areas show evidence of wind damage and, in particular, of landslides probably triggered by windthrows. Individual areas of damage or slip are generally not extensive although a number of such areas may show on air photographs as being concentrated in one locality (and may well be due to turbulence induced by one storm). No directional pattern is apparent as strong winds in such areas are much modified by physiographic factors. Ashton (1964: 11) considers wind damage on steep hillsides in Brunei to be more extensive than in the peat swamp forests there. This is not the impression gained from air photographs within the Area; younger, less-consolidated rocks and more easily eroded soils in much of Brunei may be a factor here. This subject deserves further research. In an American study of hurricane damage (Touliatos and Roth, 1971) considerable difference was noted in the susceptibility of species to windthrow. In addition to features such as buttressed roots and sparse crowns, the characteristics which gave resistance to damage included some which are modified by the soil conditions, such as the development of deep, well-established lateral and tap roots. Deep-rooted trees on sandy soils were less likely to be windthrown than shallow-rooted trees on clayey soils or on soils with high water tables.

The Climate in Relation to Soils and Agriculture: General Comments

The hot, wet climate of the Area is conducive to intense chemical weathering. With the exception of some massive sandstones and such rocks as the Piring granodiorite, which are of very restricted extent, surface rock exposures are normally confined to stream beds and gully bottoms. Geological bores in west Sarawak have recorded 'fresh' rock at varied depth but in sedimentary formations it is commonly at 40-50 feet below ground surface. Sedentary upland soils are not, however, deep as a rule. Well-weathered rock is normally encountered within 1.5 metres of the surface regardless of rock type. The relatively shallow soil depth partly reflects the geomorphological history of the Area but is also a response to the high rainfall regime and the loss of surface soil material through wash and slumping.

Downward and lateral leaching is intense and, apart from clay minerals formed during the weathering process, the mineral material of upland soils is, in most profiles, dominated by quartz, iron and aluminium oxides and those accessory minerals which are highly resistant to chemical weathering. Minerals which are easily-weathered are largely confined to young alluvial soils, although some feldspar may be present in upland soils derived from greywackes. Upland soils are thus characteristically moderately to very

strongly acid and have a low base status. This may be considered a reflection of the parent material which, in most cases, is derived from sedimentary rocks which have been recycled a number of times and are highly siliceous. As, however, soils derived from basic igneous rocks elsewhere in Sarawak are equally acid and base-poor these features are more directly a function of the extreme climate.

With no definite dry season even soils with free external drainage rarely dry out at depth unless the texture is very coarse. As a result subsoil structure is at best weakly developed and most fine-textured soils appear massive in fresh profile exposures.

Upland soils commonly have gley mottles in the subsoil and, particularly in fine-textured profiles, a concentration of gley features in the surface 25 cm is frequently noted. Much of the rainfall is in short but heavy showers, and it may be the case that the topsoil and upper subsoil are quickly saturated in such storms but, due to their short duration and the generally low subsoil permeability, the lower subsoil is less commonly affected. While no measurements are available much of the rain recorded on days with high rainfall totals is lost in surface run-off, as once the surface horizons are saturated the rainfall intensity greatly exceeds the soil infiltration rate.

Apart from encouraging the development of infertile acid soils the climate affects agriculture directly. The lack of a definite dry season limits the range of possible crops to those which do not require such a season to stimulate flowering and fruiting. Crops such as rubber and oil palm can perform well in the soil and rainfall conditions of the Area but the promotion of many perennial and annual crops entails either very high fertilizer additions or the acceptance of erratic returns dependant on the rainfall distribution.

The variations in the rainfall pattern also affect the cultivation of swamp rice, a predictable rainfall regime being needed for efficient irrigation. Most swamp rice in the Area is grown near the main Rajang distributaries. The high tidal range in these channels together with the erratic flood pattern dependent on the rainfall in the interior catchment areas means that such farms are at risk not only from random droughts but also from serious inundation, of either fresh river water following a period of very high rainfall in the interior or brackish water during peak tides. Only limited protection by bunding and drainage works is economically possible and, even were such improvements provided, the unreliability of the rainfall is such that the controlled drainage and supply of irrigation water necessary for efficient production would be very difficult to achieve.

Hill rice, on which much of the population of the Area presently depends, is grown on a land rotation system and the success of the crop depends to a large extent on the efficiency of the 'burn' once the forest is cut over, as little added fertilizer is used. The absence of a long dry spell at the appropriate time to dry out the brush before the burn can lead directly to a severe rice shortage in the following year. Very heavy rainfall during the later part of the growing season can be equally disastrous.

It must, on the other hand, be noted that as much of the rain is concentrated in the late afternoon and night there is far less agricultural work time lost through rain than might be supposed from the published rainfall figures. The point is particularly important in affecting the number of tapping days lost by this cause on rubber estates (cf. Wycherley, 1963).

Wind damage is not considered a major local hazard to agriculture but the widespread evidence of windthrows in peat swamp forest indicates that this may be a limiting factor in large-scale development of peat lands for such tree crops as coconut or sago, particularly where the crop is established before the completion of peat drainage and shrinkage.

Contrasts (particularly in rainfall, but also in other respects) have been noted above between the climate of the coast and the interior. It would thus be dangerous to assume that the results of agronomic trials at an inland site will be valid near the coast unless the crop has a wide tolerance to climatic variation (especially drought). The point is of minor importance in the Area, as the coastal agricultural zone is separated from the cultivable interior areas by broad peat swamp tracts and also has a contrasting range of soils. It is unlikely that the crops promoted in these two zones will be the same. It is very relevant, however, in the Bintulu-Suai and Bekenu-Miri areas farther north, where the interior hill lands extend to the coast itself.

In the following sections the restricted agricultural potential of the Area and its poor endowment in soil wealth are recurring themes. In large measure these deficiencies stem, directly or indirectly, from the Area's extreme climate.

CHAPTER 3

SOIL PARENT MATERIALS

The geology of the Area has been reconnoitred by Wolfenden (1960) and this chapter relies on his information for details of structure and mineralogy. Geological mapping has been mainly confined to bounding formations, as the lithological variation is great.

The Area is largely underlain by Tertiary geosynclinal deposits with outcrops of younger rocks confined to the northeast. Except for certain acid igneous material, which is also restricted to that locality, all rocks outcropping in the Area are of sedimentary origin. Some 55 per cent of the Area is mantled by organic deposits or unconsolidated recent and subrecent alluvium. The stratigraphy is summarised in Table 3 and the Geological Formations included in Fig. 10.

Cretaceous And Early Tertiary Rocks

Most of the Area is underline by strong folded geosynclinal sediments of Upper Cretaceous to Upper Eocene age. In Upper Cretaceous time, Paleozoic and Mesozoic rocks, comprising an extension of the 'Sunda Shield', formed a wedge in western and central Borneo. On the northern flanks of this mass deep-water geosynclinal sediments, styled the *Belaga Formation* (Wolfenden, 1960; 92-98; Haile, 1961; Geiger, 1963), were deposited in four stages over a vast area stretching through central and northern Sarawak to Sabah. The southern rim of the geosyncline was roughly at the line of the present Lupar River, outwith the Area to the southwest. Some uplift occurred during deposition and Stage IV of the Belaga Formation is probably partly derived from rocks of the earlier stages. More intense folding followed in Upper Eocene time.

All four stages distinguished in this Formation are lithologically complex. Mapping boundaries between them have been established only on paleontological evidence. Argillaceous rocks are widespread in each stage and are rarely unaltered, Wolfenden (1960) distinguishing argillites, slates and phyllites. Following Liechti (et al., 1960), however, all are described as shales in the present study. Hard, indurated, dark grey to black shales are dominant, with some greyish red to greenish grey shales locally present in Stage II (to the south of the Rajang River) and soft unaltered shales confined to stage IV (Mukah and Balingian headwaters). Stage IV as a whole is less metamorphosed than the earlier stages. The shales (and less common siltstones) generally show in thin section scattered clastic grains (dominantly quartz with sodic or potassic feldspars) set in a microcrystalline matrix of quartz, sericite and chlorite, together with fine-grained carbonaceous material (Wolfenden, 1960; 26 et seq.)

Arenaceous rocks are of minor importance in Stage I of the Formation and in Stage II are only widespread in the lower portion, out-cropping in a belt from the Kanowit and Julau headwaters westward to Sarikei and Selalang. In the Stage III and IV rocks to the north of the Rajang River, however, sandstones are more common and are locally dominant. Geiger (1963), discussing the paleogeography of the region, distinguishes a 'shale predominant' belt to the south of the Rajang River formed by deposition in a 'period of starvation', from a 'shale-sandstone alternation' zone covering the present outcrop of Stage III and IV rocks.

The sandstones (Wolfenden, 1960: 26, 33, 37, 42) are generally greywackes or subgreywackes, comprising angular or subangular clastic grains (of quartz with subordinate feldspar, some mica and fragments of such rocks as chert, shale, greywacke, granite and, rarely, lava) set in a microcrystalline matrix (of chlorite, sericite and quartz with some carbonaceous material and local carbonate). The clay and silt-size matrix material may form up to 40 per cent of the rock; feldspars rarely exceed 10 per cent. Grey-black to grey shales with thin beds of greywacke which have been classed as the 'Bawang Member' and outcrop in the Kemena and Sarupai valleys are considered by Wolfenden (1960: 45) to be also part of the Belaga Formation (Stage IV).

In addition to vertical lithological contrasts in the Belaga Formation, certain lateral contrasts can be inferred from the soil mantle. In interior areas (in the east and southeast of the Area) shales are dominant in all stages. Where sandstones outcrop they are generally hard, relatively thin beds which are resistant to weathering. These beds may modify the drainage pattern, produce rapids in the larger stream courses and form the spines to major strike ridges but they do not contribute greatly to the soil mantle, which is largely developed in material from the flanking shales. On the coastward margins of the outcrop, however, in the fragmented hill and swamp tracts bordering the swamp plain and in the zone of relatively subdued relief backing these tracts, sandstones are more important. They may be dominant over wide areas, are almost invariably deeply weathered, and greatly influence the character of the overlying soil. While this is the case throughout the Formation the lateral contrast is particularly marked in Stages II and III.

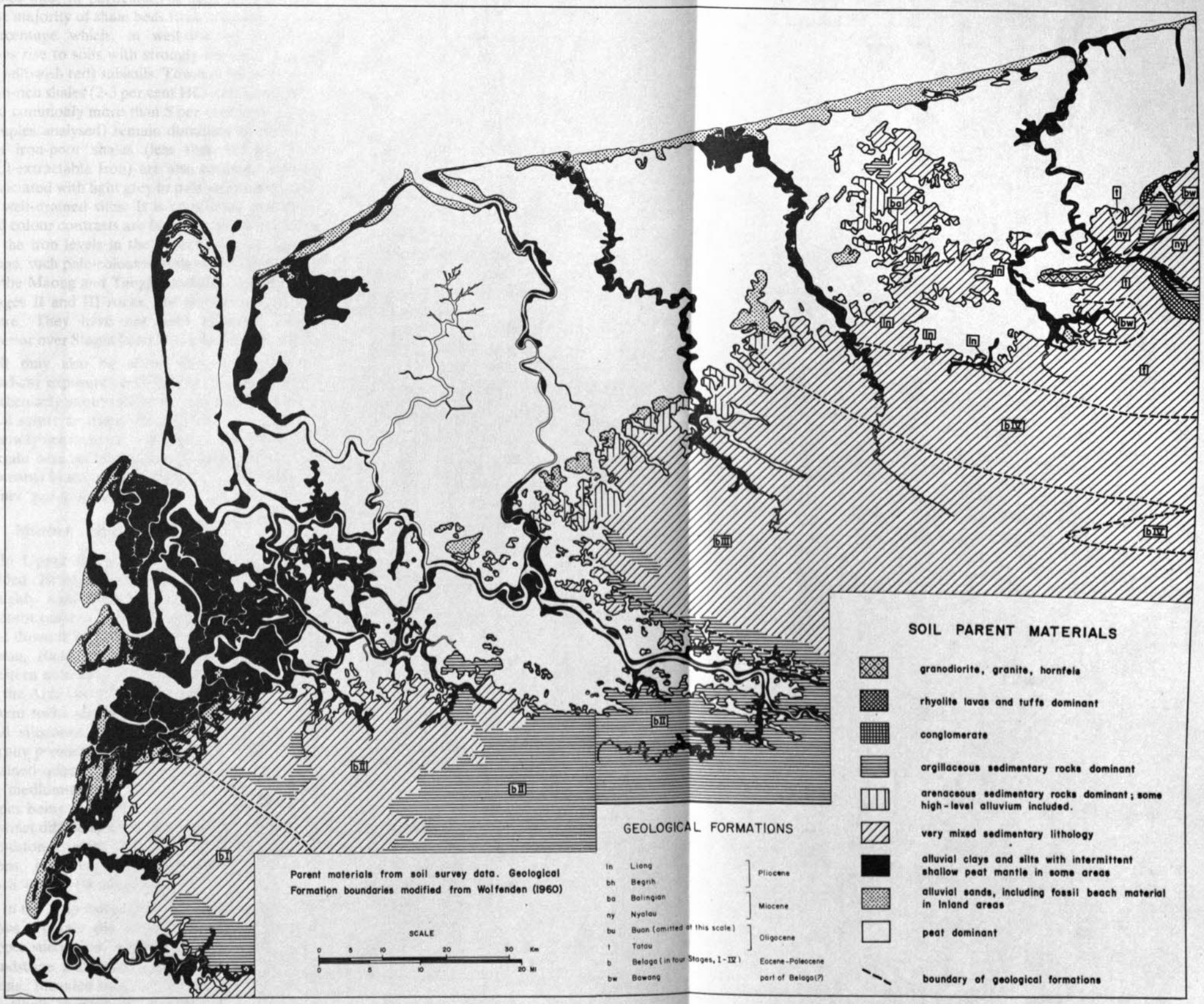


Fig. 10 Soil parent materials and geological formations

There is further diversity in the character of the shales and, in particular, in their iron content. The majority of shale beds have a significant iron percentage which, in well-drained situations, gives rise to soils with strongly coloured (yellow to yellowish red) subsoils. Towards the coast such iron-rich shales (2-3 per cent HCl-extractable iron and commonly more than 5 per cent total iron in samples analysed) remain dominant in all stages but iron-poor shales (less than 0.5 per cent HCl-extractable iron) are also common and are associated with light grey to pale yellow soils even in well-drained sites. It is considered that these soil colour contrasts are largely a direct reflection of the iron levels in the parent rock. In interior areas, such pale-coloured soils are locally present in the Maong and Tanggi localities, underlain by Stages II and III rocks, but are never extensive there. They have not been recorded in the interior over Stages I and IV rocks but may occur.

It may also be noted that comparison of road-cut exposures and nearby soil mantle data, particularly subsoil textures, suggests that individual sandy or clayey beds in this formation are laterally impersistent. Although in some localities certain beds or associations of beds appear to be traceable in the soil pattern over some miles, this is not generally the case.

Middle and Late Tertiary Rock

In Upper Eocene to mid-Miocene time, the folded Belaga rocks comprised a land mass roughly approximating, in the Area, to their present outcrop and shallow-water deposits were laid down in a geosyncline to the north of it (the *Tatau, Buan* and *Nyalau Formation*). Only the western extremity of this geosyncline is included in the Area (in the Balingian drainage basin). The Tatau rocks are dominantly carbonaceous shales and siltstones. Thick sandstone beds are also locally present, however, these being either fine-grained quartzose sandstone with rare feldspars, or medium-grained feldspathic sandstone, both types being cemented by quartz. There are thus distinct differences between the Tatau and Belaga sandstones; many of the shales in these Formations, however, cannot be distinguished from each other, (Wolfenden, 1960: 48).

In the Arip valley beds of vitreous and rhyolitic lavas separate the lower Tatau rocks from the upper succession, which largely comprises shale, sandstone and marl, together with some limestone. Intruded into the Tatau rocks is the stock of alkali granophyre, granite and granodiorite which forms Bukit Piring. An Upper Eocene age similar to that of the nearby Arip volcanics is likely for this intrusion (Wolfenden, 1960: 87). The shales adjacent to the Piring stock have been altered to biotite-hornfels.

Buan Formation rocks outcrop only in the Arip valley and comprise largely dark grey, carbonaceous and micaceous shales with subordinate beds of medium-grained sandstone. They are conformably overlain by the Nyalau Formation. The latter is dominantly hard, fine-grained to medium-grained subgreywacke or quartzose sandstone in its lower part but alternations of friable medium-grained sandstones, shales, sandy shales and siltstones in its upper portion, the latter comprising most of the outcrop.

Further deposition to the northward occurred in Upper Miocene to Upper Pliocene time, the Belaga, Tatau, Buan and Nyalau rocks forming source-material for the *Balingian, Begrih* and *Liang Formations,* (Wolfenden, 1960: 100-103). These were laid down in deltaic and swamp conditions similar to those of the coastal belt at present. Deposition was interrupted by periodic uplift and the three formations are unconformable and gently folded (although folding during this period affected the Tatau, Buan and Nyalau rocks more strongly). All three formations are characterised by unconsolidated or poorly-consolidated sediments, comprising clay, sand and pebble beds, soft sandstones, lignite, clay-shales (in the Balingian Formation) and basal conglomerate beds. The conglomerates outcropping at Bukit Tunggal have been tentatively referred to the Liang Formation.

Through the complexity of their outcropping pattern and the variety of their lithology, the Upper Eocene and post-Eocene rocks impart an individuality to the northeast of the survey area which is in marked contrast to that of the vast zone underlain by Belaga Formation rocks. This is reflected in the topography and, to some extent, in the soil mantle.

Quaternary Deposits

Marked changes in relative base-level during the Quaternary have resulted in deposition of alluvial material at a number of levels. Most of this has been removed by subsequent erosion but remnants of the lower and younger, terraces are locally widespread, particularly on the seaward margins of the hill zone. Terrace remnants in the interior are more restricted in extent and largely confined to sites close to major river floodplains.

Following the still-stands responsible for the younger terrace remnants a broad alluvial plain was formed in relatively recent times and, except in the southern part of the Rajang delta, deep surface peat accumulations developed on it. As a

Table 3

Geological Formations outcropping in the Area

System	Epoch	Rock Formations		Dominant lithology
Quaternary				Sands, silts, and Clays; peat
Tertiary	Pliocene	Liang		Sand, clay, lignite, gravel
		Begrih		Sand, clay, gravel
	Miocene	Balingian		Sandstone, shale, clay, lignite
		Nyalau		Sandstone, shale
	Oligocene	Buan		Shale, sandstone
		Tatau		Shale, sandstone, rhyolite lava and tuff
	Eocene	Belaga	IV	Shale, siltstone, sandstone
			III	
	Paleocene		II	
Upper Cretaceous	Cenomanian to Maestrichtian		I	

result the hill masses, and the terrace tracts associated with their seaward fringes, are now many miles inland from the coast in most localities.

The pattern and character of the Quaternary deposits are closely linked with the Quaternary landform history of the Area and are discussed in more detail in Chapter 4.

CHAPTER 4

PHYSIOGRAPHY

The most striking physiographic division in the Area (Map 3) is that between the dissected uplands which comprise the main interest of this study and the broad coastal plain which abuts them. The uplands grade inland to mountainous country, some tracts of which are included in the Area. Other physiographic divisions are of restricted extent or have rather diffuse boundaries.

THE INTERIOR HIGHLANDS

The upland zone as a whole is characterised by varied but commonly steep slopes, and moderate to severe dissection, but the total elevation is generally below 400 feet (120 metres). Towards the interior, however, the hills become progressively higher, the amplitude greater, and areas with slopes of less than 25° negligible. As such land is of little agricultural interest and these areas have received only cursory inspection during the soil survey they have been largely excluded from the map coverage with the exception of the upper reaches of the Oya, Mukah and Balingian drainage basins in the east, and a tract on the southern border of the Area.

The characteristic landforms of the unit are high, steeply flanked, subparrallel strike ridges, rising inland to merge with core areas in which the strike control is only partially evident and amplitude is at a maximum. Strike ridges are particularly well-developed in the Oya-Mukah area. Summits rise from about 700 feet (215 metres) in the middle section of these drainage basins to almost 3,000 feet (900 metres) in the core watershed area around Bukit Lombok. A more confused pattern is found in the south, although here also some strike ridges are prominant (such as the outlier of Bukit Sebankoi).

The ridge flanks are slightly convex and major streams are generally entrenched. With the exception of the Mukah River, significant floodplain tracts rarely extend into these upstream areas. River down-cutting along the strike is marked. Minor tributaries flowing across the strike contribute less to the dissection in most instances and although the ridge flanks are gullied the summit line itself is maintained intact over considerable distances. Slopes are varied but are generally in excess of 25° except on the ridge line and on spur summits; on the ridge flanks the slope may exceed 35°.

Towards the coast this unit grades into dissected lowlands with strong strike control and steep slopes, although the amplitude of the relief is less than in the highlands. The highland unit has therefore been broadly mapped to isolate those areas in which at least some summits rise to 500 feet (150 metres) above sea-level. In most localities, these areas have the steepest slopes and the minimum floodplain development.

It has been considered (Wolfenden, 1960: Plate IV) that the major strike ridges controlling the terrain in the highlands are formed of thick beds of hard sandstone interbedded with shale. While this may well be true in many cases, highland areas investigated in the Balingian and Mukah headwaters rarely showed sandstone outcrops and the soil mantle was dominantly clayey and derived from argillaceous material. Massive sandstone does, however, outcrop in many river valleys, particularly where the stream cuts across the strike.

THE DISSECTED LOWLANDS

The dissected lowlands, which merge into the highland unit towards the interior, are the areas in which most of the population is settled, most agricultural development has taken place and most soil investigations have been carried out.

There is a general coastward decrease in elevation and an increase in the extent of bottomland tracts between the ridges, but over most of the area underlain by Belaga Formation shales and sandstones the degree of strike control over the landscape remains marked. Four subunits can be recognised. Firstly, towards the interior, the terrain is dominated by strike ridges extending from the adjacent highland unit but narrow ribbons of riverine flats separate the ridges. The latter have very dissected flanks and are in places interrupted by major tributary streams crossing the strike. The ridge summit line is irregular but the highest summits are generally at 250-450 feet (75-140 metres) above sea-level. (Generalised summit contours are shown on Map 3).

Secondly, farther towards the coast, the ridges have lost some amplitude and breadth, but maintain their steep slopes and degree of flank dissection. The floodplain tracts which separate them are broader (and tend to be mantled by peat rather than riverine alluvium) and, while the major floodplains and their associated streams are generally strike-aligned, extensions of these bottomlands finger into the ridge mass following major gullies. The hill/floodplain boundary is thus highly irregular. The height of the ridge line is also more varied and main summits along the ridge are generally about 200-350 feet (60-105 metres) above sea-level.

The expansion of the floodplain at the expense of the hill mass and the decreasing amplitude of

the latter continue in the third subunit. Here the main summits are generally at 150-250 feet (45-75 metres) but much of the ridge line is at lower levels and at many points dissection of the opposing flanks has proceeded to the stage where extensions of adjacent bottomlands (now dominantly peat) have met across the divide and sever the ridge entirely. In places this happens repeatedly over short distances and the strike-aligned hill mass is degraded to a parallel series of separate elongated hill tracts aligned at right-angles to the strike. Complexes of hill and swamp with such patterns are only well developed in the 'Sibu Bay' (see Map 3) as where the hills abut the coastal swamp plain proper other geomorphological factors have interrupted this erosional sequence.

The progressive degradation of the ridges can, between Sibu and Kanowit, be traced beyond the hill zone proper, however. The final stage is a peat plain with small low hills, commonly widely separated, but clearly aligned with the strike of adjacent uplands. These represent the highest points of previous ridges, which are now almost completely degraded and largely covered by peat deposits.

While subaerial erosion is the dominant factor in producing the dissected landscape patterns of the first two subunits described, at lower elevation the build-up and extension of the peat swamp plain itself becomes a major element in complexing the hill/swamp patterns. No data are available for the rate at which the peat mantle has been thickening in the recent past but radiocarbon figures for basin peat swamps in north Sarawak (Wilford, 1961: 119) indicate that there has been an average increase in depth of approximately 25 cm per 100 years over the last 4,000 years, that the rate has decreased (from an initial 45 cm per 100 years) over that period and that it may at present be of the order of 15 cm per century. In addition, cross-sections of the interior valleys commonly show a slight rise at the hill foot. The evidence suggests, therefore, that the peat mantle is rising, fingering into hill embayments left by stream dissection and thus slowly extending over the lower portions of the landscape. The fringes of the hill tracts have the appearance of terrain sculpted by subaerial processes and strongly dissected, which has now been partially submerged beneath a peat mantle, leaving only the highest hills or the core areas of the ridge upstanding. This appearance is supported by the commonly abrupt transition from the convex lower flanks of the hill mass to the flat peat plain which, within a few metres of the hill, may have a peat depth in excess of 3 metres.

Average slope was calculated by the method of Wentworth (1930) over four sample areas within the dissected lowlands, each covering 9 square kilometres. All bottomland tracts were excluded and figures relate to the hill components of the landscape only. The calculated average slope was 21°and 25° 30′ in two sample areas with only 40 and 37 per cent hill land, average summit heights at 125 and 145 feet (40 and 45 metres) and maximum summit heights at 275 and 350 feet (85 and 105 metres) respectively. In two sample areas with less than 10 per cent bottomland average slope was 16° 18′ and 18°, average summit heights 210 and 345 feet (65 and 105 metres) and maximum elevation 425 and 700 feet (130 and 215 metres) respectively. These figures illustrate, firstly, the general steepness of slope in all subunits of this landscape and, secondly, the fact that while some footslope units or foothill complexes occur and have relatively gentle slopes in areas where no swamp extensions are present, and the average slope is correspondingly reduced although many slope facets remain very steep, in the country fragmented by swamp tracts these footslope areas are generally absent or have been submerged beneath the peat mantle and all present hill tracts have steep slopes.

In the extreme northeast of the Area a number of discrete landform units occupy small areas and reflect varied geology. Conglomerates give hogbacks at Bukit Tunggal and in some areas east of the Sarupai River. Acid igneous rocks build steep-sided ridges at Bukit Piring and on the southern edge of the Arip valley. Massive Nyalau Formation sandstones with only moderately inclined bedding planes are eroded to a dip-and-strike terrain north of the Arip River. These varied landforms, separated by units of more 'normally' dissected terrain underlain by argillaceous sediments, are confined to a restricted locality which is atypical of the Area as a whole and in many respects, including the range of landform types, is to be associated with north rather than central Sarawak.

Erosion Surfaces

The main impression of the lowland hill zone from any vantage point is of a confusing complex of steeply-flanked hills, reminiscent of a very choppy sea. The amplitude of relief is highly variable but generally below 100 feet (60 metres). A sufficient number of summits are at approximately comparable heights, however, to suggest that the landscape represents an old peneplain, now extremely dissected and degraded. Many hills rising above the general summit level also appear to be moderately accordant with one another.

The more widespread surface, which rises from 200 feet (60 metres) near the coast to about 350 feet (100 metres) farther inland, is ascribed by Liechti (1960) to an early Pleistocene Peneplanation Cycle. No remnants of such a surface remain and no superficial deposits related to it have been recorded in the Area. The evidence for such a peneplain is largely confined to hill summit frequencies and the reconstruction of erosion history in adjacent areas. This erosion phase does not appear to be a factor in the development of the present soil mantle and the Early Pleistocene peneplain is not considered further here. To complete the picture of the erosional history of the Area, however, the evidence for such a Cycle is discussed in Appendix I.

At lower levels, particularly on the coastal plain and in the hill fringe zone on the interior swamp margins, there is clearer evidence for more recent erosion levels. These commonly comprise terrace remnants which have a mantle of superficial deposits in which present soils have developed. They can be related to terrace levels in adjacent areas which have been studied by other workers, and the prior evidence from north and west Sarawak is therefore considered first, and these data then related to landforms in the Area.

Liechti (1960), dealing mainly with north Sarawak, recognises two cycles following his Peneplanation Cycle, these being called the Jerudong and Alluvial Cycles. He considers that after the Early Pleistocene peneplain was uplifted and tilted it suffered almost complete dissection, and erosion to the new Jerudong base level produced mature valleys and coastal flats which have themselves been later dissected. This surface is thus now largely represented by coastal and riverine terrace remnants. Liechti postulates that the Jerudong Cycle was terminated by a further period of uplift, initiating the Alluvial Cycle. He also considers (1960: 312) the Jerudong Cycle to be split into two subcycles now expressed near the coast by terrace levels at 30-50 and 60-100 feet (9-15 and 18-30 metres) above present datum. Farther inland the height of riverine terraces representing the Jerudong still-stand are somewhat higher above local base-level and are insufficiently preserved for subcycle levels to be recognised. Remnants of Alluvial Cycle terraces occur at approximately 5-20 feet (1-6 metres) above present datum near the coast.

Wilford (1961: 125) considers that all base-level changes following that which terminated the Peneplanation Cycle (his Cycles 1 and 2) to be probably due to oscillatory movement in sea-level and prefers to class the Jerudong and Alluvial Cycles together as components of his Cycle 3, which is still in progress.

Terrace remnants ascribed to these levels are quite well-preserved in many localities, particularly near the coast, and identification is helped by the alluvial mantle (generally gravel or deep sand) which is commonly present. Liechti (1960: 314, 321) lists a number of sites and other workers have also described terraces which may be related to the Jerudong or lower levels in studying specific regions. Kirk (1957: 143-157) details the characteristics of the deep white sands mantling the prominent 30-foot raised beach at Bintulu.

In west Sarawak Fitch (1953: 36) notes a 90-foot (30 metres) level, also described by Wilford (1955: 71-73), at which high-level alluvium is found. Pimm, (1965: 66-67) working in the Serian area, recognises a marine plain rising landward from 50-100 feet to 150-200 feet (15-30 to 45-60 metres). He also (1967: 50) notes evidence of this surface in the Krokong area, together with lower terrace remnants at 20 feet (6 metres) above sea level. Wolfenden (1965: 54) records a gipefelflur at 150-250 feet (45-75 metres) in the Bau area, with terraces at lower levels. A dissected surface at 100-150 feet near the sea rising landward to 300-350 feet is noted in the Penrissen area (Wilford and Kho, 1965: 153). As stated above, it remains in doubt whether surfaces at 150 feet and above should be referred to the Jerudong or to earlier cycles. Andriesse (1972), discussing west Sarawak in general, considers that four erosion levels exist: 200-350, 100-150, 20-50 and 10-14 feet above sea level, the highest surface lacking alluvial deposits.

The terrace tracts are not continuous and correlation is made more problemmatical by the degree of subsequent structural deformation in different areas. There is, for example, evidence of 'post-Jerudong' warping in Brunei (Liechti, 1960: 315-316) and upfaulting on the Miri coast (Wilford, 1961: 93). Brunei and Marudu Bays and the Balingian-Mukah-Oya area are believed to be downwarped (Liechti, 1960: 310). In west Sarawak Haile (1954: 30-31) considered the Strap-Sadong area to be downwarped to the east, as the eastern drainage is graded and terrace remnants are confined to the west of this area. He also draws attention to the apparently drowned estuaries of the Batang Lupar and Batang Saribas, in contrast to the braided deltas of the Sungai Sarawak and Batang Rajang. Furthermore, Liechti (1960: 313) notes the ease with which erosion can significantly lower the apparent height of Jerudong terrace remnants, as these are commonly mantled to depths of up to 20 feet by unconsolidated sand.

Nevertheless, observations in the west and north by many workers suggest that there is a repeating sequence of terrace deposits at three levels, these commonly being at approximately 90-120, 40-80 and 5-20 feet (or some 30-40, 10-25 and 1-6 metres) above present sea-level (cf. the 'high', 'intermediate' and 'low' terraces of Sabah (Wilford, 1968: 3-4). The lowest level is tentatively ascribed to the Alluvial Cycle and the higher levels to the Jerudong Cycle. Where a level higher that this sequence is recognised in coastal areas it is generally at 200-300 feet (60-90) metres), is markedly degraded, lacks superficial deposits and is ascribed to the Peneplanation Cycle (Appendix I). Even where terrace sequences at levels very different from the above are recorded, these also commonly have three main levels and those bearing alluvial deposits are also confined to land less than 150 feet (45 metres) above present datum.

The Jerudong and Alluvial Cycle terraces have been considered as Middle and late Pleistocene respectively (Liechti, et al, 1960: 304; Wilford, 1961: 129) based partly, in the case of the former, on the occurrence of tecktites in Brunei terrace deposits up to at least the 50-foot (15 metres) level. One of these (from a 35-foot terrace) was later dated radiometrically at 750,000 years B.P. (quoted by Tate, 1971: 113). More recently, however, radio-carbon dating of wood and coral from the base of terrace deposits, mainly in Brunei and Sabah, suggest a younger age for the Jerudong terraces. Material from levels at 100 and 190 feet (30 and 60 metres) in Brunei gave dates in excess of the radio-carbon method (at some 40,000 B.P.) (Wilford, 1961: 104; Tate, 1971: 111) but samples from three sites in Brunei at approximately 50 feet (15 metres) gave dates of 27,900-31,600 B.P. (Tate, 1971: 111) and one sample from west Sarawak (Andriesse, 1972) gave a date of 23,800-27,800 B.P. for a terrace at about the same

height. As argued by Tate, all the Brunei deposits with theoretically 'infinite' age (where the age exceeds the limits of the radio-carbon method) are morphologically comparable with the lower terraces for which precise ages are quoted above and 'for this reason, they are more likely to be 50,000 years rather than 500,000 years B.P.' (Tate, 1971: 113), the implication being that the tecktites found in the Brunei Jerudong terraces are reworked from earlier levels.

Tate points out that the available dated material suggests placement of at least the lower Jerudong terraces in the mid-Wurm inter-glacial (50,000-25,000 B.P.) which, if correct, imples some crustal uplift in Brunei, in addition to the estimated changes of sea-level since that period, to account for the present average height of these features.

For the lower Alluvial Cycle terraces three samples from sites at some 6 feet (2 metres) above present datum in Brunei and Sabah have been dated within the limits 4, 290-5, 600 B.P. (Wilford, 1961: 109; Wilford, et al, 1966: 83). Both in height and age these terraces correlate well with the Holocene Peron submergence.

The degree to which falling sea-levels, as opposed to uplift of the landmass, are responsible for these landforms remain in question but fluctuating Pleistocene sea-levels undoubtedly affected the area and, as there is no evidence for general post-glacial subsidence of the region, these must have left some record on the landscape, however modified by later warping and uplift. It can also be assumed that, unless subsequent tectonic movement was highly variable throughout, the evidence for these levels should be found at roughly comparable heights in most localities. To some extent the evidence in west and north Sarawak appears to meet these conditions and the writer considers, with Wilford (1961: 125) that the erosion levels below 150 feet (45 metres) present elevation in the coastal zone mainly reflect oscillatory sea level movements associated with the Pleistocene glacial periods. If this is accepted, it follows that comparable evidence is to be expected in central Sarawak.

The dissected country with hill summits at a variety of heights gives way abruptly in the Selalang area to rolling country with summits consistently at 75-125 feet (20-40 metres) present elevation, the hills becoming increasingly fragmented by swamp tracts towards the delta. A similar landscape is found to the north of Sibu and the majority of outlying hills within the swamp plain itself have a similar range of elavations. The summit plain at this height probably correlates with Liechti's Jerudong cycle, as (a) levels are approximately comparable with those of remnants in the west and north ascribed to this cycle; (b) in the Selalang area, if not elsewhere, there is an abrupt break between this surface and the dissected landscape with summits at about 150 feet, and in all localities the lower surface is confined to a narrow zone on the fringe of the swamp plain, both features being consistent with a waveout surface; and (c) in many localities a superficial deposits are present on hill summits, which is also a feature of the Jerudong level elsewhere.

The superficial deposits generally comprise beds of sub-rounded gravel with overlying sand. While recorded at many points, particularly good exposures are found on the Selalang Spur road where it enters the hills immediately behind Selalang bazaar (at 50—75 feet or 15—20 metres above sea level), north of Sibu near Rantau Panjang on the road to Teku (at about 50 feet) and at a borrow pit site on hills south of Sg. Siong School, to the northeast of Sibu (at 75 – 100 feet).

Two striking tracts of undulating lowland at 75-100 feet (20-30 metres) occur in the Penipah area and in the upper Pasai drainage system near Sibu. The former has not been investigated in details but does have a patchy thin mantle of surface gravel in places. The latter area has been the subject of more thorough survey and lacks superficial deposits. The position on the periphery of the hill mass, the appropriate summit elevation and the lack of dissection suggest that these tracts may also be Jerudong remnants. In both cases, however, the underlying rocks are argillaceous and at Pasai (less obviously at Penipah) the abrupt boundary between the landform unit and surrounding higher more dissected terrain coincides with a marked change in lithology to sandstones and subordinate shales. The possibility exists, therefore, that these lowlands reflect ease of weathering in the underlying rock types rather than an erosion level.

While summits plains and isolated hills with superficial deposits can be related to the Jerudong cycle with some confidence where their present elevation is between 50 and 125 feet (15 and 40 metres), superficial deposits are also found in undulating terrain at lower elevations, either at the foot of higher hills on the swamp plain margin or as outliers within the swamp plain itself. No height measurements are available for these lowlying deposits but spot heights are available for the banks of some Rajang distributaries and sections from the Oya River into the swamp were levelled as part of this study. From these data it can be inferred that deposits on the interior margins of the swamp plain which rise only a few feet above the swamp level are at some 10-20 feet (3-6 metres) above present mean sea-level in most cases. Both in elevation and in their position seaward of higher Jerudong remnants such deposits can be compared with remnants of Liechti's Alluvial cycle elsewhere. Where, however, the deposits mantle hills rising significantly above the swamp level (and are at 300 feet or more above sea-level) it is uncertain whether they should be considered Alluvial Cycle remnants or related to the lower subcycle of the Jerudong period which has been reported farther north.

These lowlying deposits, largely of well-sorted sand but with pebble beds in some localities, are mainly concentrated in a narrow belt between the hill zone and the swamp plain (Map 3). They strike northeast from Nyabor to beyond Selalang, are then manily absent in the Rajang delta itself, although remnants occur in the Bawang Assan area, and reappear beyond Bawang Assan to continue as a rather broader belt on the same alignment extending to 'Sikat Bay'. Here they are more fragmented but are found closer to the present coast, suggesting a build-up of littoral deposits in the shelter of the Penipah headland which have been later eroded by the Batang Mukah. Their distribution suggests that at the time of the Atlantic sea, and possibly in the earlier Jerudong period, a long, straight, northwest-facing coast extended from 'Sikat Bay' southwest to Nyabor, broken only by the embayment of the Batang Rajang, which may then have had few distributaries and little delta development. This prior coast appears to follow the line of major shear faults through much of the Area (McManus and Tate, 1976).

To the south of Nyabor and to the east of the Penipah headland low-level beach remnants are less extensive and are normally confined to narrow belts in hill-foot positions on the fringe of the swamp plain. Quite large tracts are present in some localities, however. A good example of apparently poorly-sorted storm-beach material extends from near Roban to Rumah Judan.

Riverine terrace tracts are not a major feature in the landscape of the Area but have been noted in some localities. Terraces are common in the lower Kanowit floodplain between Julau and Machan. A portion of this tract is mapped in Fig. 11. Low light-textured terrace material occurs some 6-10 feet (2-3 metres) above the present floodplain and heavier-textured terrace material mantles undulating hills at some 25-50 feet (7-15 metres) above floodplain. In the upper Mukah landslips on some hills close to the main river expose pebble beds below heavy-textured soils at 50 feet or more above the river level. As it is very difficult to distinguish such material from residual soil mantles unless deep cuttings are available, such high-level material may well occur near many other main streams. It is likely that terrace remnants at such height above present floodplains are relicts of the Jerudong Cycle but the remnants are so fragmented that this would be difficult to prove satisfactorily without detailed survey and levelling.

Identification Of Terrace Material

The soil profiles developed in terrace sands on nearly flat sites commonly have a pronounced podzol horizonation. Sedentary podzols also occur over sandstone where slopes are gentle, and the transition from the structureless sand of the subsoil to the underlying loam with residual rocks structure may be abrupt. The Belaga Formation outcrop within the Area comprises very mixed beds of argillaceous and arenaceous material in Stages II, III and IV and sandstones commonly become progressively more extensive towards the western end of the outcrop. Hills on the swamp fringe in the west are relatively low and may have gently slopping upper slope and summit zones, particulary where they occur in areas levelled during the Jerudong Cycle. It is commonly difficult to decide, therefore, whether podzols mantling low hills of sandstone on the swamp fringes are residual or are developed in a thin mantle of transported sands which are relicts of prior high-level beach deposits. The problem is further compounded by the fact that, while sands on the present beach are generally of medium or coarser grade, those associated with old beach lines on the interior swamp margins are dominantly fine sand which may have little contrast in mean size from that of underlying sandstones.

A similar problem exists in establishing the origin of sands at hill-foot sites on the swamp margin. Where they are backed by sandstone hills they may represent locally-derived colluvial or alluvial deposits rather than indicating an old beach line. One locality where the deposit is definitely colluvial is that north of Bukit Piring. Poorly drained sand flats extend some distance north from the hill before grading into peat swamps, and podzols have developed in the sands at some sites. The sands are here mainly medium and coarse, however, in contrast to most such deposits, and are obviously derived from wastage of the granodiorite in the hill range which backs them.

Little asssistance is given on this question by a study of the mineralogy. The sandstones have been reworked in a number of cycles and generally, like the old beach deposits, highly siliceous. The very intense leaching conditions in sites on which podzols have developed results in a negligible heavy mineral fraction in the sands and that being a residue of the most resistant minerals (such as zircon, tourmaline, brookite) giving little guidance to the origin of the material. The size distribution of the sands is also likely to reflect origin, however, and a preliminary survey of this feature was made to assess its usefulness in this context.

A total of 100 samples from 33 widely scattered sites were examined and were classified into the following groups:

I : Residual soils other than podzols, developed over sandstone or sandstone and shale (48 samples from 10 sites); only samples with over 30 per cent sand in the fine earth were considered.

II : Residual podzols developed over sandstone (10 samples from 2 sites).

III : Podzols developed in marine alluvial forming outliers in the coastal plain and with no hill source for the material nearby (15 samples from 3 sites).

IV : Podzols developed in alluvium on the fringe of the coastal plain on sites where very local derivation of the material is a possibility or developed in material of doubtful origin mantling low hills on the fringe of the coastal plain (22 samples from 14 sites).

V : Recent riverine alluvium or podzols developed in terrace riverine alluvium (5 samples from 4 sites).

Material coarse than 0.05 mm (sands and gravels) was used for the study and ten fractions between 0.05 mm and 2 mm separated by sieving; where necessary up to six further fractions were separated in the coarser material up to 13 mm. The sieve sizes were not in regular progression but roughly approximated to ½ϕ divisions. Cumulative frequency curves were reduced to ϕ values, and indices for the mean (Mz), degree of sorting (σ_1), skewness (Ski_1) and kurtosis (Kg) of each distribution calculated according to the measures proposed by Folk and Ward (1957). Mean and extreme values for each index/group are given in Table 4.

No single parameter separates the five groups studied. Although the marine podzol sands (III) are better sorted than the sands of the residual soils (I, II) the ranges almost overlap and would probably be found to do so were more samples studied. Other parameters generally show broad overlaps in all groups. When each parameter was plotted against the rest, however, the plot of sorting against mean size (Fig. 12) showed clearer relationships. In the residual sands (I, II) sorting is better where the mean size is finer; a similar trend appears to be present, but much less pronounced, in the marine podzols. No trends are apparent in the few riverine alluvial samples (V) and the samples from the swamp fringe (IV) show, as expected, widely varying sorting and size characteristics, although the majority have ratios typical of either residual or marine alluvial material. Three samples from the swamp fringe in the 'Lemai Bay' (Fig. 12, samples 1-3) are better sorted than all residual soils but less so than most marine samples. They are believed to be alluvial but comprised of reworked material of very local origin. Samples from the Nyabor-Grigat area (samples 4-7) are known to be alluvial but range from well sorted to poorly sorted. This may be a feature of coastal sand ridge complexes where poorly sorted storm beach material and better sorted sands occur together, but it may suggest that the material here is partly of local derivation from erosion of the Nyabor headland. Samples from the 75-125 feet level are all relatively poorly sorted, even where, as at Selalang, they are underlain by pebble beds (sample 8), although in this case the contrast in sorting between the alluvial material and the underlying sandstone (sample 9) is still well-marked. Distinction of residual and high-level alluvial material on these grounds is thus likely to be difficult, although where no pebble bed is present the discontinuity with the underlying material may still be indicated by the degree of sorting even where the mean size is relatively constant.

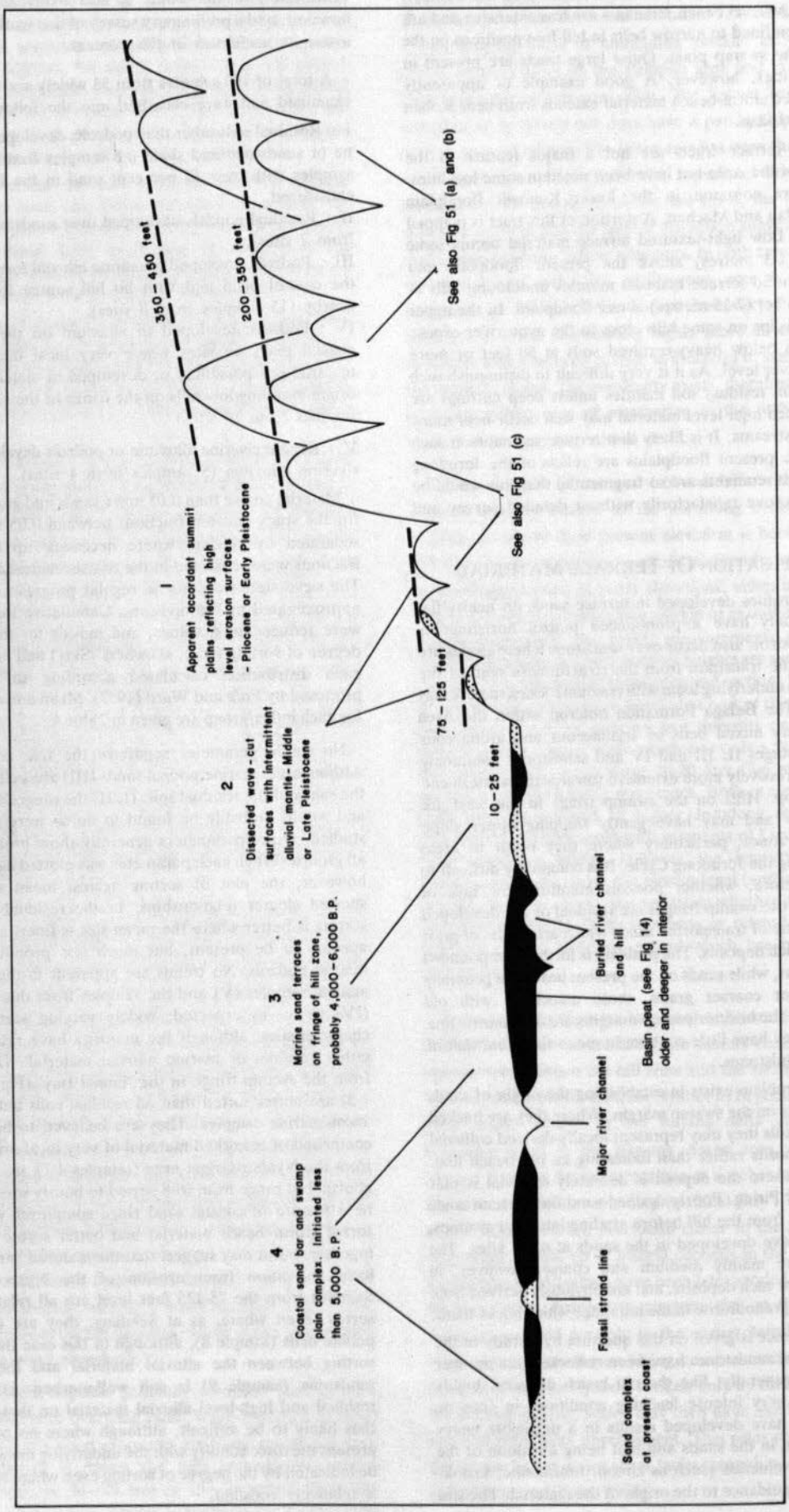


Fig. 11: Schematic relationships between landform units

Table 4

Sediment analysis parameters for selected sand fractions (figures quoted in Ø units)

	No. of Samples	No. of Sites	Mean size (Mz)			Sorting(σ_1)			Skewness (Ski_1)			Kurtosis (Kg)		
			Min	Max	Av	Min	Max	Av	Min	Max	Av	Min	Max	Av
I. Upland soils residual on sedimentary rocks, excluding podzols	48	10	1.23	3.25	2.26	0.60	1.54	1.09	-0.64	+0.47	-0.06	0.58	1.41	0.88
II. Upland residual podzols on sandstone	10	2	2.76	2.89	2.85	0.74	0.84	0.77	-0.08	+1.18	+0.22	0.65	0.89	0.81
III. Podzols in marine sand remnants on swamp plain	15	3	2.25	3.35	2.64	0.25	0.58	0.36	-0.15	+0.26	+0.03	0.76	1.46	1.06
IV. Podzols on swamp margins	22	14	0.64	3.06	2.19	0.37	1.61	0.85	-0.32	+0.43	+0.15	0.72	1.51	0.99
V. Podzols in locally-derived riverine alluvium	5	4	1.30	2.96	2.40	0.27	0.70	0.60	-0.11	+0.26	+0.05	0.90	1.23	1.03

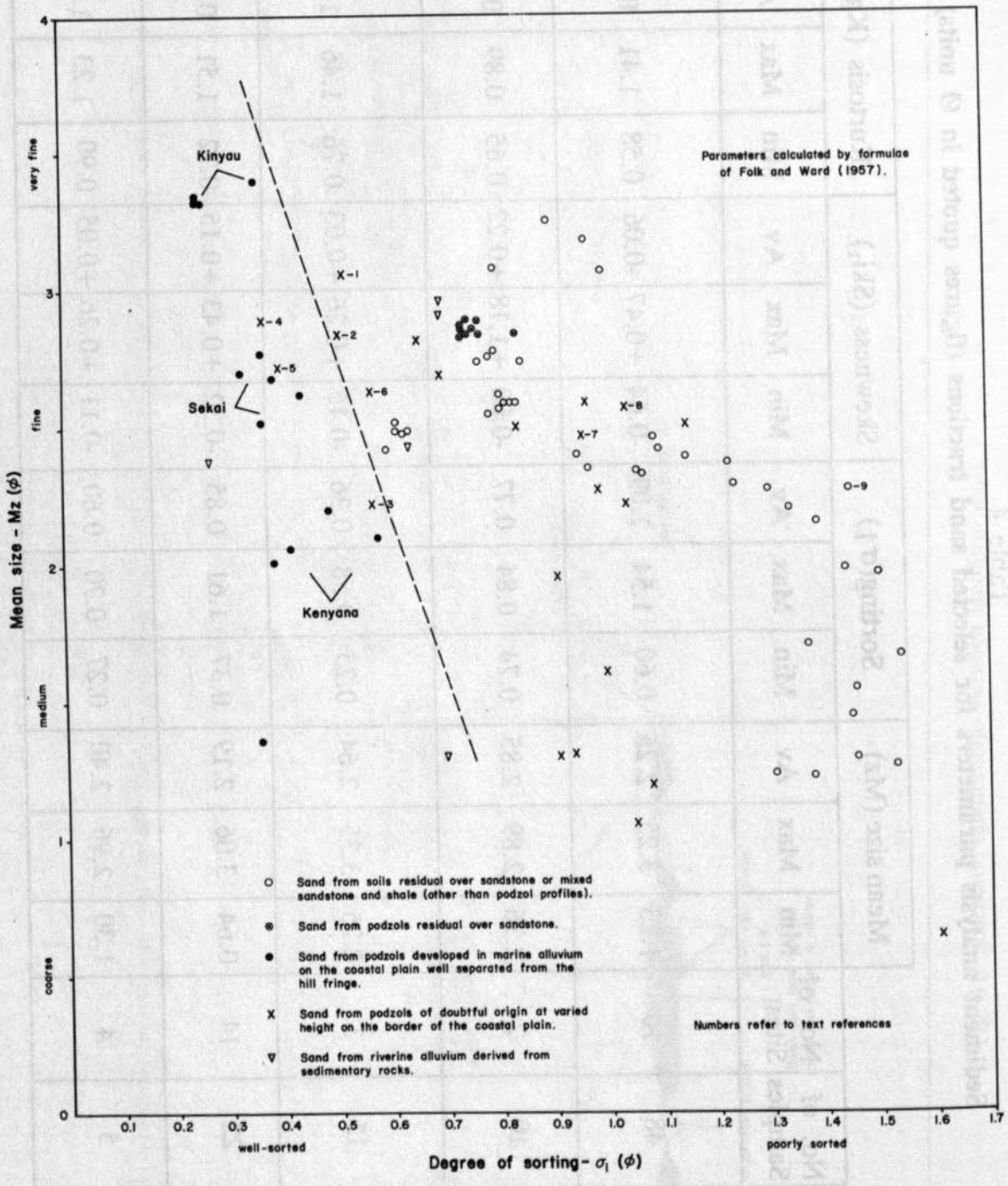


Fig. 12: Size and sorting of sand separates of varied origin

Bearing in mind that the samples used are drawn from over a wide area, enough of a pattern emerges from Fig. 12 to suggest that this approach may be a useful aid in establishing the type of parent material of swamp fringe podzols, but only an intensive study of soils in a specific locality is likely to give clear indications regarding origin.

The Swamp Plain and Coastal Beach Complex

The low-level beach deposits on the interior swamp margins indicate that the coastline at 5,000-5,500 B.P. approximately followed the present hill/swamp boundary. Since that period a slight relative fall in sea-level has taken place, but a fall of only a few feet is needed to account for the present height of these relicts when allowance is made for the height of present storm beach material above mean sea-level. Following this slight recession, sea level has been relatively stable at the present datum and this condition has allowed extensive silting of the previous offshore area and the development of a wide peat-swamp plain, a clay-swamp delta at the mouth of the Batang Rajang, and a substantial sandspit complex bounding the present coast. Radio-carbon dates from the Baram peat swamp in north Sarawak (Wilford, 1961: 119) indicate that peat accumulation at that site began at approximately 4,270 B.P. and a similar date can be inferred for the basal layers of the peat mantle on the swamp plain within the Area.

The mechanics by which these features formed remains uncertain. A bore to 13 metres at swamp site near Marudi in North Sarawak (Anderson, 1961: 112-124; 1964a: 13-14), where the peat mantle was 11.5 metres thick and was underlain by clay, showed that the basal layers of the peat were derived from mangrove and that changes in the pollen community at higher levels in the section are consistent with lateral changes in the floristic composition of the present peat swamp vegetation from thin young deposits to thicker peats with features of maturity. Anderson therefore considered that the initial phase of development was the built-up of marine clay plain on which mangrove became established. Progressive deposition offshore allowed the extension of the mangrove front but in the poorly-drained flats behind the coastal belt a shallow peat was formed and mangrove communities were replaced by peat swamp forest associations. The continued seaward extension of mangrove colonising new marine alluvial deposits, to be replaced in its turn by peat swamps, was possible as long as offshore current and wave conditions were conducive to the build-up of alluvium. Anderson (1964a: 14-15) considers that the relatively sheltered area between the Pinipah and Nyabor headlands silted up quite rapidly as the peat swamps are morphologically well-developed and, by inference, relatively old in this area, except for the peripheral swamp tracts of Bruit, Jemoreng and Matu-Daro which on structural grounds are considered more recent. He also instances the rapid seaward progression of mangrove in the Nonok area, farther west, where a sheltered embayment also occurs.

On this reconstruction the sand deposits along the present northern coast of the Area are presumed to be a late depositional feature which have stabilised the coast but have not contributed to the formation of the swamp plain behind them; it must be stressed that Anderson was writing before soil survey had shown the extent of coastal sand deposits. Wyatt-Smith (1956), on the other hand, considered that estuarine peat swamps in Malaysia were always associated with coastal sites at which a sandbank holds up drainage.

The soil survey showed that an almost continuous sand spit formation extends from Bintulu (the closest point eastward of the Area at which hill masses abut the present coast) in an almost straight line west to Igan. Within the Area the spit may be divided into three units. Eastward of Bedengan to the border of the Area it is only ½-1 mile broad (ignoring any submerged extension to seaward). The sands are low-lying and generally poorly-drained but where a peat mantle occurs it is almost invariably thinner than 1 metre. The narrow exposure may be a result of coastal erosion, as significant erosion has taken place along the Balingian coast. Near Bedengan, however, and extending west to Mukah, the spit complex is broader (averaging some 2 miles) and, while the bulk of the deposits are exposed or covered by only thin peat, it also extends inland to underlie peats as thick as 2 metres. The exposed sands are also apparently fractionally higher above mean sea level (or at least above the general local water table) as they are commonly heavily leached and shallow podzols have developed in them. The third unit extends from Mukah west through Igan to Matu. Here the sands are low-lying, generally without a podzol morphology and form an irregular but rather narrow exposed band at the coast. But they also extend under the peat plain for a distance which becomes progressively greater towards the west, being some 8 miles in the Matu-Jemoreng area (Map 3). Although data from the interior of the peat plain in this locality are scanty, the basal sand distribution on the traverses recorded suggest that the initial spit development trended southwest from near Mukah, that secondary spits than developed to seaward and straightened this section of the coast,

giving a complex pattern of broad sand ridges and intervening clay swales in this area, and coastal erosion between Igan and Jol finally truncated these complexes and halted further westward extension of the spit development. The sands between Igan and Jemoreng underlie peats of all depths, including those in excess of 3 metres.

The sand deposits between Bintulu and Jemoreng appear to form a single landform unit which has developed progressively westward. They extend over a distance of approximately 105 miles. The evidence of erosion at Balingian and between Jol and Igan suggests both that the deposits were initially even broader and that the deposits were reversed. It is difficult to conceive that this structure developed quickly and it appears more likely that the extension of sand deposits from Bintulu began early in the present erosional cycle, i.e. in the last 5,000 years during which sea-level has been relatively stable. In the zone east of Mukah, if not farther west, the extension of the sand under the peat swamp fringes to underlie a peat mantle up to 1½ metres thick indicates that the spit development antedates the later stages of peat accumulation. To the west of Mukah, and particularly in the Bruit and Jemoreng areas, the situation is rather more complex as there is here evidence that the plain has subsided (Anderson, 1961: 129). The underlying alluvium is below mean sea level and the structure of the swamps suggest they are younger than those farther east.

The stages by which the swamp plain developed and its relationship to the coastal sand deposits may therefore be as follows: (1) in the initial stages silting, followed by mangrove colonisation and later peat development, was confined to the sheltered 'Sibu', 'Sikat' and 'Lemai' Bays; sand-development began from Kidurong headland near Bintulu and possibly also to a slight extent within the Area to the west of the Penipah headland, although it is possible that the Kenyana spit is a relict of a previous Alluvial Cycle feature; (2) seaward extension of the mangrove front progressed into more exposed waters but was probably accelerated where continued spit extension gave protection for silt deposition; the swamps in the Balingian Bay may therefore be somewhat older than those farther west; (3) the progression of silting and peat formation westward and northward continued behind an extending protective sandbar to include the Matu, and possibly Bruit, area in the west and to partially cover the lower landward slopes of the sandbar complex at many points in the north.

The character of the mineral layers underlying the peat also suggests that the coastal sand complex is broadly contemporaneous with the infilling of the plain behind it. All Anderson's bores in the Area (mainly in the western part of the coastal plain and in the delta itself) found a heavy clay below the peat (Anderson, 1961: 130). Soil survey investigations (in a broader spread of localities but largely ignoring the deep interior peats between the main rivers) also recorded clays or silty clays below the peat at almost all points in every locality outside the coastal zone. The development of an offshore sandbar from a major land promontory, together with the deposition of silt and clay in the protected semi-lagoonal environment behind it, is a common coastal association. On the other hand, progressive seaward deposition of silt and clay up to 20 miles out from the landmass, with no evidence of intermittent sand phases, then followed by coastal sand deposition as extensive as that described, would presuppose a radical change at some point in depositonal conditions (off shore curents, wave direction and source of material being among the factors involved), and for this there is no evidence. The former explanation is thus inherently more likely.

While, however, it is maintained that the early presence of an offshore sandbar played a role in the development of the coastal plain in this instance, it must also be conceded that recent coastal changes at Sirik support Anderson's opinion that it is not essential to the development of such swamps. Considerable coastal advance has taken place in this century at Tanjong Sirik (Fig. 13) and it has been possible to record these changes with some accuracy (Scott, 1969: 2-5) as semi-detailed soil survey is supported by air photographs taken in 1926, 1951, 1966 and 1968 (the earlier data existing as mosaic print derived from part of the first air photography project undertaken in Sarawak). It can be seen that this headland has built up by alternating phases of sand and clay accretion but that since 1951 clay deposition has been dominant and accretion has been very rapid, averaging 29 metres per annum westward and 50 metres per annum northwards during that period (measured to the edge of the vegetation cover). Progression is somewhat irregular, however, and in the period 1966-1968 there has been little extension northwards although westward extension has been locally at the rate 36-82 metres per annum. To the east of this headland a second island (Pulau Jangau) has appeared north of Pulau Patok and has been colonised by mangrove in the last decade. The importance of the marked accretion in the Sirik area in the present context is that the coastal advance is being rapidly followed by the development of a peat mantle and that, unlike the Nonok

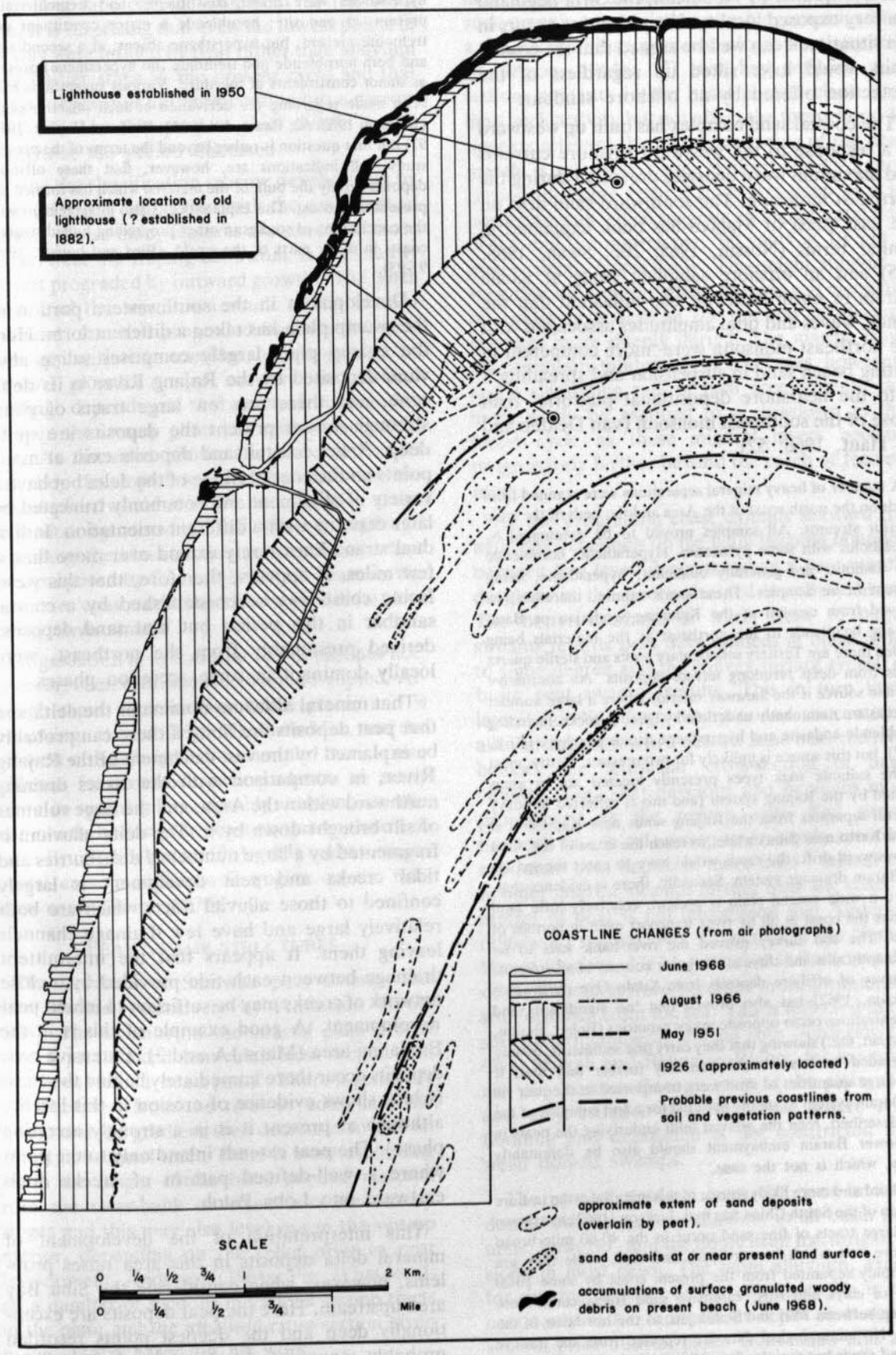


Fig. 13: Coastal advance at Tg. Sirik

example quoted by Anderson, the Sirik headland is a very exposed locality. If rapid silting occurs in this situation it can well be argued that the coastal plain would have silted up regardless of the protection offered by an offshore sandbar.

The coastal sand complex has built up westward as a response to the westward offshore currents and maximum wave energies prevalent during the northeast monsoon. The southward sand drift on the east coast of Malaya has been explained in similar terms (Nossin, 1965: 202; Swan, 1968: 115) and an offshore sampling study at Kuala Baram in north Sarawak also indicated that the winds, waves and tidal amplitudes associated with the northeast monsoon were 'more competent in setting beach sand in suspension and spreading it onto the nearshore depositional platform' than those of the southwest monsoon (van Delden and de Haut, 1966: 52).

A number of heavy mineral separations were scanned from sands on the north coast of the Area and the beds of the main interior streams. All samples proved to be dominated by amphiboles with some pyroxenes. Hypersthene, hornblende and tremolite are generally dominant, hypersthene, being present in all samples. These sands cannot, therefore, be derived from erosion of the Kidurong-Semilajau or Batu-Lobang headlands to the northeast as the materials being eroded there are Tertiary sedimentary rocks and sterile quartz sands from deep Jerudong terrace deposits. An alternative possible source is the Sarawak interior where a large number of areas are dominantly underlain by igneous rocks, including hornblende andesite and hypersthene dacite porphyry (Kirk, 1957), but this source is unlikely for two reasons. Firstly, most of the suitable rock types presently located are in areas drained by the Rajang system (and this is reflected in heavy mineral separates from the Rajang sands near Kapit and at Pulau Kerto near Sibu) while, to reach the coast of the Area by westward drift, the sands would have to enter the sea via the Baram drainage system. Secondly, there is evidence that, where a wide coastal plain is present, relatively little sand reaches the coast at all by river transport even in periods of spate. The soil survey proved the river-bank soils to be dominantly silts and clays in the lower courses of all streams. A survey of offshore deposits from Kuala Oya northwards (Jackson, 1962) has also proved that 'no significant sand concentrations occur opposite major estuaries (Belait, Baram, Balingian, etc.) showing that they carry fine sediments, mainly silt graded or less....' and one may further add that, if such large quantities of sand were transported in the past via the Baram system to supply material for a spit complex of the size described, then the alluvial infill underlying the peats in the lower Baram embayment should also be dominantly sandy, which is not the case.

A third and more likely source of this material is the inshore portion of the South China Sea bed. Jackson (1962) has shown that large tracts of fine sand occur in the 40-60 mile broad offshore belt which he surveyed, and that, while they are commonly separated from the present coast by some 10-20 miles of clays and silts, extensive sand tracts come close inshore between Miri and Semilajau, to the northeast of the Area. No mineralogical data are reported from the inshore sea-bed sands but samples from three sites farther offshore to the north-northwest of the Area have been analysed (Pimm, 1964: 139-141). Within the heavy fraction hornblende and hypersthene were major constituents, and tremolite also present, at one site: hornblende a major constituent and tremolite present, but hypersthene absent, at a second site; and both hornblende and tremolite (no hypersthene) present as minor constituents at the third. Various suggestions have been made regarding the derivation of such offshore sands (Jackson, 1962: 52; Pimm, 1964: 141; Bird and Hopley, 1969: 91) but that question is rather beyond the terms of the present study. All indications are, however, that these offshore deposits supply the bulk of the material which has formed the present sand coast. This explanation is also in agreement with the conclusions of studies in other prograding humid tropical coasts in many parts of the world, (Bird and hopley, 1969: 91-93).

Development in the southwestern portion of the swamp plain has taken a different form. Here the swamp plain largely comprises saline alluvium deposited by the Rajang River in its delta zone, and there are few large tracts of peat, although where present the deposits are quite deep. Relict coastal sand deposits exist at many points on the coastal fringe of the delta but have a variety of alignment and commonly truncated by later deposits with a different orientation. Individual strand lines rarely extend over more than a few miles. It appears, therefore, that this west-facing coast was never stablished by a coastal sandbar in this period but that sand deposits, derived presumably from the northeast, were locally dominant in some accretion phases.

That mineral alluvium dominates the delta and that peat deposits are limited there can probably be explained by the vast catchment of the Rajang River, in comparison with the rivers draining northward within the Area, and the large volumes of silt brought down by it. The delta alluvium is fragmented by a large number of distributries and tidal creeks and peat develpment is largely confined to those alluvial tracts which are both relatively large and have few drainage channels leaving them. It appears that the intermittent drainage between each tide provided by a close network of creeks may be sufficient to inhibit peat development. A good example of this is in the Empaling area (Maps 1A and 3). Extensive peat deposits occur there immediately behind the coast (which shows evidence of erosion in this locality although at present it is in a strongly accreting phase). The peat extends inland only to the point where a well-defined pattern of creeks drain eastward into Loba Paloh.

This interpretation of the development of mineral delta deposits in this area raises problems, however, when considering the Sibu Bay area upstream. Here the peat deposits are exceptionally deep and the deepest points recorded probably represent old channels of the Rajang River. If, as suggested above, the large silt discharge of the main river is the main factor in

controlling landform development in the delta zone, it is surprising that even the lowest points in this Bay were infilled by peat rather than alluvium at an earlier stage in the present cycle and that alluvial deposition has been confined to a narrow levee zone in this part of that river's course throughout the period discussed.

Using the classification scheme development by Swan (1968) in connection with the east coast of Malaya, where many features are similar to those of the Area, the Rajang delta zone is dominantly 'a coast prograded by outward growth'. The north coast, and the west coast south of the Nyabor headland, are also prograded but whether it is more appropriate to consider than prograded 'by outward growth' or by 'outward and inward building' depends on the assumed relationship between the swamp plain and coastal sand complex. As discussed above, the writer considers that they developed together and most of the coastal plain would thus be considered a 'coast prograded by outward and inward building'. Extending the classification to include the divisions proposed by Davies (1964), all coasts in the Area are 'coasts developed in a mesotidal, low energy environment'.

Progradation in at least the recent past has not, however, been continuous and uninterrupted. Although rapid accretion has taken place, and is continuing, at Sirik (Fig. 13), Pasir Mas, and the spit west of Kuala Igan, for example, there is also evidence for extensive retrogradation at many points in recent years, notably erosion into the peat mantle backing the coast on the southwest of Pulau Bruit (Anderson, 1961: 128) and extensive coastal erosion at Kuala Balingian on the northern coast (Scott, 1970).

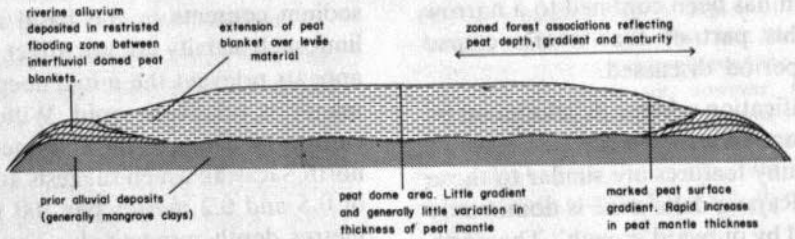
Peat Swamp Structures

The structure of Sarawak peat swamps has been studied extensively by Anderson (1961; 1964). The swamps on the coastal plain proper have a pronounced lenticular cross-section and have been termed 'basin peats'. There is generally a marked rise from the river or coast into the swamp and the gradient then decreases to give an almost flat central tract. There is a corresponding fall in the height of the basal mineral material from the river-bank or coast into the swamp fringes and this may also level out in the swamp interior, depending on the relief prior to peat development. Anderson (1964a: Fig. 2) has levelled a number of sections in various swamp tracts on the plain and the idealised cross-section given in Fig. 14a is based on his work.

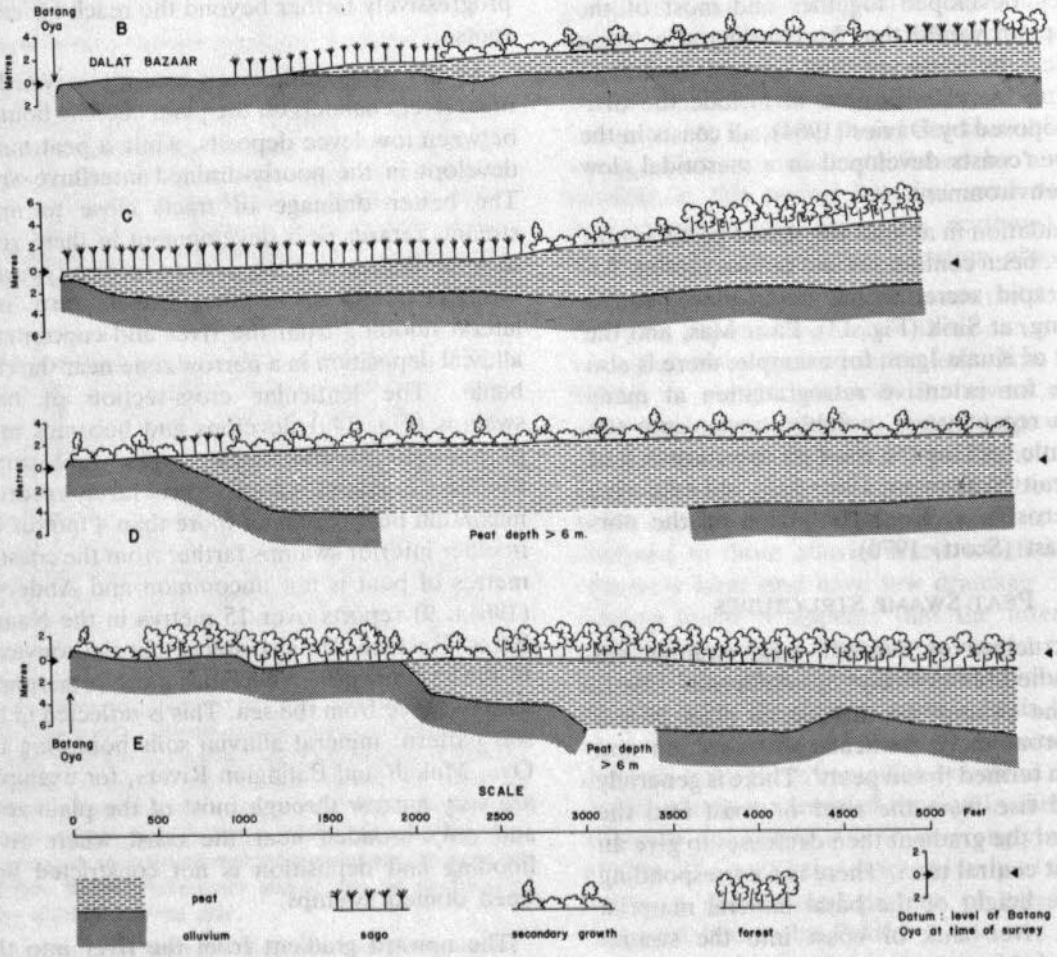
The initial development of the peat mantle requires permanently saturated conditions. It has been suggested (Mohr and van Baren, 1954) that such organic accumulation may be encouraged by a soil toxin inhibiting microbiological activity and (Anderson, 1964a: 13) that high sulphur and sodium contents in the basal marine clays may limit such activity but not affect the forest flora. It appears relevant the initial deepening of the peat mantle is relatively rapid. Wilford (1961) quotes carbon-14 dating from a 10-metres deep peat in north Sarawak which suggests an incremental rate of 0.5 and 0.2 metres per 100 years at 10 and 5 metres depth respectively. This might support a view that the limiting effect to toxic soil elements on oxidation lessens as the mineral substratum becomes more deeply buried. The marine clays are commonly moderately rich in bases, however, and a slackening rate of peat accumulation can more easily be ascribed to a slowdown in the forest cycle as these mineral layers become progressively farther beyond the reach of feeding roots.

As the prograding coast extends seaward the main river channels on the plain become bounded between low levee deposits, while a peat mantle develops in the poorly-drained interfluve areas. The better drainage of tracts close to major streams retards peat development in these zones to some degree and the convex surface typical of basin peat swamps results. This in turn limits lateral flooding from the river and concentrates alluvial deposition in a narrow zone near the river banks. The lenticular cross-section of basin swamps (Fig. 14a) develops and becomes more pronounced as the swamp ages. Soil survey transects in coastal swamp tracts rarely recorded maximum peat depths of more than 4 metres but in older interior swamps farther from the coast 10 metres of peat is not uncommon and Anderson (1964a: 9) reports over 15 metres in the Naman Forest Reserve. He also states that the convexity of the swamp surface becomes more pronounced with distance from the sea. This is reflected in the soil pattern: mineral alluvial soils bordering the Oya, Mukah and Balingian Rivers, for example, are very narrow through most of the plain zone and only broaden near the coast where river flooding and deposition is not constricted between domed swamps.

The upward gradient from the river into the domed swamp quickly shallows in all basin peat units, however, and the dome itself has little or no slope in most cases. The basal alluvium, except for riverine deposits on the swamp edges, is also commonly rather uniform in depth as it represents a prior alluvial plain. Both small hills and old river channels may, however, be buried under the basin peat mantle and such features become



A. Schematic relationship between landform units in a basin peat swamp between two major river channels (based on Anderson, 1961)



B-E Levelled sections from Batang Oya into peat swamp margins (sections located on Map I)

Fig. 14 : Peat swamp structures

increasingly evident towards the interior margins of the plain. The basal profile – and the depth of peat – in such situations can be highly irregular. Anderson (1964a: Fig. 2) includes a striking section from the Naman Forest Reserve south of Sibu in which the lenticular cross-section of the basin peat is preserved but steep-sided hillocks up to 45 feet in height rise from the mineral base to just break the swamp surface, the peat mantle here being some 40 feet thick. In addition, as stated above, a 50-foot probe could not reach the peat base at some points on this transect and, in view of its location, these low points probably represent old channels of the Rajang River itself. In the partially drowned landscape typical of the hill/swamp transition zone in 'Sibu Bay' such highly varied peat depths are likely to be common.

Irregularities in the peat swamp surface, other than those due to uprooted trees, are normally not marked – although the combination of high water-tables, stilt roots, and pockets of spongy log-free peat in which one can quickly sink to the waist makes it difficult to appreciate this point when traversing swamp areas. Low areas do occur, however, and may be unrelated to the few defined drainage channels crossing the swamps. In the Sirik areas west of Kampong Bruit a depression approximately ½ mile across has been recorded (Scott, 1969: 4, quoting Drainage & Irrigation Dept. levelling data) in which the peat surface drops abruptly some 12 feet below the general level for that locality. Seismic surveyors in the 'Balingian Bay' in 1967 reported (pers. comm. to the writer) the blow-out of a bore in that swamp and concluded that the probe had tapped a gas pocket at depth. The depression in the Sirik swamp may be the result of a natural blow-out of the same type. Small methane gas springs bubble up through many peat swamp streams and are commonly of sufficient concentration to ignite with a match.

The basin peat structure is a feature of the coastal plain proper and only develops where large tracts of peat swamp (of the order of 20-100 square miles in area) occur without the interruption of major river channels. Where the peat mantle extends into valley bottomland tracts on the hill fringe such domed structures do not occur. The swamp surface in these areas is more or less flat or, if a major river occupies the valley, may even lose height away from the river levee. Four transects were levelled in the lower Oya as part of this study (Fig. 14b–e, located on Map 3). These are confined to the swamp fringes, which are of particular interest to agriculture. Transects B and C are located in the lower Oya where basin peats have developed and both show a marked gradient from the river into the swamp. This is particularly pronounced in transect C which is orientated directly towards the dome in that area and, judging by the forest zonation in this locality, almost reaches the flat bog plain which caps the dome. Transects D and E are farther upstream and are located in the hill/swamp transition zone. A very slight gradient occurs on the edge of the peat mantle in D, which is immediately coastward of the hill zone, but the surface quickly levels off and remains virtually flat throughout the transect. In E, which is located in peats enclosed by scattered hill tracts the peat level drops slightly away from the river. This is probably a result of the more extensive alluvial deposition by the Batang Oya in this part of its course, the peat mantle extending to cover old levee structures. These sections also confirm Anderson's data from the swamps west of the Oya (Anderson, 1964a: 9) that the peat mantle tends to thicken towards the interior of the plain and towards the hill fringe zone. The increasing irregularity of the clay base in the interior is also shown by these transects. One drowned hillock is apparent on transect E.

Coastal Structures

Where clays and silts have been deposited in estuarine and coastal situations, most notably in the Rajang delta but also in the Bruit and Daro areas and at the mouths of rivers draining to the northern coast, a complex pattern of microrelief develops. Immediately back from the low water mark is a gently-graded foreshore zone, partially colonised by mangrove species and with no microrelief. Proceeding landward into the area inundated by all spring tides and most high tides, the mangrove cover is thicker, the deposits are cut into by short, but commonly deep, creek channels and have a complex microrelief due to the activities of the mud-lobster (*Thalassina anomala*). This lobster-like crustacean is an efficient soil miner which throws up large mounds of excavated material through the top of which vertical channels emerged with their exits generally above high water level. The mounds are irregular but approximate to a broadly-based cone rising commonly to 1 metre above the general surface of the deposit; mound spacing is varied but there may be 3 or 4 metres between each main cone. Localities were also noted on the survey, however, where mounds are relatively narrow-based, rise to some 2 metres and are closely packed with virtually no intervening mound-free ground. Such pronounced microrelief appears to be particularly associated with the head of creeks, especially where backed by hill tracts. It is probable that the

back-up of tidal water in such areas gives an abnormally wide tidal range and thus encourages higher mound-building.

Mud-lobster microrelief is generally confined to heavy-textured deposits, sandy areas being avoided. In other respects, however, the mud-lobster is less discriminating. An instance was noted in Ulu Aur, east of Selalang, where an abnormally resistant shale bed extends out into the delta swamps, rock outcrops occur in the creek channel crossing it and the clayey alluvium bordering the creek is locally underlain at depths of less than 50 cm by weathered shale. The alluvium is well-colonised by mud-lobsters and their mounds are equally common where the alluvial mantle is shallow. The mounds are there, however, composed of clay with as much as 30 per cent of platy weathered shale fragments up to 4 cm long, suggesting that the mud-lobster will burrow into the upper layers of any weathering rock zone near the surface which is soft enough to penetrate.

Microrelief in coastal areas built of sands is generally very subdued. Even where sand deposits are dominant for some distance back from the coast there is virtually no dune development, a feature typical of coasts in the humid tropical zone (Bird and Hopley, 1969: 92). The storm beaches produced in the low-energy environment of the area are only a few feet high and, while these are preserved to some extent as relict features in the landscape behind the coast when further accretion takes place, their presence is commonly more apparent from the vegetation and land use patterns on air photographs than by variations in the ground surface. Abrupt changes in elevation are the exception rather than the rule except where alternations of sand ridges and marine clay swales occur. Even in such areas the amplitude of relief is generally of the order of only 1-2 metres. It must be stressed, however, that even where the coastal zone is comprised entirely of sands the soil pattern is a complex one, and the varied trends in soil development are commonly linked with slight variations in elevation and with the resultant change in the average depth of the water table (Fig. 39).

Examples of microrelief and soil complexity in the coastal sand landscape are given in Figs. 35 and 37.

DRAINAGE

The Rajang is Sarawak's largest river and its lower course and delta are central to the Area. Despite this, less than half the Area (47 per cent) drains to the Rajang system and, of that part which does, 34 per cent drains into the delta directly or into the separate Igan distributary. The remainder of the Area drains north (37 per cent) via the Oya, Mukah or Balingian systems, southwest (6 per cent) via the Krian system, or comprises coastal fringe areas (10 per cent) drained by local streams rising in the swamp plain. All the percentages quoted are very approximate as boundaries in the swamp plain between drainage systems are of necessary rather arbitrary.

Within the hill zone the majority of major and minor streams are controlled by the regional strike and flow west and northwest, reflecting the structure of the geosyncline. This is true also of the Rajang River itself upstream of Kanowit (outwith the Area). An exception to this rule is the Kanowit River and its major tributary the Julau. These rivers cut across the strike and apparently follow fault zones.

The pronounced dissection of the Area has entailed extensive headward erosion by minor streams and many examples of well-developed trellised drainage patterns are apparent on 1:50,000-scale mapping, particularly in the upper Kanowit, Mukah and Balingian. Rapids have commonly developed in those sections of major tributaries which cut across the strike and which flow over resistant sandstone beds. The subsequent course of the main rivers are normally free of rapids outside the headwater area, but prominent rapids may develop in those short sections which do not conform to the structure of the Area. One instance is the Batu Balu rapids on the Oya River.

There is also some sketchy evidence for large-scale river pattern changes in pre-Quaternary time. Liechti (1960: 322) suggests that in the Miocene the proto-Rajang flowed into the Balingian-Bintulu area, and upwarping at the close of his Peneplanation Cycle caused its southern deviation via the Pelagus Rapids to Kapit. The alignment of the upper Rajang between Nanga Merit and Belaga, however, together with the relatively advanced development of the upper Mukah valley in comparison to those of the Oya and the Balingian, suggests that proto-Rajang followed the line of the Batang Mukah at one stage. Both possibilities may be correct, progressive uplift causing a succession of adjustments in the main drainage lines.

Adjustment of the drainage to Quaternary falls in sea-level is well-advanced in the case of the major rivers, which are all deeply entrenched and meander in very narrow floodplain tracts bounded by steeply sloping hills.

As the main rivers enter the dissected lowlands their floodplains tend to broaden and the river

channels to meander more widely. Many of the smaller valleys in this zone, however, have been invaded by the extending peat swamp mantle and as, in addition, relatively less alluvium is brought down by these streams from their restricted catchment areas and deposited along their banks, the river channels tend to meander erratically through the floodplain tract. They commonly have the appearance of misfit streams, as peat infilling has broadened the apparent floodplain area through extension into the lower tracts between surrounding hills.

The main rivers enter the coastal plain with little change in their characteristics. As the peat mantle has risen and extended into the seaward parts of valleys in the hill zone these rivers have achieved grade – if such a term is applicable in the unstable conditions of the Area – well before they debouch onto the plain and, once in it, their potential for lateral flooding and alluvial deposition is restricted by the development of domed peat structures in the interfluve areas. Rivers large enough to have kept their channels open as the plain silted up and the coast retreated have tended to maintain their general course, although both the Oya and Balingian Rivers show marked changes of direction before reaching the present coast and most rivers of this size tend to meander more broadly as they cross the plain.

Smaller streams within the coastal plain, both those rising in the hill zone and those originating in the peat swamps, have a rather more erratic pattern and, if the distribution of forest types is a reliable indicator of the distribution of peat domes, show a close relationship to these structures. Once a peat mantle has developed there appears to be a strong tendency for it to perpetuate itself and, given adequate areal extent, to develop domed structures in this coastal environment. Having once developed, the presence of the domes and the gradients on their flanks tend to confirm the intervening drainage channels and to encourage their persistence. But the pattern of peat deposits in the present Rajang delta indicate that there is a very fine balance between the creek patterns in the alluvium and the potential for initial peat accumulation. This combination of factors leads to a possible conclusion that some of the present minor streams crossing the swamp plain may reflect the line of creeks in the initial alluvial plain, that these were a major factor in determining the distribution of domed peat structures but were later swamped by peat (unlike streams arising in the hill zone and depositing alluvium along their lower courses) as the mantle extended. Present streams in these localities would, on this reconstruction, owe their continued existence to the gradients of the domes flanking them but would broadly reflect the alignment of initial creeks, or zones of dense creek complexes, in the now-buried alluvial deposits.

No data can be presented to support the above suggestion, although plan levelling of the alluvial base below such surface streams would help to resolve the point. Such a reconstruction does have attraction, however, when the rather erratic creek pattern in the present delta is noted and is compared with the very random alignment of the mapped streams within the swamp plain and the equally varied distribution of apparent peat domes. A process which can be considered the opposite of superimposed drainage appears to fit many of the observed features of the swamp plain.

Throughout their courses the volume and level of water varies greatly in all the major rivers of the Area. In their upper sections dry periods find rivers such as the Mukah reduced to small shallow streams winding through shingle banks in the river bed, but heavy thunderstorms in the watershed or upper catchment areas can transform them in a matter of minutes to deep foaming torrents filling the whole bed, such flash floods lasting some hours before subsiding. In the middle sections of the main rivers flash flooding effects tend to even out but here, as farther upstream, the river level tends to rise in the wetter months of the year and remain high for long periods. In exceptionally wet years or when very high run-off from the interior coincides with spring tides at the coast (and these have their greatest amplitude during the nominal 'wet season') the rivers top their banks and cause extensive flooding in the lowland tracts bordering them.

Brackish water enters the lower courses of main rivers at each high tide and may extend far upstream at peak tides if flow in the river is low. When the river flow is low backflooding effects at high tide are great throughout the coastal plain section of the course and well into the hill zone. River levels in the lower part of each drainage basin are thus as variable as in the upstream area. Almost every year some low-lying riverfront sections of Sibu are under one or two feet of water.

In January and February, 1963 the most disasterous floods in Sarawak history were experienced. 'On a world-wide basis during the period of flooding, Sarawak apparently had a greater amount of rainfall than any other place' and the total recorded rain at Sematan, in west Sarawak 'was probably the greatest for any station in the world for this period'. Continuous heavy rain coincided with peak tides and resulted in devastating floods in lowland areas, river levels, velocities and flooding depths breaking all records at many places –

Matu and Dalat were flooded to a depth of some 9 feet, for example – and considerable agricultural losses and damage to property suffered, some 15,000 people being affected, although there were fortunately only 4 deaths by drowning reported in the State. The 1963 floods have been ably reported by Jeeps and Gates (1963) from whom the above quotations are taken.

Jeeps and Gates map the areas within which low-lying land was flooded during this period. The Rajang River itself flooded over a belt 2-6 miles broad throughout its course upstream of Bawang Assan and in all sections of the Igan distributary, but not, apparently, in the delta. Effects of tides and river levels in this area were presumably dissipated among the many distributaries to a greater degree than in other areas. The Matu-Daro area flooded extensively but other sections of the coast apparently escaped except where near major river mouths. Serious flooding on the Oya, Mukah and Balingian extended upstream to Nanga Tamin, Nanga Sikat and Nanga Arip respectively. On the Kanowit River the head of the flooded area was some miles upstream of Julau.

The mapped area is obviously based on reports received and appears to have omitted a number of localities where deep flooding probably took place but the population is very sparse and no records were returned. However, the map does indicate that the greatest risks of flooding causing serious damage are in areas close to main rivers in the coastal plain and in the hill/swamp transition area. This statement must however, be modified by the observations that floods approaching the 1963 magnitude have a low incidence and that many riverine and coastal areas are permanently only just above flood level and are flooded to at least a minor degree in the wettest months of most years.

Landforms And Soils In Upland Areas

As described above, hill slopes within most tracts underlain by sedimentary rocks are largely convex, there is little or no footslope development, rock outcrops are rare and they are generally confined to local beds of hard sandstone exposed in gully bottoms. On almost all slopes a soil mantle has developed although where slopes are steeper than 30 degrees (and on gentler slopes over certain rock types) only a thin skeletal mantle is generally present.

Soil depth in areas with uniform parent rocks appears to be mainly a function of slope. Soils are uniformly deep or moderately deep over all slopes in gently undulating country on the swamp fringe (or, alternatively, uniformly shallow and moderately shallow in areas where shales relatively resistant to weathering are dominant) but towards the interior, in areas where amplitude and degree of dissection is greater, the deepest upland soils are commonly found on the ridge line and the flanks or spurs. On the steeper middle and lower flanks of convex slopes, and on any steep slopes in other situations, the soil mantle is consistently shallower.

This pattern reflects the increased surface erosion rate on steep slopes but the rate of surface soil loss under natural conditions appears to be relatively small as shallow soils on steep slopes are generally not accompanied by marked colluvial accumulations at the hill foot. In this context the landform must be considered together with the forest vegetation cover. The importance of the forest mantle under humid tropical conditions in limiting soil losses and modifying the form of erosion has been stressed by a number of writers (e.g. Birot, 1968; Douglas, 1969).

The importance of splash erosion and unconcentrated wash is very apparent on forested slopes of about 10-30 degrees and is no doubt equally important, although less obvious, on steeper slopes. Tree roots are exposed by scouring effects, particularly on the downslope side. Filling on the upslope side is commonly seen, particularly where large buttress roots encourage capture of surface flow material, and also occurs behind fallen trees lying across the slope. Gullies are present but are generally widely spaced. Most appear to be due to headward extension of local drainage systems, although in some cases gullies on steep slopes are apparently initiated by treefall which triggers (or is the result of) minor land-slips and leaves an exposed scar of disturbed material in which a gully can develop. In general gully erosion does not appear to be dominant under natural conditions. The erosion effects observed in upland tracts under primary forest are similar to those described from a comparable area of New Guinea (Ruxton, 1967). Following clearance of the primary cover other conditions apply (Chapter 5).

Studies in the Ivory Coast (Birot, 1968: 76) suggest that diffuse wash selectively carries silts and clays. On this model increasingly fine-textured soils would be expected downslope where the slope was uniform or concave, a general loss of the finer fractions, increasing downslope, where slopes are convex, and relatively little loss on upper slope and summit sites where the wash has least volume, velocity and opportunity for local concentration. In all cases some differentiation in soil texture would be expected on different facets of the hill flank. A detailed study of sites in Johor (Swan, 1970) indicated that silt and clay decrease downslope, although the content also varies with slope steepness and other factors. The sites studied appear to have been largely under a secondary cover, however, and it is uncertain whether the results are relevant to primary conditions. In the New Guinea study under primary forest there was 'no tendency for soils to become finer downslope' (Ruxton, 1967: 91) and this was taken to support the conclusion that the major erosive agent is indescriminate dislodgement of material by splash rather than selective removal by wash.

Observations in the Area tend to support the last conclusion. With the exception of the depth of the solum (and variation in this feature is only marked where slope steepness also varies widely on one hill unit) there is little differentiation in soil characteristics, including the texture of the topsoil and upper subsoil, in different slope positions. Marked contrasts related to lithology occur but these are independent of the landform. Tracts in the dissected lowlands in which slopes do not generally exceed 25 degrees commonly have a strikingly uniform (or uniformly complex) soil mantle over all hill slope facets. Where this is not the case contrasts are normally limited to lower-slope colluvium or upper slope truncation which can be confidently linked with recent land-use history and do not reflect the balance of erosive processes active under natural conditions on these landforms.

Natural catenary contrasts related to the landform do occur in some situations, however, contrasts resulting from soil creep being locally important. Where light-textured soils developed over sandstones occur on steep slopes there is commonly an increasing thickness of creep material downslope. This may have an abrupt boundary with underlying material and commonly contains much coarse sandstone rubble (cf. App.IV, Profile 9). Over argillaceous rocks evidence of creep is rather less marked although distorted bedding in road-cut exposures of the weathering zone indicate that general slumping does take place over a long time-scale. Basal stone-lines in many medium-textured profiles may also result from creep but more probably develop through faunal churning.

Catastrophic erosion through slope failure occurs but is again mainly confined to light-textured and medium-textured soils on steep slopes and, in natural conditions, appears to be a rather rare event even on such sites. It may occur as a result of over-saturation of a porous poorly-coherent soil mantle but the pattern of land-slips on some aerial photographs suggests that many such slips are initiated by the wind-throw of large trees during local storms. Such events are not confined to particular soils or landform units although light-textured and medium-textured soils are likely to be most susceptible and the results are certainly most damaging on steep slopes where the wind-throw of one large tree will uproot others as it falls downslope, the upper part of the soil mantle within the rooting zone will be greatly disturbed, and a vertical swathe of slope left exposed to direct rainfall.

Observations within the Area suggest, therefore, that local changes in the characteristics of upland soils are generally not associated with landform variations, and the contrasts in erosion forms and erosion effectiveness which might be expected in such varied topography are – under natural conditions and ignoring for the present the results of human interference – only noteworthy on very steep slopes, where accelerated surface losses generally maintain skeletal profiles in contrast to those on other slope facets. With this exception, erosion by splash and diffuse wash of soil under a primary forest cover appears to affect all upland slope facets to a degree which is sufficiently comparable that few soil contrasts can be linked to the landform type through this cause. The erosion rates, despite the extreme rainfall regime and the prevalence of steep slopes, are also sufficiently low that moderately deep soil profiles, with distinct genetic horizon development, are widespread on all slopes up to 25-30 degrees unless the parent rocks are particularly resistant to chemical weathering.

CHAPTER 5

VEGETATION AND LAND USE

Most of the coastal sand belt, virtually all of the dissected lowlands and much of the interior highlands have been cleared in the past for shifting cultivation or permanent cropping. Many large tracts, particularly in the swamp plain, the saline clay delta of the Batang Rajang and the remoter parts of the interior highlands remain, however, under a relatively undisturbed cover. In the equatorial monsoon climate of the Area the natural climax vegetation is forest in all landform units. The main forest types are briefly described below following divisions used by the Sarawak Forest Department (Brunig, 1969). The main local names are indicated in parenthesis against important species. The generalised distribution of forest types is shown on Map 4.

Forest Types

Beach Forest

A thin belt of *Casuarina spp.* (Ru laut) is typical of sandy beaches and strand lines behind the coast, but most such areas have been cleared for coconut and other crops.

Mangrove Forest

A number of forest types occur under this heading. All are associated with saline silts and clays and vegetation changes are commonly a reflection of the degree of tidal influence. On coastal flats and on river-bank sites which are

strongly tidal *Avicennia, Rhizophora* and *Sonneratia spp.* (api-api, bakau, pedada) are dominant, in either pure or mixed units. More sheltered areas or zones farther inland from the river or coast are commonly dominated by a mixed cover of *Xylocarpus* and *Bruguiera spp.* (nyireh, berus), or by *Nipa fruticans* (nipah), the latter being particularly widespread. In an interior transitional position between the main mangrove forest associations and peat swamp forest a zone of *Oncosperma filementosa* (nibong) may occur. Mixtures of the interior mangrove forest types are also common.

Some areas of Mangrove Forest have been extracted and locally this forest has also been cleared for agriculture (particularly interior tracts under *Nipa*) but the bulk of the land under mangrove remains relatively undisturbed apart from selective pole cutting. Mangrove Forest is dominant over much of the Rajang delta and is locally widespread in some other coastal areas.

Peatswamp Forest

There are marked changes in forest type within the swamp plain, largely related to the development of basin peat structures. The forest types tend to be zoned from the swamp fringes into the interior and a number of divisions are possible. With regard to the swamps within the Area three main types are important.

Mixed Peatswamp Forest occupies the swamp fringes where there is a significant gradient at the swamp surface or outliers of the swamp mantle in which no basin structures have developed. Among the great variety of species which occur *Gonystylus, Campnosperma, Alstonia, Dyera* and *Shorea spp.* are important, and a number of subdivisions within this forest type can be made on the species combination which is dominant. Many species are of considerable timber value and are grouped on their timber characteristics under a separate local terminology. 'Ramin and 'meranti' are important timber groups extracted from the Mixed Peatswamp Forest.

Shorea albida Forest is associated with the domes of large basin swamps and, although a number of subtypes occur within the unit, *Shorea albida* (alan) is dominant or important in each subtype and forms a consociation in many areas. *Litsea* and *Parastemon spp.* are also important.

Padang Paya Forest covers restricted areas in the centre of the basin swamp dome in the Oya-Mukah and Matu-Daro areas but is absent from the succession in most other swamp units on the coastal plain. It has been included with the *Shorea albida Forest* in Map 4. This type has a rather heterogeneous composition, *Tristanium, Parastemon* and *Palaquium spp.* being important, among others.

Large tracts of Peatswamp Forest remain on the coastal plain but many areas have been extracted or, in the Sarikei-Sibu area in particular, cleared early in the century for rubber. The *Shorea albida* Forest is also very susceptible to windthrow and many tracts in the interior of the swamps are broken and disturbed for this reason.

Mixed Dipterocarp Forest

Almost all hill lands in the Area have a natural cover of Mixed Dipterocarp Forest. This has been divided into a number of types, many of which are broadly associated with particular lithology-soil-landform situations. Within the Area, however, most hill tracts other than parts of the interior highlands have been cleared for shifting agriculture in the past and are under regrowth of varied age. Within the tracts of mountainous terrain in which primary forest remains, the confused terrain and varied soils are such that no significant subdivisions of this forest type can be made.

The Mixed Dipterocarp Forest is characterised by the great variety of species present in all subtypes and the few situations - such as ridge lines - in which pure stands locally occur.

Riverain Forest

In riverain tracts a forest type occurs which is similar to Mixed Dipterocarp Forest in many respects but is noted for the common occurrence of species of economic importance such as *Eusiderosylon zwageri* (belian) and species of *Shorea*, collectively termed engkabang, which are a source of illipe nut.

As Riverain Forest only occurs close to major natural waterways and these are both the main channels of communication and the site of most settlement concentrations, undisturbed tracts of this forest type are rarely found in the Area. Most of the forest cover on well-drained riverine alluvium has been either cleared for rubber, settlement or other uses, or has been selectively extracted for local use leaving a high proportion of belian, engkabang, durian and other fruit trees.

Heath Forest

Heath or Kerangas Forest is the normal cover of sandy terrace deposits on the fringe of the hill zone and on other coastal and interior sites in which podzols have developed. Species are varied but one or more may be locally dominant, such as *Gymnostoma nobile.* Emergents are commonly *Shorea spp.*

As Kerangas Forest is associated with very infertile soils it has normally been left uncleared except in areas where land pressure is great.

Vegetation And Soil Mapping

Those parts of the Area which remain under a natural forest cover are mantled mainly by Mangrove, Peatswamp, Mixed Dipterocarp or Heath Forest. Tracts of Beach and Riverain Forest are too restricted to require further consideration in this section.

Mangrove Forest

Within the Mangrove Forest a number of important species have distinct characteristics which can be easily recognised without special botanical knowledge. The *Avicennia-Rhizophora-Nipa-Oncosperma* succession is particularly obvious and, together with the distribution of mudlobster mounds, gives an indication of the extent of tidal influence and soil salinity levels. Vegetation is in this situation of great assistance as the soil profile characteristics identifiable in the field may show little variation throughout the zone covered by Mangrove Forest and soil divisions of importance to agriculture have to be established from chemical analysis where inference from the vegetation cannot be made with confidence. Such inferences are, however, less easy where mixed forest subtypes occur.

On air photographs Mangrove Forest types can also be clearly identified where relatively pure stands occur. The low, open canopy of *Sonneratia* woodlands, with a relatively light tone on the photographs, is distinctive, as is the more irregular canopy of *Avicennia* and the dense, small-crowned, dark canopy of *Rhizophora*. As soils under these subtypes can be confidently mapped as saline soils with few ground checks, the cover is in this case of considerable assistance in interpretation. Pure stands of *Nipa* are also easily recognised by their dense, feathery, dark-toned appearance, but other subtypes are more difficult to identify with confidence, particularly if the cover is very mixed. Confusion also arises in areas where sago is established, as this may be difficult to separate from *Nipa* in air-photo interpretation.

The assistance given by the vegetation cover in soil mapping within the Mangrove Forest is reduced, however, by the fact that the soil features with which the forest subtypes are most closely related do not appear to be those of most importance from an agricultural viewpoint. The vegetation reflects the general salinity levels but all areas under Mangrove Forest require drainage improvement for agricultural development and high salinity can be relatively easily corrected as part of such improvement. A more serious limitation is the soil sulphide content and the danger of acid-sulphate conditions developing following drainage. It was initially considered that potential acid-sulphate conditions were largely confined to those soils which were strongly or moderately saline (and under *Avicennia, Rhizophora,* etc) and that this was not a serious problem in slightly saline soils (under *Nipa*) in interior positions farther from the coast or river. This view was reflected in the previous local soil classification (Soil Survey Staff, 1966) and on many early survey projects the boundary between a *Rhizophora* and *Nipa* cover was used to separate Rajang and Pendam soil families. A subsequent detailed study of a coastal delta swamp area in west Sarawak (Andriesse and Sim, 1968) was later completed, however, and indicated that this assumption was ill-founded. Most of the area studied was under *Nipa,* or *Nipa* mixed with *Avicennia, Sonneratia* and *Bruguiera*. Virtually all samples (99 per cent) gave less than 4 millimhos conductivity when wet and only 4-10 per cent gave conductivities exceeding 8 millimhos when dry, the incidence increasing with depth. Almost all the area would, on these data and the vegetation cover, be considered as a weakly saline clay unit mapped as Pendam Family in the previous local classification and, by implication, be classed as suitable for agriculture without major limitations other than drainage improvement. However, the majority of samples had significant levels (0.1-1.0 per cent) of total sulphur and many also had high levels of water-soluble and Morgan's-extractable sulphate. In subsoil samples below 50 cm depth, levels commonly exceeded 2 per cent for all three determinations. In addition, the pH (H_20; 1:2.5) of air-dry samples was below 3.5 in 40 per cent of the 660 profiles analysed, and was commonly in the range 2.0-3.0. The pH of wet subsoil material was generally 1.0-1.5 pH units higher than that of dried samples.

Some 40 per cent of the samples therefore have potential acid-sulphate characteristics in this study area, and these samples are scattered throughout the area in an apparently random pattern. The area as a whole must thus be considered to have a potential acid-sulphate limitation to agricultural use. This includes the large tracts under a pure stand of *Nipa:* the analytical data indicated, in fact, stronger potential acid-sulphate conditions under *Nipa* than under a mixed *Avicennia Sonneratia* cover.

In the soil classification adopted for this study pH (KC1) is used as a parameter separating the Rajang Family (with potential acid-sulphate characteristics) from the Pendam Family (with only salinity limitations), and in field practise samples must be retained for this determination and no reliance place on vegetation subtypes within the Mangrove Forest. Many areas mapped as Pendam Family in early project reports are likely to be classed as Rajang Family by the present definition.

The main contribution of the vegetation cover in Mangrove Forest to soil mapping in the Area appears, therefore, to be (a) the location of tracts under distinctive subtypes associated with Rajang Family soils, as mentioned above, and (b) the approximate delineation of the boundary between alluvial clays and peat soils from the Mangrove Forest/Peatswamp Forest boundary prior to field survey.

Peatswamp Forest

Distinctions between the subtypes of the Peatswamp Forest detailed above are commonly easily made from air photographs. Mixed Peatswamp Forest has an uneven, moderately dense and generally rather dark-toned canopy. *Shorea albida* Forest, where best expressed, has an even, dense, very light-toned canopy, and in transitional zones between these types scattered emergents of *Shorea albida* are also easily identifiable by their tone and form. Padang Paya Forest, where present, is distinguished by its dense pattern of small crowns. There are many areas, however, where very mixed types occur, or the cover is greatly disturbed by windthrows, and identification is less easy.

These distinctions also appear to have rather limited value in soil mapping. All three types are underlain by raw woody peats and, where these are deeper than 1 metre, they are grouped together in one soil series (Anderson Series). Depth phases are distinguished at 2 and 3 metres, but peats in excess of 3 metres thickness are not considered to require separation even at phase level. In almost all situations, and invariably where basin swamp structures are present and zonation of forest types occurs, the increase in the depth of the peat blanket to more than 3 metres takes place in the zone mantled by Mixed Peatswamp Forest. The interior portion of this forest type, together with the types associated with the dome of the basin, are underlain by peats exceeding this depth. The forest type boundaries do not therefore have relevance to soil mapping within the terms of the soil classification used in the past, nor in that proposed in the present study.

Recent chemical studies of the peats under various forest types (Anderson and Ahmed, pers. comm.) suggest that there are contrasts between the peats which relate to the forest cover and that there is a general decrease in mineral content and in nutrient levels towards the interior. The data are still being studied but do suggest that peat soil differentiation on the basis of the forest type may prove of significance. However, the data obtained were derived from large composite samples and even when these results were averaged for groups within one forest type the variability of results for each characteristic studied remained very great. While general trends appear to have been established, it therefore seems unlikely at present that any chemical parameters can be derived from these data which could be incorporated in a practical soil classification.

Mixed Dipterocarp Forest

On air photographs Mixed Dipterocarp Forest shows an uneven dense canopy which is very variable in texture. Outside the interior highlands few tracts of primary upland forest remain within the Area and the forest cover, where present, is secondary or much broken. Secondary upland forest has even greater variety in appearance.

Mixed Dipterocarp Forest is characterised by a very large number of species, normally not occurring in pure stands and rarely with one species dominant. Ashton (e.g. 1958; 1964) has found an association between many species and soil characteristics in Brunei (texture and drainage being of particular importance) but the variety of species within any one stand means that unless the pedologist is also a forest botanist few inferences regarding the soil can be made from viewing the forest cover during ground survey. In some instances it has proved helpful, particularly where primary or secondary upland forest occurs in association with other forest types on gently undulating land and residual upland soils with little change in the terrain. In general, however, the writer has placed little reliance on interpretations from the forest vegetation cover in mapping soils in upland areas.

Inferences from the forest mantle have proved useful in north Sarawak (Wall, 1966) and the lack of assistance given by the vegetation within the Area is probably the result of (a) the few tracts of primary forest and the confused pattern of secondary covers within the dissected lowland zone in which most work on the hill soils was concentrated, and (b) the great variability in soil and landform characteristics in these areas, as opposed to the strongly expressed strike-and-dip terrain and other well-developed landforms occurring in my other parts of the State which give abruptly-bound landform units the rather uniform soil characteristics of which are reflected in the forest mantle and can commonly be clearly interpreted on air photographs.

Heath Forest

On air photographs Heath Forest presents a rather varied appearance but the best developed examples have a dense even canopy of small crowns which is very distinctive and is particularly easy to identify when mantling podzols (the most typical soils associated with this forest type in the Area) on flat or gently undulating terrace remnants adjacent to swamps under Mixed Swamp Forest or uplands under secondary covers. The boundaries to many terrace podzol tracts on the interior margins of the coastal plain (Map 1, mapping units 20, 23 and 38) rely heavily on the identification of a Heath Forest mantle on air photographs.

Heath Forest, or thin forest transtional to secondary covers, also occurs in upland areas and is there usually associated with soils on gently undulating terrain characterised by poor subsoil drainage. Vegetation boundaries are normally less well-defined in such situations and a broad range of soils may also be present. The forest cover is a less useful indicator in these conditions.

Conclusions

The natural vegetation cover has been of some limited assistance in the soil mapping project but, because of the great local variability in both landforms and soils in the uplands and the degree to which the natural cover has been cleared or disturbed for agriculture in such areas, its usefulness in this context has largely been confined to mapping soils on the coastal plain. Even on the plain itself direct assumptions regarding the soil mantle from the vegetation cover are usually dangerous and the contribution of this information has generally been confined to guidance in interpolating boundaries between ground traverses. Few units have been mapped on vegetation data alone.

Land Use

In the 1970 census enumeration of the State the Area had a population of almost 271,000, comprising Chinese, Iban, Melanau and Malay groups who make up roughly 40, 34, 17 and 9 per cent of the population respectively. Almost one quarter of the population (and 44 per cent of the Chinese community) are concentrated in Sibu and other District centres. Outside these towns and other small urban concentrations the population is largely agriculturally-based, and many of those classed as urban are also partly dependent on agriculture.

Although current development trends are blurring cultural divisions, there remains a marked association between cultural group and agricultural land-use type. Thus the Melanau are associated particularly with sago cultivation on Gley and Organic Soils in the Rajang delta and on the northern coast. Rural Malays, in the coastal parts of Kalaka District and in the Rajang delta, cultivate the largest acreage of wet rice on riverine Gley Soils, although a variety of other crops are grown by this group and they are responsible for large coastal tracts under coconut in Kalaka District. The concentration of rubber and pepper between Sarikei and Sibu is mainly the preserve of Chinese farmers, although other groups also grow these crops. Pepper is mainly confined to upland well-drained clays and silts in the Red-Yellow Podzolic Soil Group. Rubber is found on almost all soils, including very deep Organic Soils near Sibu. The broad zone of shifting cultivation land covering most of the dissected lowlands and extending into the interior is almost exclusively settled by Iban practising a hill rice economy, although here also some other crops are grown, particularly in riverine tracts. Hill rice is found on both Red-Yellow Podzolic and Skeletal Soils. Examples of the agricultural landscape and its adjustment to the soil and landform pattern are given in Plates 1-18. The broad land-use pattern is shown in Map 4.

This pattern is of quite recent origin. The main waves of Iban settlement occurred in the last 150 years and the large Chinese urban and rural components of the population date mainly from this century. The stages in which the Area was settled and the degree to which the resultant land-use pattern is due to historical accident rather than land potential are described in Appendix II, where some broad analysis of the agricultural population are also made from the 1970 census data and the relationship between soil type and the main crops of the Area discussed. In this Chapter emphasis is concentrated on the effect of agricultural use on soil formation and development, and particularly on the degree to which soil erosion has been accelerated by farming.

Agriculture and Soil Erosion

Erosion and conservation trials have recently been initiated in west Sarawak (Hatch, 1978) but only a few months data are yet available from them. The only other quantitative work on soil erosion in agricultural land in the State comprises preliminary studies undertaken in north Sarawak (HTS & HO, 1974) on profiles of Merit, Bekenu and Nyalau Series, these being Red-Yellow Podzolic Soils with clay, silt and loam subsoils respectively. The studies comprise (1) calculation of erodibility factors from average parameter values by the method of Wischmeier et al. (1971); (2) soil loss measurements from 10 × 1 metre plots at five sites with varied slope and cover (the plots being duplicated at three sites); (3) laboratory estimation of erodibility under a rainfall simulator, using single upper subsoil horizons from four profiles and applying simulated rainfall at an intensity of 3.8 inches per hour for 30 minutes.

Only tentative conclusions can be drawn from these limited studies. Using Wischmeier indices (which may or may not be applicable in Sarawak conditions) all Al horizons had relatively low erodibility (0.15–0.22) while all subsoils had higher indices (0.33–0.46). Upper subsoil horizons of Merit and Bekenu Series were particularly susceptible (0.45 and 0.48 respectively), while that of Nyalau was rather lower (0.33). The results of the laboratory tests were comparable. Soils losses from Nyalau, Merit and Bekenu Series respectively (using the mean of four replicates) were in the relationship 1:2.0:2.3 and the computed erodibility 1:8:11. There are thus strong indications that surface losses are greatest on the medium-and heavy-textured, poorly structured and rather impervious Merit and Bekenu Series than on the light-textured, porous Nyalau Series, and on all soils surface loss is accelerated if the thin topsoil is removed.

These measurements are indicative of the relationship between surface losses through sheet wash and minor rill development and the texture and porosity of soils over sedimentary rocks. On slopes above 20°, however, there is also a danger of slumping following soil disturbance, especially if the topsoil is removed. Nyalau Series is more susceptible than the heavier-textured soils in this respect. Slumping was observed within the Area at Meradong following terrace construction by bulldozer and the removal of most of the topsoil in the process. It has also occurred on a catastrophic scale in north Sarawak on moderately steep slopes under rubber. In both cases Nyalau Series was the dominant soil.

All field trials were sited on Merit Series and have been maintained following the consultancy study. Three years data have been reported by Tie (1976) from whom Table 5 is abstracted.

The results are varied and there is no close correlation of soil loss with either slope or total rainfall. Data on rainfall intensity and distribution would be more relevant than annual figures. Tie (1976) also criticises the experimental design.

The results do, however, emphasise the high erosion rate under pepper. For other crops not involving complete clearance of the soil surface the consultants suggested from the results of Year 1 that a slope limit of 25° for agricultural use was indicated, assuming a permissible annual soil loss of 12.5 tonnes/ha/yr (Hudson, 1971). This supports previous local recommendations.

Although many cases of gullying are observed in rubber gardens on steep land and significant losses from wash can be assumed in the period when the garden is established, the general impression gained from observations within the Area is that soil erosion in dissected terrain under rubber is generally not excessive. Terraces are usually cut – invariably where the planting is on hill land under a Government assistance programme – and are prepared manually (and normally with reasonable efficiency). There is relatively little soil disturbance and a secondary cover of ferns and shrubs establishes itself quickly as do seeded cover crops where these are used.

In contrast to areas under rubber, hill land under pepper suffers considerable erosion, as little attention is paid to conservation by pepper farmers and their preference for such hill soils as Merit and Jakar Series results in the majority of gardens being sited on slopes of 10–30°. In establishing the garden the soil is thoroughly hoed throughout to provide material for the mounds

Table 5

Results of soil erosion trials in north Sarawak over a three-year period (from Tie, 1976)

Plot	Cover	Slope(°)	Soil loss (tonnes/ha/yr) Year 1	Year 2	Year 3
A1	Oil palm planted in Year 1. (Cover crop sprayed in Plots A2, B2 and C2)	35	15.0	11.8	nd
A2		35	15.0	9.1	16.4
B1		26	23.0	7.7	5.2
B2		26	72.0	4.5	16.5
C1		21	4.0	6.4	21.6
C2		21	5.0	12.2	16.0
D1	Grass and scrub regrowth	33	4.5	18.2	11.0
D2	Pepper, planted Year 1	31 (not terraced)	107.0	136.1	26.7
Rainfall, Plots A – C (inches)			101	96	127
Rainfall, Plots D1 – D2 (inches)			125	122	124

and to collect roots for 'burnt earth' preparation. (Nearby forest is now rarely available to provide wood; under the traditional method in which 'burnt earth' was applied repeatedly 4–5 acres of jungle were required to maintain one acre of pepper). The ground between the vines, which are normally planted 8 feet apart, is clean-weeded to reduce root competition, berry loss and disease induced by poor surface drainage. Terracing is practised in some gardens or brushwood soil traps built across the slope, but in the majority of gardens no such measures are adopted.

There is thus considerable soil loss from the between-vines areas during the life of the garden. Any remaining topsoil material is quickly removed; the exposed subsoil is puddled in wet periods by the frequent passage of the gardener in maintaining the vines and is eroded in shallow gullies. The unconsolidated material of the mounds is also washed downslope and is replaced by the farmer with new material. The recorded soil wash quoted from the trial in north Sarawak may, in fact, be lower than average as the year in which these trials were conducted included a very abnormal two-month drought.

Under shifting hill rice cultivation the degree of soil erosion varies greatly at different stages in the cycle.

During the fallow period the available evidence suggests that erosion rates are very low, and may well be less than under primary forest. Ferns, shrubs and grasses which may or may not have been controlled by diligent weeding during the growing period of the rice are allowed to flourish after the harvest and quickly cover the farm. It is not uncommon within one year of the harvest for the farm to be mantled by fern growth almost 2 metres high resting on a surface root mat some 10–25 cms thick. Virtually no rain reaches the soil directly in these conditions and surface wash is reduced to a minimum on even very steep slopes. The north Sarawak trial under regrowth tends to support this observation.

As secondary forest develops the fern and shrub cover thins out but the canopy of secondary forest is more broken than that of primary jungle and higher levels of light penetration allow a thicker gound cover to persist. Surface erosion rates thus increase somewhat as the secondary cover matures but are unlikely to reach the levels found under the previous primary cover. It is also logical to expect that the incidence of treefall triggering off gullying and landship is less than under the primary cover: during most of the regeneration cycle trees large enough to be significant in this respect do not exist and once the secondary cover has matured to the extent that they are present in any quantity it is, by Iban reckoning, time to clear again for a new rice farm.

Whether the reduced erosion rate during the regeneration phase of the cycle balances the accelarated erosion of the cultivation phase remains in question. The exposed and devastated appearance of a newly burnt rice field on a 30° slope suggests that catastrophic erosion would take place with the first rain storm. While most such fields in the Area are on medium–and heavy–textured soils with a relatively high

resistance to slumping and conditions in areas where soils such as Nyalau Series are dominant may be different, observations suggest that such extreme erosion does not generally take place. This is due to a number of factors:

(1) the clearing-burning-planting sequence involves a minimum of soil disturbance. The scrub is cut first, followed by progressively larger trees (Freeman, 1955: 41 et esq.). These are cut at waist height (higher if buttress roots are present) and the stumps left in the ground. As the largest trees are felled last they rarely uproot others in falling. The planting process is simply one of dropping seed into conical holes made by a dibbling stick to a depth of only some 3 inches (Freeman, 1955: 48). No hoeing is practised and little attempt made to tread earth in to cover the holes after seeding;

(2) in the few weeks between felling and burning the soil is well-protected against direct rainfall by a thick confusion of fallen brushwood and leaves and, as planting takes place within days following the burn, and weeds and padi seedlings quickly emerge, the soil surface is probably at greatest risk from erosion by direct rainfall for less than two months in the period following the burn. By the end of that time it is protected to a large degree by a cover of growing padi, other minor crops planted at the same time, and by weeds;

(3) the period of clearing and exposure of the soil coincides, in theory and more often than not in practise, with a period of low rainfall. The efficiency of the burn is critical to the success of the farm and clearing is timed to finish when the farmers judge a few weeks of dry weather is due and the brushwood will dry out satisfactorily. Because of the erratic rainfall pattern their forecast is often wrong but it is still generally the case that rainfall is below average in the period between clearing and the early stages of rice growth. Even when this does not happen rainfall in the period July–October, when these activities are carried out, is generally not both continuous and heavy. Light drizzle or short heavier downpours at this time have little erosive effect and from the viewpoint of soil protection (although not that of the harvest) are beneficial in promoting a more rapid weed colonisation of the clearance.

One may also observe that the Iban have centuries of experience in planting hill rice and a culture which revolves around this grain. It can be argued that if excessive erosion on steep slopes were a normal event following planting the Iban would be more selective in the slopes they clear, particularly as the planting depth is very shallow.

The writer's observations thus support those of Freeman (1955: 127): that when 'virgin jungle is cultivated for one season only, erosion is very slight indeed', and the statement can be extended to cover mature secondary forest. Where, due to land pressure, a farm clearance is used for a second or third year this is more doubtful, however. Three years use is rare, although tapioca is sometimes farmed in the year following the rice harvest and two crops of rice may be taken if the farmer thinks the land will support it. The rate of erosion in such conditions will depend to a large degree on the extent of protection given by the crop and weed growth and this in turn depends largely on the rapidly decreasing natural fertility of the soil under continuous farming. A number of areas, particularly in the Kanowit drainage basin, have been surveyed in which soils are very shallow (Lalis Series being widespread) and shale fragments litter the surface of newly burnt rice fields on steep slopes. The degree to which the immaturity of the soil profile is maintained by erosion during progressive rice cycles is difficult to estimate as soils appear to be equally shallow under all covers in these areas, including primary forest where such remains. Soil depth apparently varies with slope rather than land use history. It has been maintained (Andriesse, 1972) that secondary regeneration on upland soils is improved if truncation by erosion brings fresh weathering material into the plant feeding zone. One may add that exhaustion of the limited topsoil nutrient supply by overfarming results in retardation of secondary regeneration but that this in turn limits further erosion as a protective fern and shrub cover may persist for many years on such land before maturing to a forest stage. The relationship between regeneration, erosion rates, farming history, nutrient levels and other factors (such as length of slope and varying rainfall patterns) is obviously complex and no measurements have been made, but it is possible that a balance is achieved in some situations.

Whether, as contended by Freeman (1955: 130) and disputed by Andriesse (1972), shifting hill rice cultivation can be maintained indefinitely in a 12–15 years cycle is a question which is of more than academic interest. There are many parts of the interior highlands within the Area (and vast tracts farther east in interior Sarawak itself) where the practical choices for development appear to be shifting cultivation (as at present) or forestry, with no other agricultural alternatives. The land is extremely dissected; slopes are rarely less than 25° and frequently over 35°. The population is sparse, dependent on hill rice

cultivation, and very attached to the land. The people are commonly not attracted to the idea of moving elsewhere to be settled in an agricultural development scheme and want 'development' to be in their own locality. But large-scale agricultural development is precluded by the terrain and communications difficulties. Minor tracts of better soils and slopes could be considered for such crops as pepper, cocoa and coffee, and although negligible in terms of acreage such introductions would be significant adjuncts to the subsistence economy, but shifting cultivation is likely to remain the mainstay of these areas. Whether or not this can be considered a viable form of agriculture for the future in such areas is a question which is likely to recur with increasing persistence as development in 'downriver' areas proceeds and economic contrasts with the 'upriver' areas become more marked.

Soil Development and Past Land Use

The late arrival of agriculturalists into most of the hill zone is described in Appendix II. Map 4 indicates that, until very recently, most of the hill zone has only been affected by shifting cultivation. This, as discussed in the previous section, is likely to have led to relatively little erosion outside the farming phase of the cycle and there is some doubt whether much accelerated erosion takes place under normal conditions even during that period.

With the exclusion of Kalaka District, it seems safe to assume that fallows were not shortened due to land pressure to any important degree within the Area until at most some 50 years ago, and in many localities serious land pressure probably did not develop until much later. If cycles of 12–15 years (or longer) are assumed for most localities until, say, the turn of the century, and it is likely that the reduced cycles of 8 years or less reported at present in some of the most densely populated localities (such as parts of the lower Kanowit) date only from the past 30 years or so, then it can be very roughly estimated that since the Area was first cleared from a primary forest cover most of the Kanowit Basin has only been subject to some 13 farming cycles, the Mukah to about 10 and the Balingian to 7 at the most.

Except, therefore, where soils have been used for pepper or disturbed by terracing for rubber, it appears likely that accelerated erosion due to human interference has been less important in the development of present upland soil profiles in most parts of the dissected lowlands than the present farming landscape would suggest. This tends to be borne out by certain characteristics of the soil mantle itself. There is generally little change in texture and soil depth towards the footslope and, except where light-textured soils are found on steep slopes, significant colluvial accumulation at the hill foot itself is rather rare. Nor, in many localities, can it be the case that significant surface wash is balanced by the removal capacity of hill-foot streams; valley peats commonly mantle the bottomlands and the transition from mineral hill soil to raw woody bottomland peat is characteristically abrupt.



PLATE 1

Dissected uplands under shifting cultivation of hill rice. Most slopes are in the range 10° — 25° although steeper slopes also occur. The hill flanks are generally convex and the shallowest slopes are commonly on the upper hill flanks, which steepen downslope to narrow gullies. All slope facets have been cleared for hill rice cultivation. Most tracts in the foreground and middle distance are under young regrowth. Land near the farm huts is probably currently under cultivation. In the far distance a tract of older secondary forest enters the picture. The landscape is typical of much of the upland shifting cultivation zone both within the Area and elsewhere in Sarawak.



PLATE 2

Rather poor secondary forest cut over for a new hill rice farm and now drying prior to being burnt. No trees have been left standing and the soil surface is littered with crowns, trunks, branches and leaves. Some soil remains exposed as the forest has been cut before maturity, probably due to land shortage. The terrain is relatively subdued, with most slopes less than 20°. The locality is in the middle Mukah drainage basin, with a soil mantle mainly of Bekenu and Nyalau Series.



PLATE 3

A newly-planted hill rice farm on steeply dissected terrain. All slope facets have been planted apart from the gully bottom itself (hidden by the hill flank) and a narrow belt of forest which was not cut-over on the far hill flank and which may represent an ownership boundary. Litter, crowns and small branches have been consumed in the burn and partly-burnt trunks are now scattered over the farm. Slopes exceed 30° and the soil mantle is skeletal (Lalis Series). At this stage in the farming cycle such land has its greatest exposure to surface erosion, if heavy rain is experienced before weeds and the growing rice offer some protection to the soil surface.

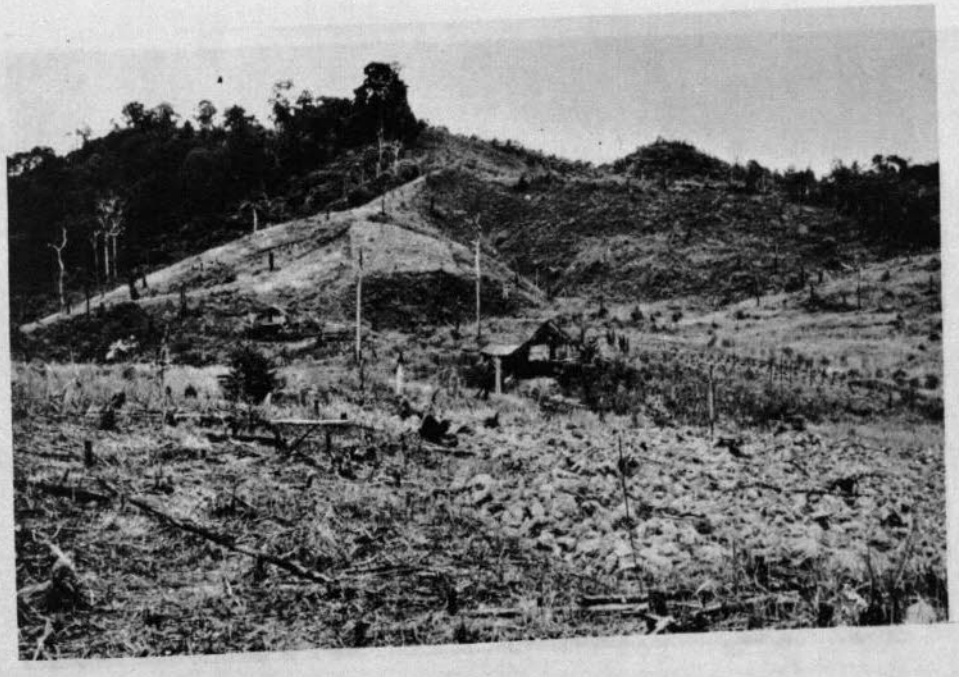


PLATE 4

Cleared land north of Pakan, showing typically confused slope facets in the dissected lowlands. The upland soil mantle is a complex of Merit, Bekenu and Nyalau Series. The land is under young regrowth following hill rice cultivation but lower slope tracts in the middle distance have recently been planted with pepper. The new cultivation in the foreground is intended to be a further pepper garden. The huts are temporary farm huts built for the rice farm. They may be replaced by more permanent structures if settled pepper cultivation is anticipated on this land. The locality is close to a new trunk road, which has stimulated many Iban rice farmers to diversify into other crops.



PLATE 5

Mixed agriculture on Merit Series between Sarikei and Jakar. A Chinese smallholding with rubber, bananas, fruit trees and pepper. The mature pepper garden (centre right) has vine rows oriented across the slope but, as in the newly established pepper garden (centre, left) where the rows run up the slope, no terracing is practised. The vines in the foreground have probably been affected by foot-rot. The rubber is old seedling material and is tapped only when the local price for rubber sheet is attractive. The smallholding also contains vegetable plots and fishponds.

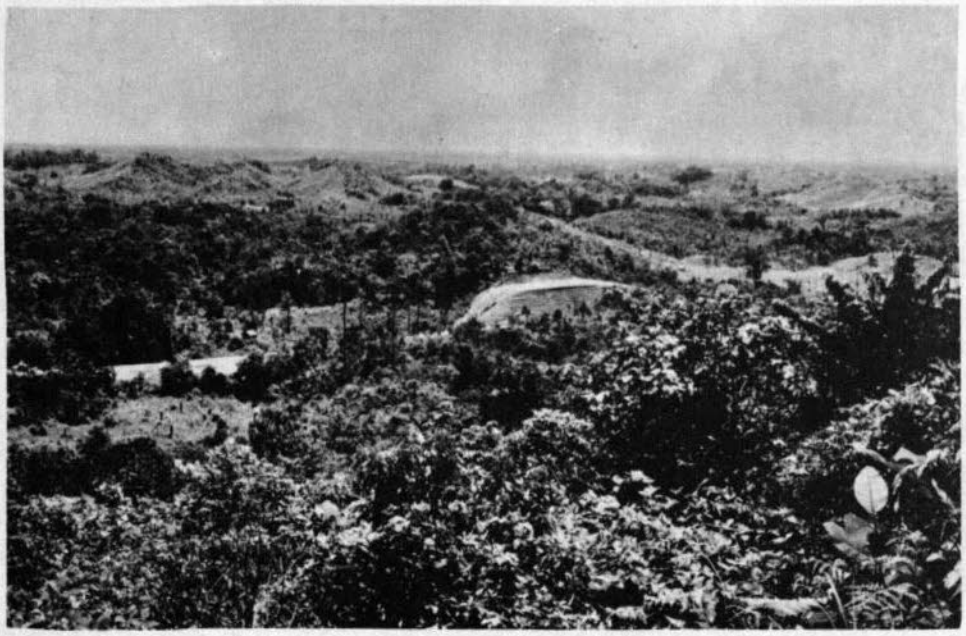


PLATE 6

A dissected lowlands tracts between Kelupu and Julau. The roughly concordant summit heights have been related to Leichti's Peneplain Cycle (4.15 and Appendix I), here at some 200 feet (60 metres) above sea level. The view looks northwards and the hill land becomes increasingly fragmented by swamp tracts in the distance, where the 'Sibu Bay' swamps of the Naman Forest Reserve form the horizon. The soils on the hills are mainly Bekenu and Nyalau Series, under a secondary cover of varied age following hill rice cultivation. A section of the newly-completed Kelupu-Durin Road crosses the picture (taken in 1967) and crop diversification near this road has been noticeable in recent years.

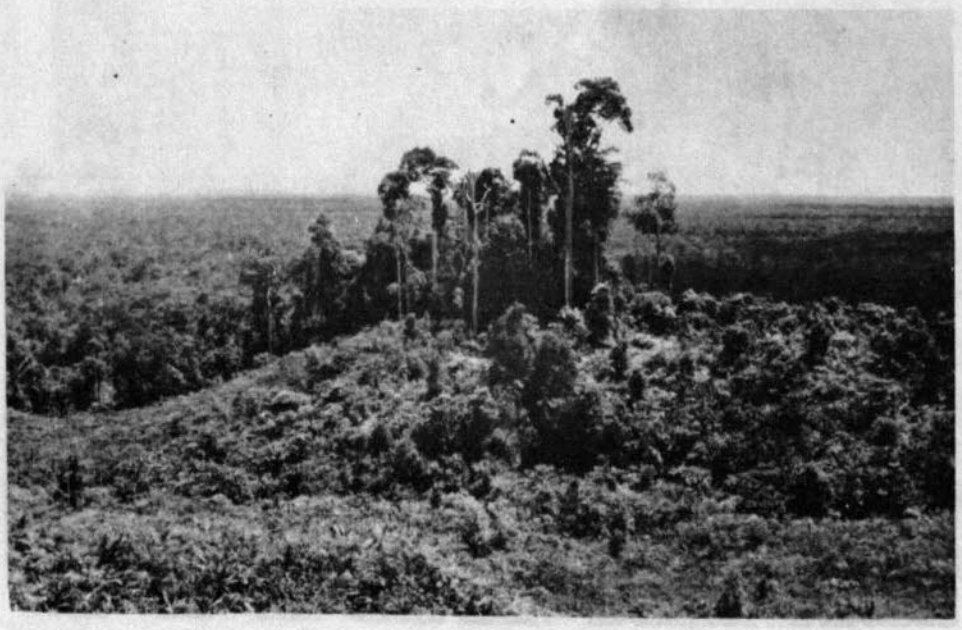


PLATE 7

The swamp plain from the foothills of Bukit Piring. The view looks north to the coast approximately five miles distant. Except in the zone immediately behind the coast itself, the soil mantle on the plain is entirely Organic Soils. These are dominantly Anderson Series and are deeper than 3 metres except near the coast. The basal clay is believed to be of marine origin.



PLATE 8

A portion of the upper Mukah drainage basin. The river follows the predominantly east-west strike of the Belaga Formation and major strike ridges are prominent. Deep dissection of the ridge flanks is apparent even under the forest canopy. The area is largely under a cover of primary Lowland Dipterocarp Forest but some tracts close to the main river have been cleared by Iban for hill rice cultivation and are under a secondary cover (Scale 1:25,000)



PLATE 9

A portion of the Upper Bawan drainage basin. The main strike ridges which characterise the interior highlands are here separated by broader tracts of lower country, although the strike alignment is still apparent and, despite considerable dissection, the ridge lines generally remain continuous. Except on the higher ridges in the northeast, most of this tract has been cleared for hill rice by Iban farmers and is under various stages of regrowth. The large areas in the south which have a low cover have been over-farmed and regrowth is slow. A riverine alluvial tract is seen in the extreme south and is under intermittent cultivation for wet rice. This locality drains south towards the Rajang River near Kanowit. The main upland soils are Merit Series, although other soils also occur. On the higher ridges in the north Lithosols are dominant. (Scale 1:25,000)



PLATE 10

Part of the lower Paloh tributary of the Oya River. The pronounced strike control of the terrain in more interior areas is less evident and the uplands are a confusion of dissected hills with little overall pattern. Almost all the area has been farmed for hill rice and is under secondary covers of varied age. Near the river some riverain forest remains but this is very broken and has been partly replaced by seedling rubber and fruit trees. Two longhouses are sited near the river bank and others occupy hilltop sites farther away from the stream and may be temporary structures near recently farmed areas. The upland soils are a complex of Merit, Bekenu and Nyalau Series in this locality. (Scale 1:25,000)

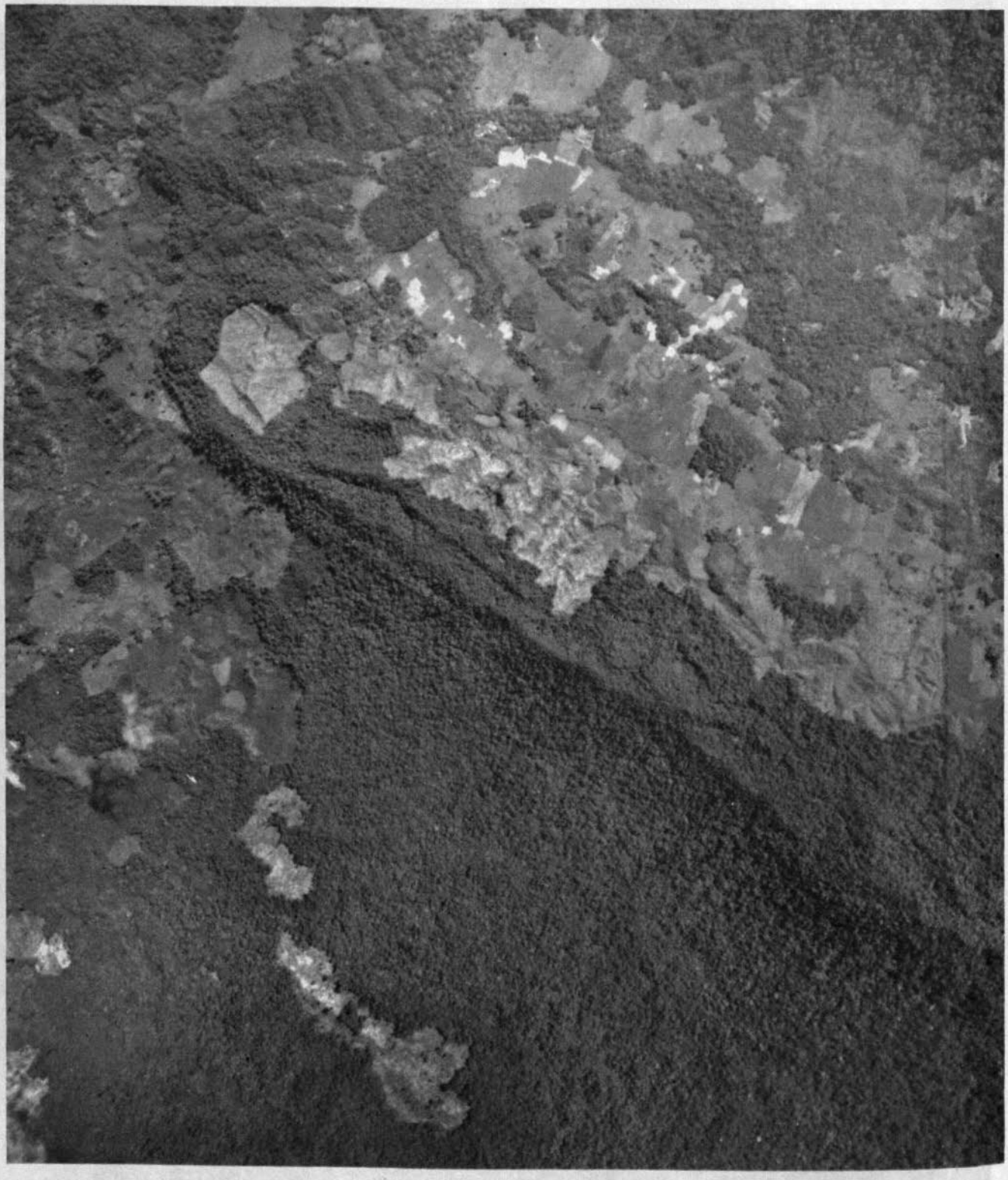


PLATE 11

A portion of the upper Arip valley in the northeast of the Area. Alluvial and Gley Soils in the valley itself have been cleared for wet rice and a continuous zone of rubber, with some fruit trees, follows the river bank in the north. A number of Iban longhouses are also sited close to the river. The rhyolite-derived soils of the Arip Ridge itself (mainly Arip Series) which crosses the centre of the photograph have largely been left under thin primary forest although a new hill-flank clearance for hill rice is seen at centre. The lower terrain to the south of the ridge, mantled by Merit and Bekenu Series, has for the most part not been farmed but isolated new hill rice clearings are now extending into this tract. Part of the sandstone scarp which bounds the Arip valley to the north and is mantled by very shallow soils of Meluan Series, is seen in the extreme northeast corner of the photograph. (Scale 1:25,000)



PLATE 12

The dissected lowlands between Sarikei and Binatang: the Meradong rubber development scheme. Undulating and rolling hill land, showing little structural control, has been cleared for terraced rubber. Most of the rubber was recently planted when the photograph was taken, although an older block is seen near the trunk road which crosses the photograph in the southeast. A planned village for scheme settlers is clearly evident at centre right. On the western margins of the photograph (and to the south of the main road) is settled land outside the scheme boundaries in which smallholder rubber and pepper gardens are common. Narrow bottomland tracts drain northwards and have largely been cleared for wet rice, but some bottomland areas are mantled by peats and have been partially left under forest. Much of the settlement outside the scheme area is by Chinese farmers, but Iban longhouses are seen near the northeast and southeast margins of the photograph. The upland soils are complex in this locality. Bekenu, Nyalau, Kerait and Saratok Series are most common. (Scale 1:25,000)

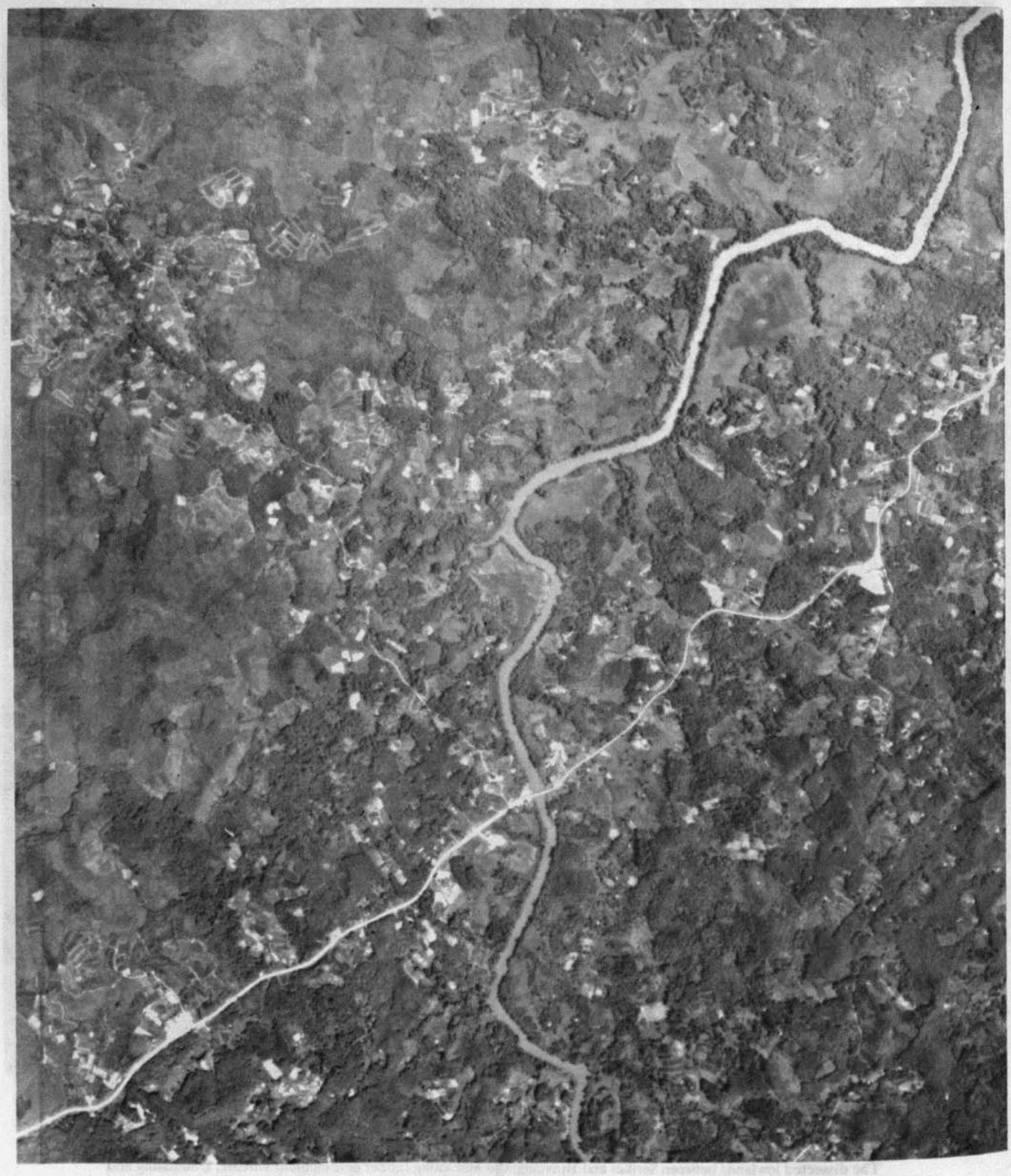


PLATE 13

The trunk road crossing the Sarikei River at Jakar. Terrain is very similar to that of Plate 12 farther east, but the main upland soils are here Jakar and Merit Series and settlement is largely by Chinese smallholders. Most of the area is farmed for rubber (much being terraced) and for pepper, this being one of the earliest centres of pepper cultivation. Tracts in the west and northwest remain under shifting cultivation of hill rice by Iban farmers. Near the Sarikei River to the north of the road bottomland Gley Soils have been farmed for wet rice. (Scale 1:25,000)



PLATE 14

The Rajang delta margins at Binatang. A narrow belt of Gley Soils forms the banks to all river channels here and is backed by peats of varied depth. The area is tidal and soils on the river banks are weakly saline and are partly left under a stand of *Nipa*. Most of the swamp forest cover has been cleared for agriculture in the past and later abandoned to regrowth except where the peat is shallow and is intermittenly cultivated for wet rice. Bordering the main road in the south are stands of old rubber. Near Binatang town, and close to the river banks to the north of it, are many orange plantations on weakly saline Gley Soils and shallow peats (II. 86). These show as regular stippled areas similar in appearance to pepper gardens at this scale. The area is dominantly settled by Chinese but a number of Iban longhouses are sited close to the main river channels. (Scale 1:25000)

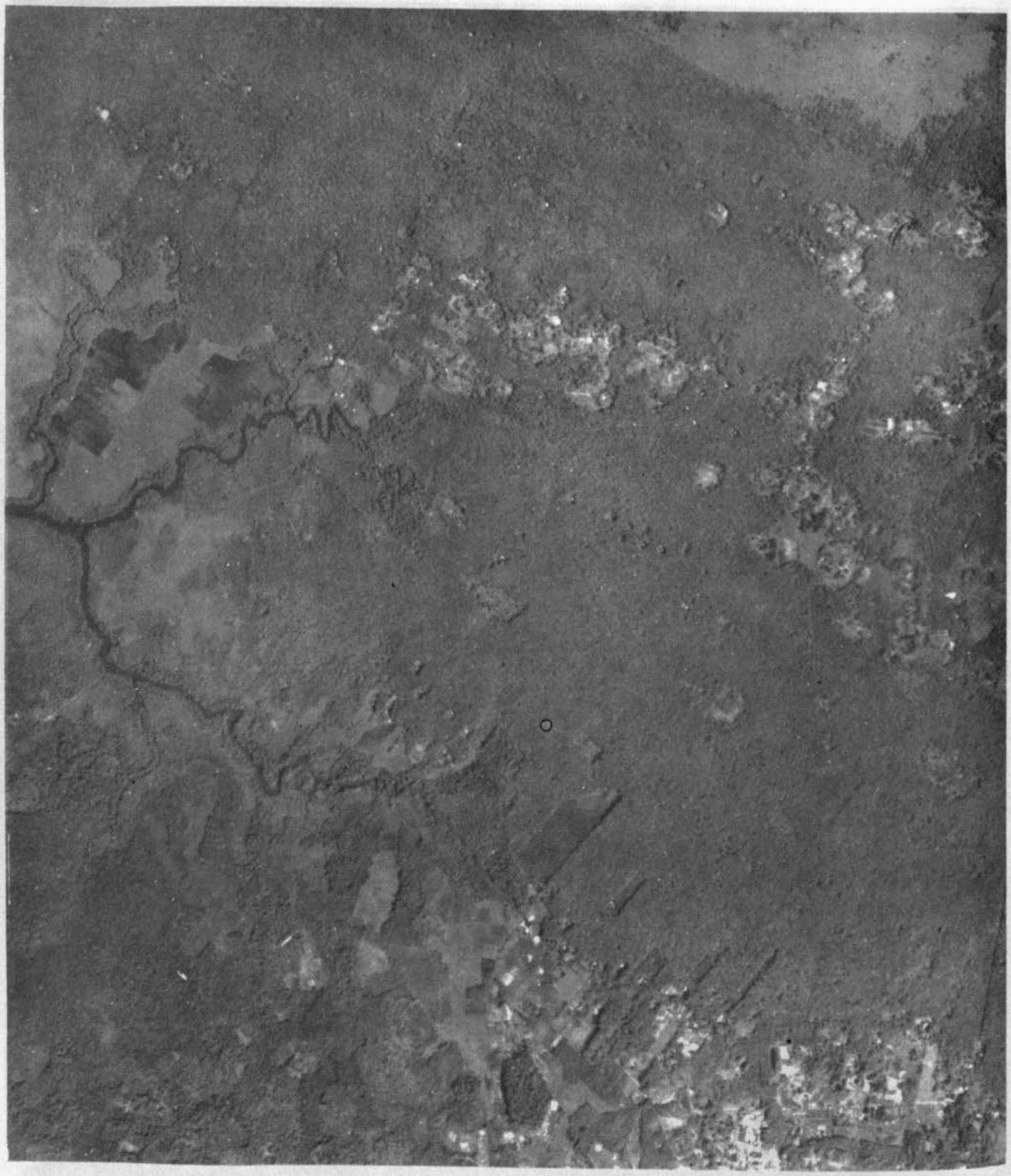


PLATE 15

The Tulai River headwaters between Binatang and Sibu. The area is mainly swampland but lines of low hills strike across the south and centre of the photograph and represent the summits of prior strike ridges now buried beneath a peat mantle. These hills (mainly of shales with a Merit Series soil cover) have been used for settlement, vegetable and fruit plots and for pepper gardens. The intervening swamp tracts are cleared for wet rice near the river, where the peat mantle is shallow, but elsewhere have been largely used for rubber, planted regardless of peat depth with some shallow and generally ineffective drainage works. Most of these plantings are very old. (Scale 1:25,000)



PLATE 16

The coastal beach complex near Jerijeh. Saline clay soils in the south show a zoned succession of mangrove covers. This is repeated locally elsewhere in the photograph but most of the area has a complex of fossil sand ridges and clay swales, with some shallow peat tracts. The low sand ridges have been cleared for agriculture at various times in the past, but much of this clearance has later been abandoned to poor regrowth. There remain, however, some tracts where coconuts and vegetables are grown and wet rice is also grown in some clay bottomland areas. The photograph was taken in 1972. This area has since been included in a regional development scheme. (Scale 1:25,000)

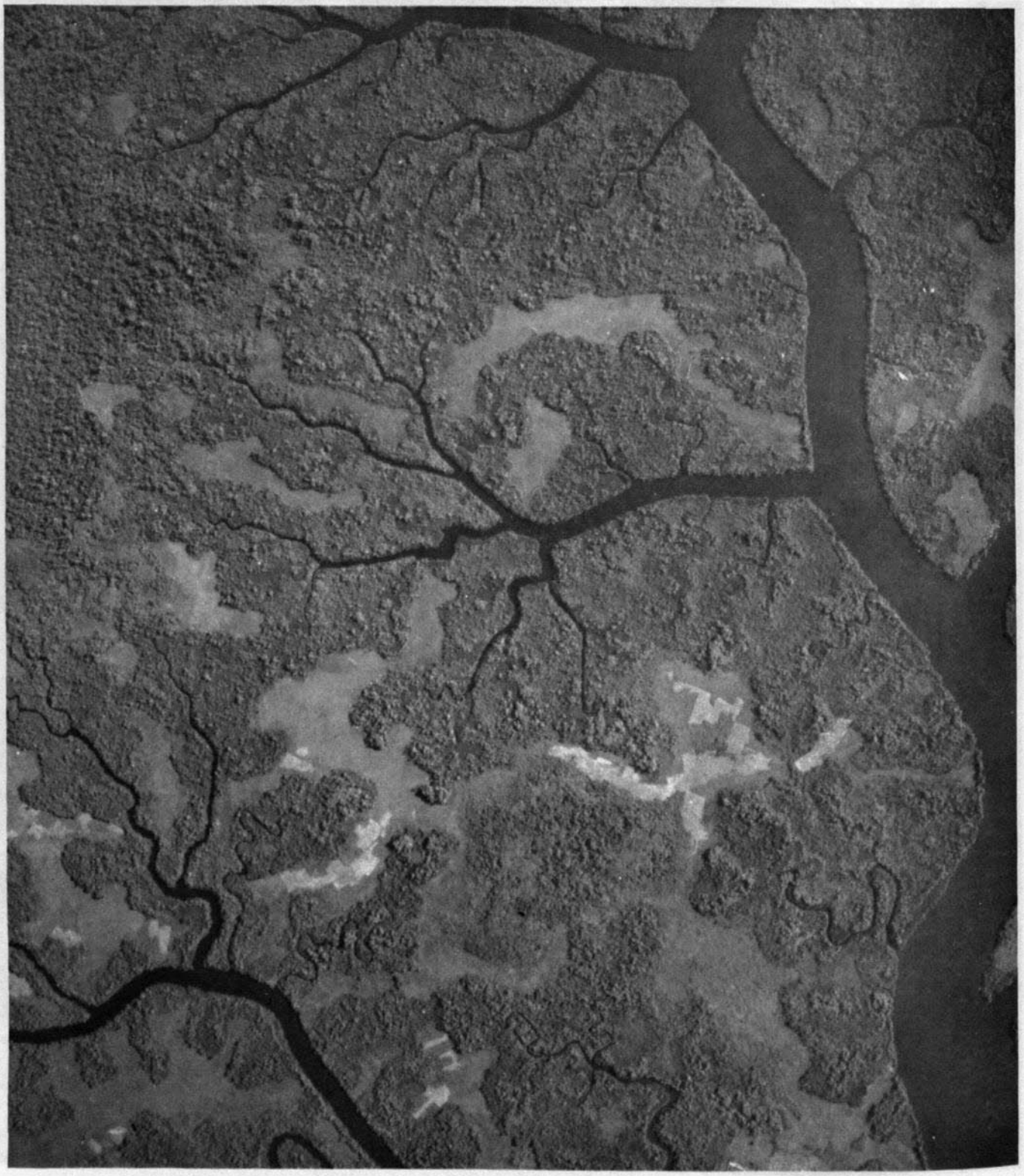


PLATE 17

The headwaters of the Lassa river. Mineral Gley soils border the river and creek banks and are believed to be developed in material deposited by backflooding of this highly tidal river. Brackish water extends periodically to the headwaters to the Lassa and the cover on these mineral soils is largely mangrove forest species, stands of *Nipa* being particularly common. Farther from the creeks the dominant soils are deep peats of Anderson Series (normaly deeper than 3 metres). These have been sporadically cleared in the past for wet rice. The majority of such clearances have been long abandoned but some recent farming areas are seen in the southern half of the photograph (Scale 1:25,000)

Part II

THE SOILS OF THE CENTRAL SARAWAK LOWLANDS

CHAPTER 6

METHODS OF INVESTIGATION

Review of Soils Investigations in the Area

The first formal soils investigations in Sarawak were carried out by Dames in 1955–1956 and 1958–1959 (Dames, 1962). The early project was a reconnaissance of heath forest areas from the viewpoint of forestry problems and resulted in a classification of the soils (mainly Podzols) associated with this forest type. The later project included a number of surveys of areas with agricultural potential and resulted in a general soil classification of the soils studied and recommendations regarding the establishment of a formal organization for soil survey. Dames undertook a number of investigations in west, north and interior Sarawak during these projects but did not work in the present Area.

The Soil Survey Division was established in 1960 and – considering only investigations within the Area – a broad reconnaissance was made of the coastal zone and Rajang delta (e.g. Wall, 1961a; 1961b; 1962; Wall and Lim, 1962) and of selected interior areas (e.g. Andriesse, 1962). The term 'broad reconnaissance' refers to nomenclature in local use and, together with other such terms, is discussed below. In 1963 the present writer assumed responsibility for survey within the Area. Most of the areas investigated in 1960–1962 have since been reconnoitred at a more detailed level. The earlier traverse records have been incorporated in the present map where this adds to the detail. A number of localities have been studied at a semi-detailed level and the soil map also incorporates the results of certain semi-detailed survey projects conducted by Assistant Surveyor Ahmad Haji Ebon and more recently by Soil Surveyor Tan In Kok. The degree to which the present soil map is based on the work of these investigators is indicated in Map 2.

Although a regional reconnaissance coverage has been considered an important aim of the Soil Survey Division, it must be stressed that the Area has largely been surveyed piece-meal and that the present soils map is a compilation derived from many separate survey projects. A number of levels of survey have been employed and methods have varied depending on, among other factors, the aim of the project, the ease of communications, and the soil and terrain patterns.

Soil Survey Procedures

Sources of information

In compiling the soil map for individual survey projects information from a number of sources have been employed. The importance of each source varied with the level of survey and other factors.

Geological maps on a scale of 1:250,000 are available for the Area (Wolfendèn, 1960) but are of little assistance in localities underlain solely by Tertiary sedimentary rocks as no attempt is made (or could be made at that scale) to map lithology. In the northeast of the Area, however, the geological pattern is complex and these maps have proved a useful guide to many soil association boundaries.

Air photographs are available for the entire Area but vary greatly in date and scale. Since 1962 the Lands and Survey Department has operated its own air survey programme and a coverage of recent photography on a scale of 1:25,000–1:30,000 is available for most parts of the Area, together with coverage on 1:10,000 scale for some localities. Air-photo-interpretation has been used extensively in all reconnaissance surveys and in many semi-detailed surveys. As the flying programme is arranged each year with the requirements of other Departments in mind, many of the semi-detailed survey projects have had the benefit of air photo coverage flown in the year of the survey and at a scale requested by the soil surveyor.

Contour maps were not generally available for the Area during the course of the soil survey project although an extensive part of it has now been included in published contour coverage on 1:50,000 scale. For some localities, however, contour mapping from photogrammetric plots on 1:10,000 scale had been completed by Lands and Survey Department and were used as base maps for semi-detailed surveys in upland areas (see, for example, Figs. 31 and 32). The reliability of the contour plots depends partly on the degree of forest cover in the photography used for interpretation but these maps have, in general, proved very reliable.

Other base maps were available for the entire Area on 1:50,000 scale and, until production of the current contoured series commenced, mainly comprised compilations of drainage and coastal details, settlement, roads and footpaths. As these details were derived from air photo coverage dating from 1949–1956 the information is of variable accuracy. Many longhouses have moved; footpaths which showed well on the air photographs included many which were new

tracks to hill rice farms cleared in the year prior to the photography and have since been abandoned; even the coastline has altered significantly in some localities within a decade. These base maps were used throughout the reconnaissance soil survey but an important phase of the pre-field work was to update and correct them in the light of the most recent air photography available.

Levels of investigation

Three general levels of survey were employed: reconnaissance, semi-detailed and detailed. Reconnaissance surveys were further sub-divided to indicate the level of detail achieved.

As the project was geared to an assessment of the agricultural potential of the Area some tracts of both deep basin peat and mountainous terrain were mapped solely by air-photo-interpretation or were briefly investigated on the ground by broad reconnaissance methods. On such surveys ground checks were confined to broadly spaced traverses or rapid path inspections. Soil maps of these areas were thus largely derived from air-photo-interpretation and were circulated on a small scale unless part of a larger project.

The bulk of the Area – comprising those localities with at least some land suitable for development for agriculture – was surveyed at reconnaissance or detailed reconnaissance level, the distinction being made on the density of ground observations. The sampling density may relate to soil complexity or the degree of agricultural interest in the locality but may also be a reflection of the standard of communications there: if access was easy a greater number of traverses could be sampled within the time allocated to that phase of the project.

On reconnaissance surveys no formal traverse grid was attempted. Access was mainly by river, using longboats or speedboats on the larger streams and paddle canoes on smaller side-streams. Generally the most significant soil cross-section for sampling purposes proved to be that on a line at right-angles to the general direction of the stream, extending from the river-bank alluvium into the hills flanking the bottomland (or to the swamp plain basin peats in downriver areas). In the dissected lowlands the navigable drainage net is relatively dense. Rather than continue a traverse beyond one or two days work it was normally found preferable to move to a new point on the river and traverse a fresh line through an adjacent locality. This method proved to involve less positioning time for the field parties than a series of parallel traverses and the field camp (occupied by one or two parties) was commonly moved only once a week. It was also advantageous to locate traverses in relation to the river pattern as, for many areas, the drainage was the only information reliably plotted on available base maps. The traverse coverage, as indicated on Map 2, largely reflects the drainage network. Traverses are generally 1–1½ miles long and fan out from the main waterways. Footpaths were traversed where they could be confidently located on the photographs but were roughly compassed by the field party as a check on this.

As a result of information gained during the reconnaissance of large areas, localities with potential for development were identified and many of these were later surveyed at a semi-detailed level.

Methods of survey for semi-detailed projects varied with the terrain and soil conditions of the locality concerned and the availability of base maps. In upland areas photogrammetric contour plots on 1:10,000 scale were used as base maps if available. Soil boundaries interpolated on such plots were more accurate than those based on an air-photo-mosaic and, wherever possible, an advance request was made to Lands and Survey Department for such contour data (usually at 25-foot interval) prior to the field survey. Where time did not allow preparation of such maps, or no ground control was available for plotting, an air-photo-mosaic base was employed. Air-photo-mosaics were invariably used as base maps in coastal and swamp surveys where there was no significant relief. On such surveys it was found convenient to prepare the mosaic from photostat negative prints. A number of photostat positive copies of the laydown could then be made for use in the field and drawing office. Provided the original bromide photographs were available for comparison the loss of definition on such mosaics was not a serious drawback. The lack of control was unimportant provided the survey area was reasonably small (2,000–5,000 acres was an average project) or unless the mapped boundaries were later married to a contour plot. In the latter case the field information usually had to be replotted on the new base and boundaries redrawn. Mosaic base maps were prepared at 1:10,000 scale if photography on that scale was available. Where the coverage was at 1:25,000 or 1:30,000 scale, enlargements were prepared to give a field mapping scale of 1:15,000 or 1:12,500.

Field sampling on semi-detailed surveys generally followed a formal traverse grid. An irregular grid was employed in some localities where many footpaths were available for traversing, provided they showed clearly on the photo coverage. On swamp and coastal surveys, however, a formal sampling grid was essential as the soil pattern is generally complex in such areas and little guidance to interpolation of boundaries is given by the vegetation or terrain data. The soil map was therefore entirely a rationalisation of the field sampling records and its accuracy a function of the sampling density. This was best controlled by parallel traverses.

These methods were also used for detailed surveys, although on such work the sampling density was close and little use was made of air photographs. Survey at this level was confined to two special project areas (a forest experimental nursery and a proposed agricultural station) and to a number of sample strips. Detailed contour mapping was available for the two project areas. For the sample strips the writer prepared a contour map by levelling along each sampling traverse, using an assumed datum.

In addition to report maps prepared for each survey project the individual project maps were combined on 1:50,000 scale master sheets and semi-detailed (and detailed) project maps were generalised as necessary for plotting at this scale. The present soil map is based on this compilation. Further generalisation was necessitated by the reduction to 1:125,000 scale and many of the original mapping units, which were preserved in the 1:50,000 scale compilation, were grouped together at this stage in order to keep the Key to Map 1 within manageable proportions.

The degree to which the general map is based on each survey type is indicated in Table 6, which has been calculated from the 1:50,000 scale master sheets.

Table 6

Levels of survey used for soil map compilation

	Survey Type	*Percentage coverage on Map 1*	
Air-photo-interpretation only	Mountainous terrain	9.5	27.0
	Basin peat swamps	13.7	
	Areas remaining unsurveyed at close of project where field work was not possible due to temporary security restrictions	3.8	
Reconnaissance	Broad reconnaissance	8.2	68.2
	Reconnaissance	57.4	
	Detailed reconnaissance	2.6	
Semi detailed			4.8
Detailed		less than	0.1

Sampling densities

The sampling density achieved by each survey method and implied by the local survey type name has varied to some degree. Densities calculated for representative survey projects within the Area are shown in Fig. 15, where sampling density, publishing scale for the individual project map, and nomenclature for the survey type are compared with those adopted by the United States Department of Agriculture (Vink, 1963, modified from USDA, 1951: 15–21) and FAO (1968). It can be seen that there is little agreement with either scheme but as these tend to assume conditions in which a regular sampling grid over the surveyed area gives optimum reliability to the soil boundaries it is doubtful if comparisons with methods used in the present Area are valid. In much of the upland zone soils vary rapidly along each traverse, and are unrelated to landform or vegetation. Even in semi-detailed investigation of some upland tracts the complexity of the pattern is too great for differentiation of family or series mapping units. On reconnaissance surveys close sampling along each traverse indicates clearly the range of soils occurring in complex within one upland locality. Adjacent traverses, separated by 2–3 miles, may indicate that this range varies little over a broader area. One complex association can then be inferred for mapping purposes from these data. Were, however, the same number of sampling points redistributed as a regular grid over the area (at four samplings points per square kilometer, for example) a very different impression of the soil mantle would emerge and the fortuitous location of adjacent sampling points on similar soils would suggest mapping boundaries which have no reality.

Soil survey in Sarawak has developed independently of that in Peninsular Malaysia (Malaya) but conditions of work are comparable in some respects and the types of development in view are commonly similar. It is not surprising that the nomenclature of survey types and the density of observations associated with them are broadly comparable to those used within the Area, (Fig. 15). Map publishing scales are rather different, however, as is the sampling pattern on reconnaissance and semi-detailed surveys: the interval between traverses is generally less in Malaya than in Sarawak and the distance between sampling points on each traverse much greater.

A lack of correlation between national surveys in respect to survey nomenclature, sampling density and publishing scale is very general, however, (see, for example, data quoted by Bie and Becket, 1970) and, while this has obvious disadvantages, it is more important that these features be reasonably well-standardised within each survey organisation and the levels of accuracy applicable to each map type understood by local government agencies and other normal clients. To a large degree these conditions have been met in Sarawak.

Field methods

Each field party normally comprised five temporary labourers together with the team leader (either the surveyor or an assistant). Traverses were cut on a bearing controlled by a 2-inch prismatic compass and were sampled as the line was cut. Traverse measurement was in units of 100 feet on early surveys and 25 metres for the later projects which comprise the bulk of the work. The most convenient measure to use in the thick vegetation characteristic of most localities proved to be cut lengths of plastic-coated three-ply telephone cable with copper or equivalent binding marking the measuring points near either end.

Numbered pegs were placed at each 25 metres and soil sampling on the traverse was confined to the pegged points unless surface conditions directed otherwise. On both reconnaissance and semi-detailed surveys a standard sampling distance of three pegs (75 metres) was normally adopted. The soils were sampled to a depth of (48 inches) (1.2 metres) using an Edelman barrel auger. Sarawak soils are almost invariably moist and rarely so stony that it is difficult to operate this type of auger. A screw auger was therefore never employed. In swamp areas the auger was discarded once the peat mantle exceeded 48 inches in favour of a pole cut on the spot and used as a probe. In most areas mantled by peat swamp forest there is no difficulty in locating a thin straight pole over 12 feet (3.7 metres) long and it was not necessary to carry a special probe for this purpose. The end of the pole was pointed and small notches cut immediately above the point and at 10-inch intervals at higher levels to a length of 10 feet (3.1 metres). Underlying clay is caught satisfactorily in the notches to indicate the thickness of the peat mantle. Basal sand clings less well but was rarely encountered except in coastal areas. Probing at a large number of points around the peg was sometimes necessary as the peat mantle is raw and woody and the pole was commonly stopped by submerged tree trunks. On traverses directed into the basin swamps the sampling interval was extended to 125 metres once the zone was reached where the peat mantle was consistently deeper than 10 feet (3 metres on later surveys).

Soils were described at each sampling point by standard methods (USDA, 1951), Samples were discarded after field description unless required for pH or conductivity determinations. If the traverse party was led by an assistant samples were retained for the surveyor's inspection where unusual features or problems in description occurred, and field parties carried a supply of sample bags for this purpose. In addition to soil descriptions, records were made at each sampling point of vegetation and land use, landform type and slope. A landform profile of the traverse was also drawn and details of settlements, streams and paths were recorded in order to check the location of the traverse on the air photograph or base map.

Traverse description forms of various designs were tested on early surveys but were discarded in favour of lined hard-covered pocket-sized notebooks without an itemised format. These could be used for all field projects and allowed freedom

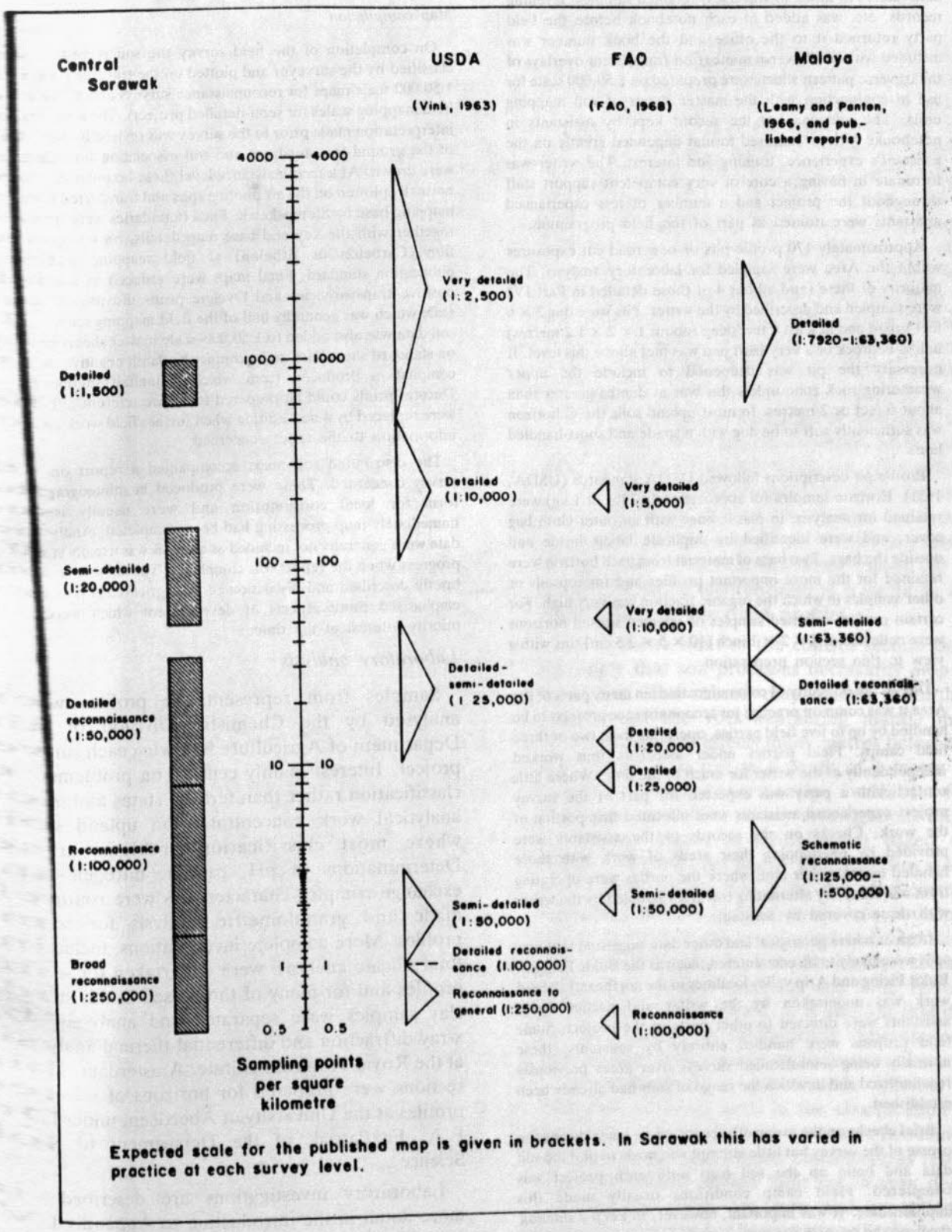


Fig. 15: Sampling densities and survey types used in the Area and by selected other soil survey organisations.

to add to the field record when required. They could also be numbered and stored conveniently for easy retrieval of the data later. An index to traverses, retained samples, levelling records, etc. was added to each notebook before the field party returned it to the office and the book number was included with the traverse number on transparent overlays of the traverse pattern which were prepared on 1:50,000 scale for use in conjunction with the master sheets of soil mapping units. The adequacy of the record kept by assistants in notebooks with no itemised format depended greatly on the assistant's experience, training and interest. The writer was fortunate in having a core of very competent support staff throughout the project and a number of less experienced assistants were trained as part of the field programme.

Approximately 170 profile pits or new road cut exposures within the Area were sampled for laboratory analysis. The majority of these (and all but 4 of those detailed in Part IV) were sampled and described by the writer. Pits were dug 3 × 6 feet broad and at least 4 feet deep (about 1 × 2 × 1.2 metres) unless bedrock or a very hard pan was met above this level. If necessary the pit was deepened to include the upper weathering rock zone unless this was at depths greater than about 6 feet or 2 metres. In most upland soils the C horizon was sufficiently soft to be dug with a spade and short-handled hoe.

Profile pit descriptions followed USDA standards (USDA, 1951). Horizon samples (of approximately 2 lbs or 1 kg) were retained for analysis, in plastic bags with an outer cloth bag cover, and were identified by duplicate labels inside and outside the bags. Two bags of material from each horizon were retained for the more important profiles and for topsoils or other samples in which the organic fraction was very high. For certain profiles oriented samples of selected subsoil horizons were collected in 4 × 2 × 1 inch (10 × 5 × 2.5 cm) tins with a view to thin section preparation.

Due to the difficulty of communications in many parts of the Area it was common practice for reconnaissance projects to be handled by up to five field parties, operating from two or three field camps. Field parties under assistants thus worked independently of the writer for much of the time. Where little contact with a party was expected for part of the survey project experienced assistants were allocated that portion of the work. Checks on the records of the assistants were provided by overlapping their areas of work with those handled by the writer and, where the parties were operating from one camp, by alternating traverses sampled by the writer with those covered by assistants.

In areas where geological and other data suggested that new soils were likely to be encountered (such as the Bukit Tunggal, Bukit Piring and Arip valley localities in the northeast) all field work was undertaken by the writer and parties under assistants were directed to other parts of the project. Some field projects were handled entirely by assistants, these normally being semi-detailed surveys over areas previously reconnoitred and in which the range of soils had already been established.

Brief checks on the assistant's records were made during the course of the survey but little attempt was made to plot the soil data and build up the soil map until each project was completed. Field camp conditions usually made this impracticable. It was important, however, to keep a running check on the traverse progress as traverse lines proposed prior to the survey might not prove possible in the field. Starting points established from the air photographs were sometimes difficult to locate on the ground. A number of factors could halt the traverse half-way, ranging from flooded swamp tracts and difficult vegetation conditions to frequent hornet's nests or ripening hill rice (which cannot be entered due to restrictions under Iban customary law). Alternative traverses had therefore to be chosen during the course of the survey.

Map compilation

On completion of the field survey the soil records were classified by the surveyor and plotted on the traverse grid (on 1:50,000 scale maps for reconnaissance surveys and at various field mapping scales for semi-detailed project). The air-photo-interpretation made prior to the survey was revised in the light of the ground investigations and soil association boundaries were drawn. At a reconnaissance level these boundaries were normally plotted on the air photographs and transferred to the mapping base by Stereosketch. Final boundaries were traced, together with the key and base map details, on transparent film (Carbelon or Ethelon) at field mapping scale to publication standard. Final maps were reduced as Kodalith positive transparencies and Dyeline prints distributed on a scale which was generally half of the field mapping scale. The soil data was also added to 1:50,000–scale master sheets based on standard sheet lines and a contact Kodalith negative of the compilation produced from which a limited number of Duostat prints could be prepared for office reference. These were replaced by a new edition when further field work added information to the sheet concerned.

The distributed soil maps accompanied a report on the survey concerned. These were produced in mimeographed form for local consumption and were usually issued immediately map processing had been completed. Analytical data were generally not included as analysis was usually still in progress when the report was completed. The soils were only briefly described and discussion of the agricultural potential emphasised those aspects of development which were of priority interest at the time.

Laboratory analysis

Samples from representative profiles were analysed by the Chemistry Division of the Department of Agriculture following each survey project. Interest mainly centred on problems of classification rather than fertility status and most analytical work concentrated on upland soils where most classification problems arise. Determinations of pH, carbon, nitrogen and exchange complex characteristics were routinely made and granulometric analysis for some profiles. More complete investigations, including total silicate analysis, were undertaken for some profiles and for many of those used in this study clay samples were separated and analysed by x-ray diffraction and differential thermal analysis at the Royal Tropical Institute, Amsterdam. Thin sections were prepared for horizons of selected profiles at the University of Aberdeen, under Dr. E.A. FitzPatrick of the Department of Soil Science.

Laboratory investigations are described in more detail in the introduction to Appendix IV, in which the analytical results for representative profiles are tabulated. Some further data are included in Chapter 10. The Chemistry Division analyses followed standard methods for most determinations and references to these are given in Appendix III.

CHAPTER 7

SOIL CLASSIFICATION

The Development Of Soil Classification In Sarawak

The first tentative classification of soils in Sarawak was made by Dames (1962). A broader range of data was gathered following the establishment of the Department of Agriculture Soil Survey Division in 1960 and a number of broadly-defined soil families were named. These were more precisely characterised, and some additional families created, in a formal classification prepared in 1966 by the then soil survey staff (J.P. Andriesse, J.R.D. Wall, and the present writer) (Soil Survey Staff, 1966). Amendments were subsequently made to certain Groups (Scott, 1967) and the system was further modified for west Sarawak (Andriesse, 1972) but in all major respects the 1966 system has remained the basis of classification.

The system employed Great Soil Groups and Families, the former relying heavily on the framework of Thorp and Smith (1949). Families were distinguished on a variety of grounds and certain 'diagnostic horizons' were adopted from the later USDA system (USDA, 1960). Partly influenced by that system, precise definition was attempted at both Group and Family level.

Application of the system over subsequent years showed up many inadequacies and inconsistencies, which have been dealt with at some length by Andriesse (1972). In general, however, it proved well-suited to ordering the majority of soils in the lowlands of the State (the interior has only recently been investigated) and formed a basis on which an improved framework of classification could be built and some of the inconsistencies resolved. A revision to the diagnostic parameters employed was made in a Key covering the soils of the Area and of similar areas in north Sarawak (Scott, 1973) and the classification adopted in this study is based on that revised version, with some further changes which mainly aim towards simplification. While the classification strategy and terminology differs considerably from those of the 1966 system it must be emphasised that the contrasts are more apparent than real. A major consideration has been to preserve, as far as possible, the central concepts of the system constructed in 1966, as these have for the most part proved very appropriate to a useful ordering of the soil spectrum in the Sarawak lowlands.

The Proposed Classification Strategy

The control section

Except in very shallow mineral soils, the profile is classified on features expressed in a control section, which essentially comprises the subsoil (the A2 and B horizons where present). The control section is limited towards the soil surface by the base of the A1 horizon or a depth of 10 cms from the surface, whichever is deeper. At its base it is limited by the C horizon, any continuous stoneline subhorizon of the B horizon which is more than 10 cms in thickness, or a depth of 1 metre, whichever is shallower. The emphasis on the A2 and B horizons follows Northcote's approach, these generally being 'the most expressive and consistent portions of the profile' (Northcote, 1974: 2). The A1 horizon has a particular bearing on agricultural suitability but varies greatly in characteristics, especially in areas such as central Sarawak where many mineral soils have been in agricultural use. It is also that part of the profile most affected by surface wash and creep. The A1 horizon is ignored in the present development of the classification, except for its texture, which is incorporated as a suffix to the Series name in described profiles.

The 1 metre limit to the control section does not imply that soil processes necessarily stop at this point. The subsoil may extend to further depths, and the rock-weathering mantle may show pedogenetic effects many metres below the soil surface. The soil to a depth of 1 metre is, however, that consistently available for inspection on routine survey investigations using a standard auger. A classification based on features beyond the depth available for study other than in profile pits or road-cutting exposures would be difficult to operate. A deeper control section could be adopted and extending augers used routinely, but the control section limit would remain arbitrary and little further precision would be gained. It is also felt that if a soil unit cannot be satisfactorily differentiated from another in the system on its features down to 1 metre depth it is questionable whether a separation of these units in the classification is necessary of justified. There are one or two minor instances where unfortunate classifications result from the control section limit (as in very deep Podzols) but these are rare and exceptional provision for them has been made at Series level.

Texture

Texture groupings are used at Family and Series level (and for Group definition in the case of Regosols). These are largely based on the

particle-size classes of the USDA system (USDA, 1975: 383–386). This differs from the 1966 approach, where the texture class of the B horizon was emphasised. Fragmental and skeletal particle-size classes have not been required in the current system, which uses only divisions in the sandy, loamy (loams and silts) and clayey classes. These three groups are employed at Family level in the Groups of Gley, Alluvial and Organic Soils. In upland soils, where texture appears to justify greater emphasis at this level, Family separation between loams and silts is also made. This affects the Groups of Red-Yellow and Grey-White Podzolic Soils and the Hydromorphic Upland Soils. Regardless of the level of division in the Families, distinctions of particle-size class at Series level employs the primary classes recommended in the USDA scheme for all Great Soil Groups. These comprise sands, coarse loams, fine loams, coarse silts, fine silts, and two divisions of clay. The USDA definitions are followed except in dividing the clay class. The USDA scheme proposes a division at 60 per cent clay between fine and very fine clays. Sarawak soils so far investigated rarely have such high clay content. Some heavy-textured soils do, however, have distinctive structure, colour, depth and association with specific parent materials. They also have relatively high clay percentages and it is convenient to use that characteristic to separate them in the classification. By weighted-average, however, clay in the control section approaches but rarely exceeds 60 per cent. A limit at 50 or 55 per cent by this method would be required to isolate these soils. Too few profiles are available from the Area for a decision to be made on this and in the present development of the classification a provisional Series distinction is made between light and heavy clays, the latter having at least 45 per cent clay throughout the control section and at least 50 per cent clay in some horizon. The problem appears to concern only Series within the Merit and Serin Families of the Red-Yellow Podzolic Soils.

The division of the loamy class into loam and silt subclasses at Family level in some Groups does not follow USDA recommendations but serves to preserve the distinction between some long-established Families (particularly that between Bekenu and Nyalau Families in the Red-Yellow Podzolic Soils). The further subdivision into coarse and fine loams and silts may also require reconsideration. No coarse silts have been recorded in the Area, and very few coarse loams. This may reflect the range of parent materials which are present or the relatively few profiles which are supported by granulometric analysis.

The control section used for weighted-average particle-size class calculation is that defined above for local use, not the control section defined for the USDA soil taxonomy.

It was initially proposed (Scott, 1973) to combine the particle-size class division with texture profiles, modelled on those of Northcote, for Family classification. Further study suggests, however, that the texture profile adds little to the classification framework, at least in respect to soils present in the Area. Most upland soils have, in Northcote's terms, uniform or gradational texture profiles but they differ little in other respects and the gradational forms are not markedly so. In Grey-White Podzolic and Hydromorphic Upland Soils more pronounced gradational texture profiles are found and contrasting texture profiles are also common, but here also the profile similarity in other respects suggests that a division on these grounds would be an unnecessary complication. Texture profile parameters may be required to allow for certain strongly bisequent soils on terrace sites in west Sarawak but these require further study.

Colour

Upland soils in Sarawak have a broad range of subsoil colour, and the close juxtaposition of reddish yellow and light grey soils in road-cutting exposures is a particular feature of many localities in the Area. Colour being very obvious, there is a danger that it may be over-emphasised as a classification tool. Data from the Area suggests that many strong colour contrasts relate mainly to levels of iron in the parent materials and that the profiles concerned may differ little in other respects. Nevertheless, colour is used in both Family and Series classification and also serves as a parameter in some Group definitions.

Colour is classified in terms of value/chroma ratings and in colour classes based on the dominant hue. The value/chroma ratings (Fig. 16) are modified from Northcote (1974) and are particularly used in differentiating Red-Yellow and Grey-White Podzolic Soils. The ratings are also used at other points in the system. The definition of Gley Soils on colour parameters is necessarily more complex and limits drawn from the definition of certain aquic subgroups in the USDA soil taxonomy are provisionally adopted.

No further colour distinction is made at Family level, Families being separated on particle-size class and other parameters. Within the broad spectrum of red and yellow soils in the Red-Yellow Podzolic and Alluvial Soil Groups, however, Series division has been made within each Family on, among other parameters, the

subsoil colour class. Three colour classes have been recognised – yellow, red and dark red – and are defined as follows:

Yellow – the matrix hue is 10YR or yellower in some part of the control section above a depth of 50 cms.

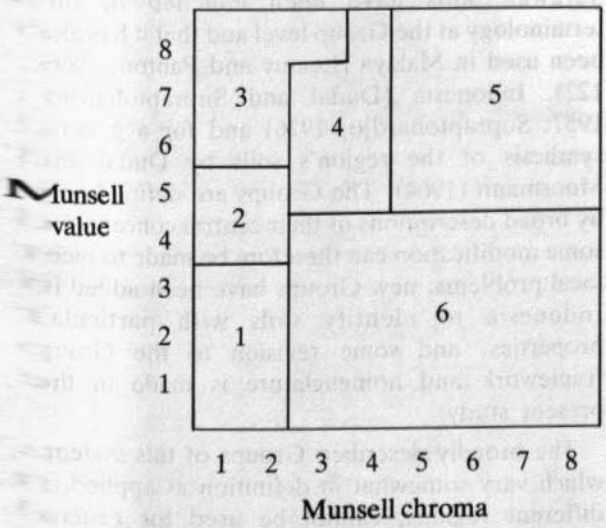
red – the matrix hue is redder than 10YR throughout the control section but yellower than 2.5YR in some part of the control section above a depth of 50 cms.

dark red – the matrix hue is 2.5YR or redder throughout the control section.

A further colour class term – 'pallid' – encompasses soils in the Grey-White Podzolic Group and refers to profiles with a value/chroma rating of 3 throughout, or in most parts of, the control section, regardless of hue. The dark red colour class is introduced to isolate a particularly red Series reported in west Sarawak and does not concern soils in the Area.

FIGURE 16

Value/chroma ratings used in defining soil classification units



The colour class distinction has only been employed in Groups where soils have subsoil colours which are either uniform throughout or are redder in the B than the A2 horizon, and the above definitions assume that only this range of profile forms is concerned. It is arguable that Series separation would also be justified between profiles which lack any significant colour change in subsoil horizons and those which have a definite 'colour B' (where the B horizon is the horizon with maximum chroma, using Northcote's definition). It is felt, however, that the classification strategy is already more than sufficiently biased towards colour distinctions without a further colour parameter being introduced.

The classification framework allows for colour intergrades at certain points. These are discussed below.

Parent materials

The properties of upland soils commonly reflect characteristics of their parent materials but, partly due to deep chemical weathering, it is often difficult to establish the parent materials of particular profiles with any certainty in the field. Broad groupings of parent materials are used to define Families. Further subdivisions are used at Series level. These are commonly distinctions of lesser importance, but some separations on parent material type or origin are placed at Series level because the identification cannot be made with certainty in all situations, although some of these distinctions may be quite significant and could arguably be considered appropriate at Family level. The intention in this matter is, as far as possible, to define Families by parameters which can be established consistently with little difficulty and thus construct a classification framework by which soils can be confidently assigned to their Families even though the Series designation must remain in doubt in particular cases. Groupings on parent material type and origin are discussed under the Great Soils Groups concerned.

Intergrades

There is a continuous sequence of soils, bounded in the classification on colour parameters, from the reddest Red-Yellow Podzolic Soils to white Grey-White Podzolic Soils. A similar sequence extends from poorly-drained Gley Soils to well-drained Alluvial Soils. Other continue with one main variable also occur, at both Group and Family level, the term 'variable' meaning here a variable used in the classification strategy (many other profile characteristics not used for the classification are also likely to vary through the soil sequence concerned). At some points in the system it has been convenient to leave 'gaps' between the Group definitions and to consider soils with intermediate properties which place them in such a 'gap' as being intergrades between the Groups concerned. This treatment is only introduced where the Groups involved have a common particle-size class division in the lower tiers and where no confusion can arise regarding which Families or Series the intergrade lies between.

The use of intergrades has three advantages. Firstly, the definitions at the Group level are narrower than would otherwise be necessary and there is consequently less variability within such Groups, which form simpler conceptual units. Secondly, it allows a number of classification divisions without consequently adding to the number of Family or Series names. The intergrade is named from the Families or Series between which it lies in the system. Thirdly, it reduces the number of points in the classification where a very slight change in profile properties implies a change in Great Soil Group designation. The classification is no less artificial – it remains an artifact dividing the soils spectrum into units on precise but largely arbitrary parameters – but the nomenclature of the system using the intergrade facility does go some way to reflecting the reality that soils with one common and recognisable profile form tend to grade towards soils with another.

The hierarchical bias

The Soil Series is commonly taken as the basic unit in soil taxonomy; higher-level divisions group Soil Series communities which have common properties. Classification on this basis presupposes an adequate body of data on soil properties at the Series level. When regional reconnaissance soils studies are undertaken in tropical areas, such data are commonly not available. Particularly lacking are agronomic data on which lower-category taxonomic divisions can be made which have meaning in terms of rating the taxonomic unit for agricultural use, and it is towards that end that most such studies are undertaken in developing countries.

Classification of the profile forms recorded on reconnaissance investigations are nevertheless required and in the classification used for the present study the Soil Family is considered the pivotal tier in the system, as in the classification constructed in 1966. The Family unit identifies a set of profile forms with a conveniently narrow range of variation in easily-identifiable properties and, in most Families, common genetic features. Broad statements regarding limitations to agricultural use can be made at this level and certain parameters of particular relevance in that context, such as potential acid sulphate characteristics in Gley Soils, have been used as Family differentiae. Even in that example, however, agronomic data are inadequate to confirm that the depth limits chosen are those of most significance to plant growth and the Family division at this point mainly emphasises that this constraint exists.

The choice of criteria for Series differentiation is biased towards easily-identifiable properties not employed at the Family level. Some, such as the particle-size subclass in upland soils which reflects parent material and bears on crop suitability and erosion hazard, have a general relevance. Others are included on less certain grounds. The degree to which minor subsoil colour contrasts in well-drained upland soils, for example, reflect parent materials, genetic process, plant growth limitations or associated profile properties remains to be demonstrated. They are very obvious in the field, however, and can be recorded consistently with no difficulty. Some of these contrasts have therefore been incorporated in the classification structure at the Series level. As the body of knowledge grows, particularly regarding agricultural use, it is to be expected that much expansion and revision of the classification at this level will be required.

In organising the classification at the Great Soil Group level the practical choice has lain between continued use of a grouping on the Thorp and Smith model or redefinition within the terms of the USDA soil taxonomy or its derivative used for the World Soil Map legend (USDA, 1975; FAO, 1974). The Thorp and Smith framework is advantageous in that previous classifications of Sarawak soils have been couched in this terminology at the Group level and that it has also been used in Malaya (Leamy and Panton, 1966: 122), Indonesia (Dudal and Supraptohardjo, 1957; Supraptohardjo, 1976) and for a general synthesis of the region's soils by Dudal and Moormann (1964). The Groups are defined only by broad descriptions of their central concept and some modification can therefore be made to meet local problems: new Groups have been added in Indonesia to identify soils with particular properties, and some revision to the Group framework and nomenclature is made in the present study.

The broadly described Groups of this system, which vary somewhat in definition as applied in different regions, cannot be used for general correlation without some confusion resulting or without a prior statement defining terms used. For such correlation the current USDA soil taxonomy (USDA, 1975) is of value, but a number of disadvantages make it unacceptable as routine classification tool in Sarawak. This system is discussed in Chapter 11, where the Area's soils are correlated with this and other classifications.

The soils of the Area are schematically related at Group, Family and Series level in Figs. 17 – 29. Families not represented in the Area are largely omitted. Where some Series of a Family are

present, the relationships between all Series of that Family are shown, but those not found in the Area are not discussed further. Diagnostic criteria are defined under the appropriate Great Soil Group in the following sections.

A Proposed Classification Of Soils In The Area

In this section the Great Soil Groups are defined and the criteria for Family separation summarised. Only brief reference is made to Series divisions, as these units are described in Chapter 8. The Group definitions diverge at some points from those adopted elsewhere. Discussion of the Group concepts is largely deferred to Chapter 11, where the proposed classification is correlated with other established systems.

TABLE 2

Great Soils Groups and Soil Families recorded in the Area

Great Soil Group	*Soil Families*
Red-Yellow Podzolic Soils	Merit, Bekenu, Nyalau, Serin, Abok, Gading
Grey-White Podzolic Soils	Kerait, Bandang, Saratok
Podzols	Miri, Silantek
Hydromorphic Upland Soils	Ajoh, Timang, Penipah
Gley Soils	Bijat, Pakan, Plan, Tatau, Pendam, Sirik, Paloh, Rajang
Alluvial Soils	Seduau, Bemang, Kayan, Kabong
Regosols	Peninjau, Tika
Lithosols	Meluan, Kapit, Lalis
Organic Soils (shallow)	Mukah, Igan
Organic Soils (deep)	Anderson

Red-Yellow Podzolic Soils

As defined for this study, Red-Yellow Podzolic Soils are mineral soils of upland areas. They are deeper than Lithosols, i.e. they do not have a lithic or paralithic contact within 25 cms of the surface, nor do they have more than 50 per cent weathered rock fragments within that depth. They are non-accreting and are largely residual soils, although many show some effects of slope-creep and profiles developed in colluvium are included in the Group, as are some soils on high-level terraces which have developed in old alluvial deposits. The parent materials are derived from acid sedimentary rocks, or from acid or some intermediate igneous rocks. The profile is normally very acid throughout the control section but, outside the Area, some soils developed over calcareous shales have been included in the Group and these have a slightly alkaline reaction at depth.

The profile has an A1–B–C or A1–A2–B–C horizonation. The particle-size class is loam, silt or clay (sands being excluded). There is normally more clay in the B than the A2, but the clay increase with depth may not be marked. In shallow profiles and in some loams and heavy clays the clay percentage shows little contrast in subsoil horizons. The texture profile may therefore be uniform, gradational or contrasting, although contrasting texture profiles, where the clay increase in the B is both marked and abrupt, have not been recorded on the present study. The clay increase within 30 cms in profiles examined from the Area gives maximum B:A2 ratios of 1.1–1.4, the majority being less than 1.3. Many profiles grade to lithosolic material within 1 metre of the surface, and others are underlain by thinly bedded parent materials of varied texture. Texture comparisons between the B and C horizons are therefore difficult. In general, however, the C has a clay content similar to or slightly higher than that of the B. A slight 'clay bulge' may be present in some deep loam profiles. Where analyses suggest this in silts and clays, however, the lower clay figures in the C probably result from the break-down of rock fragments during sample preparation and are not supported by field observations.

The colour class is yellow or red. The value/chroma rating is 5, either in the B or throughout the control section. The value/chroma rating of the A2 horizon may be 3 or 4 but soils with pronounced bleached or albic A2 horizons within this Great Soil Group were not recorded in the Area and appear to be rare in Sarawak as a whole. The profile normally comprises a brownish yellow A2 over a reddish yellow or strong brown B. There may, however, be little or no colour contrast between these horizons. The B may or may not be redder than the C.

Except in shallow or coarse-textured profiles, where no definite trend may be evident, there is more iron in the B than the A2 and molar silica:sesquioxide ratios decrease with depth in the control section. The trends are not strongly marked in many profiles, however. The A2:B

iron contrast may be slight, or the relative iron peak may be confined to a subhorizon of the B. The Si:Al ratio is more than 2 in most profiles over acid sedimentary rocks but lower in some minor soils over igneous or metamorphic materials.

The solum may be friable or firm. Subsoil structure is massive to weakly coarse or medium blocky. In silt and clay profiles there is commonly a friable massive A2 over a firm and weakly blocky B. Loam profiles may be friable throughout.

Soils over shales may have a high silt content, which is not found in profiles over sandstone. Silt:clay ratios therefore vary considerably. Kaolinite is the main clay mineral in some profiles but illite and vermiculite are commonly more important. The clays commonly have a CEC of 5–25 me/100 g in subsoil horizons, although some soils fall outside this range. Profile variability in these respects largely reflects the variety of parent materials involved.

Where undisturbed, the A1 horizon is well-defined but thin. In all profiles analysed from this Group the topsoils meet the criteria of an ochric epipedom in the USDA taxonomy (USDA, 1975). C:N ratios vary widely in the A1 horizon of soils examined (which largely have a cultivation history) but are below 10 in all subsoil horizons where base saturation is also invariably below 50 per cent and generally below 20 per cent.

A number of features which have been considered typical for soils in this Group in other regions (Chapter 11) are generally lacking here. Most soils do not have an albic horizon, a well-developed textural B or strong B structure, as has been noted above. A C horizon comprising deeply-weathered material with prominent red, grey and yellow reticulate mottling has also been associated with the Group. C horizons approaching this description occur under some profiles developed over shales or mudstones but this is only one of a number of C horizon forms in Red-Yellow Podzolic Soils recorded in the Area. The textural B horizon may or may not qualify for an argillic horizon (USDA, 1975).

Within the Area, soils in this Group have been recorded over shales, mudstones, sandstones and interbedded sedimentaries, over reworked material from these rocks now capping some high-level terraces, and very locally over granite, granodiorite, rhyolite and acid metamorphic rocks. At a Family level (Fig. 17) an initial distinction is made between soils over acid igneous and metamorphic rocks and those developed from sedimentary materials. Within the Area the former can be isolated through association with specific landforms. More direct parameters are required but must be established in other areas where such materials are more widespread. Total iron or criteria adopted from USDA mineralogy classes may prove appropriate. Terrace soils are combined with their residual associates at Family level due to the difficulty of establishing their origin in all cases. Soils over calcareous sedimentary rocks are separated to cater for certain soils confined to north Sarawak, which are not discussed further in this study. Families are further defined by particle-size class. Series separations are outlined in Figs. 18 – 20, the criteria used being largely field parameters. The CEC of the clay fraction is provisionally used to separate some soils common in the Area and farther north from otherwise similar soils recorded in west Sarawak. Levels are at present loosely defined as many of the west Sarawak soils require further study; the range of recorded exchange capacities in the Area's Podzolic Soils are tabulated in Chapter 8, (Table 8).

This Group covers the most widespread soils of the upland zone outside the steeply-dissected interior. They are thus the main soils in the zone where population and dry-land agriculture is concentrated and where most opportunities for upland agricultural development exist. In addition they have particular problems of classification and correlation. They therefore receive more attention than other Groups in the following Chapters.

Grey-White Podzolic Soils

Certain pallid upland soils for which there appear to be few close parallels in adjacent regions have been separated in this Group. They commonly occur in complex association with Red-Yellow Podzolic Soils and are developed over parent materials which have very low iron levels or which have lost iron at an early weathering stage. Within the Area these parent materials are exclusively sedimentary. The lack of iron gives grey to white subsoil colours. The value/chroma rating of the control section is 3. These soils are, except for colour, morphologically similar to the Red-Yellow Podzolic Soils to which they are related. Colour intergrades between these Groups occur, in which the upper subsoil has a value/chroma rating of 5 but the soil becomes progressively paler with depth.

The texture profile is commonly uniform or gradational in loam and silt Families (Bandang; Saratok) but clay profiles (Kerait Family) are

more usually contrasting (duplex) and may comprise a light grey loam over a light grey or pale yellow clay. Some faint subsoil mottling may be present in these soils but drainage is generally good to imperfect. As little indication of drainage condition is given by subsoil colour in these iron-deficient soils further criteria are required to distinguish them from Hydromorphic Upland Soils and the drainage limits are reinforced by site parameters. Grey-White Podzolic Soils are confined to sites with moderate or rapid external drainage; if the slope is less than 5° the site is normally a summit or upper slope facet of dissected terrain or is a footslope facet with a nearby drainage course. These soils are not found on upland flats with slow or intermittently ponded surface drainage.

Three Families are recognised in the Area and are separated on the particle-size class (Fig. 21). Further subdivision on texture is made at Series level. The colour range of the Group being narrow, no division on subsoil colour class is necessary. Nor are soils developed in old alluvial materials at present distinguished in the classification, as none have been encountered in the Area. Some soils on terrace sites in west Sarawak may qualify for inclusion in this Group but these require further study and, in the present classification framework, may be considered Hydromorphic Upland Soils. The Grey-White Podzolic Soils discussed in the present study are thus termed 'residual' although it needs to be emphasised that there is a colluvial element in the development of many of these soils. Except where colluvial soils are associated with colluvial fan landforms (as in some Lithosols) and can therefore be easily recognised as such, no distinction on this basis is attempted in the proposed classification.

Podzols

The Podzols recorded in the Area are characterised by a Bh horizon, below which a Bir horizon may or may not be developed. They are therefore Humus or Humus-Iron Podzols. They are developed in marine or riverine terrace sands and, less extensively, in residual situations over sandstones. The site is invariably flat to gently sloping. Internal drainage in most profiles is imperfect to poor but may be excessive in some very deep Podzols.

It is intended that the Group as conceived in the proposed classification should equate as far as possible with the USDA Spodosols (USDA, 1975). No data are available, however, on Fe and Al extractable by pyrophosphate and dithionite-citrate, which are used in defining the spodic B horizon. On the other hand, where Podzols are developed at all the humus B is normally pronounced (Colour Plates 10 – 12), both in the Area and elsewhere in Sarawak. In advance of more complete chemical data, therefore, a classification based on physical properties is practicable, and a particular emphasis on subsoil colour contrasts is convenient.

This Group comprises acid soils developed in siliceous parent materials and having a sand or coarse loam particle-size class in the control section. The subsoil has a strongly leached A2 horizon with a value/chroma rating of 3 (less commonly 2 or 4). This overlies a B horizon which either wholly or in its upper portion has a value/chroma rating of 1 and which has a higher carbon content than the overlying A2 horizon. Lower subhorizons of the B may have a value/chroma rating of 5 if there is significant iron accumulation. The normal profile is therefore a light grey or white sand (A2) over a black or very dark brown sand or sandy loam (Bh), which may be underlain by a yellow to strong brown subhorizon (an incipient or well-developed Bir) before the more pallid C horizon is reached. Where undisturbed the A1 horizon is thin but well-defined and is commonly capped by an A0 horizon of raw litter. The normal vegetation cover is Heath Forest.

Eroded Podzols occur and are included in the Group where the podzols morphology can be confidently recognised. The Group therefore includes profiles which lack an A horizon and where the Bh horizon is at the surface, provided the Bh horizon is either indurated or is thicker than 25 cms (i.e. where this horizon can be easily distinguished in the field from an A1 horizon). Very deep Podzols also occur, although these are rare in the Area. Where the Bh horizon is not present within 1 metre of the surface (and the control section thus entirely comprises bleached A2 sands) the profile is classed as a Regosol. If the presence of an underlying Bh is established, this feature is recognised at Series level.

The Bh is loose or friable in some profiles, but strongly indurated in others. A Family division is made on this basis. For classification purposes an indurated Bh horizon is considered to be one which cannot be sampled through to an underlying Bir or C horizon using an Edelman auger. The induration in thick Bh horizons may only affect part of the horizon and an upper subhorizon may be friable and augerable.

The distinction between residual and terrace Podzols (Fig. 22) is made at Series level, as in some situations this is difficult to establish. Other parameters serve to isolate particular profile

forms but only three Series (Miri, Buso and Silantek) are widespread.

Profiles in which the Bh is very weakly expressed and has a value/chroma rating of 2 (colour Plate 9) are considered as intergrades to other Groups (Grey-White Podzolic Soils; Regosols; Gley Soils).

The emphasis on subsoil colour contrasts to characterise this Group is over-simplistic but, as stated above, it is necessitated by the lack of analytical data available for these soils other than routine determinations. The proposed classification scheme has proved useable largely due to the narrow range of Podzol morphology encountered in Sarawak. It is accepted, however, that revised parameters giving greater emphasis to chemical properties will be required when these are known. A classification strategy based on that of USDA Spodosols may then prove appropriate.

Hydromorphic Upland Soils

This Group is introduced to separate certain soils classed as Gley Soils in 1966. These are related to the Grey Hydromorphic Soils of Dames (1962) and Dudal and Moormann (1964) but the correlation is not exact and an alternative Group name is adopted. The Hydromorphic Upland Soils comprise pallid or variegated loams to clays on upland flats. They have a uniform, gradational or contrasting texture profile and are commonly similar to Grey-White Podzolic Soils in profile morphology. They contrast with the latter in drainage condition. Soils in this Group are strongly to profusely mottled or (in west Sarawak) have a strongly gleyed horizon at depth within the control section. The Group also includes, however, some pallid iron-poor profiles which give little indication of internal drainage in subsoil colour and which are, on profile characteristics, difficult to distinguish from Grey-White Podzolic Soils. Emphasis is therefore placed on site properties. Soils in this Group are confined to upland flats with slow surface drainage. The landform may be gently undulating but slopes do not exceed 5°. Within the Area these soils are confined to two localities where the landform may relate to the Jerudong Cycle erosion level. In north Sarawak, such soils have also been reported on long dip-slopes.

The Hydromorphic Upland Soils are developed over acid sedimentary rocks. The upper part of the solum may, however, comprise old alluvial material in some profiles. Such morphology appears to be less important in this Area than in west Sarawak (Andriesse, 1972) where strongly bisequent profiles have been reported on terrace remnants. Classification divisions at Family and Series level on this basis are not proposed but further study of west Sarawak soils may justify such divisions.

Three Families are separated on particle-size class, these comprising loams, silts and clays (Fig. 23). Series divisions are made on the particle-size subclass and the degree of wetness as expressed in subsoil colour. Within the Area each Family is represented by one Series comprising soils with strongly mottled or variegated subsoils but which lack a completely gleyed horizon within the control section.

Gley Soils

The Great Soil Group of Gley Soils covers the Gley and Saline Gley Groups used in 1966. The only Saline Gley Soils in Sarawak are those developed in coastal marine alluvium. At the Group level it seems appropriate to combine them with other bottomland gley soils.

The Gley Soils comprise shallow to deep, poorly-darined or very poorly-drained soils developed in riverine, estuarine or marine alluvium on present valley bottoms, river floodplains and coastal or deltaic flats. They are subject to river or brackish-water flooding. They may or may not show evidence of active accretion. Subsoil textures range from sands to clays. There may be a surface peat or muck layer, provided this is not thicker than 25 cm.

There is a broad drainage range in the coastal plain which, near the main rivers, extends from well-drained soils on the river banks through to permanently saturated peats in the basin swamps. With this in mind, the Gley Soil Group is defined as comprising soils which are poorly-drained throughout the control section. Both strongly mottled and completely reduced soils are included but profiles showing better drainage characteristics in a part of the upper subsoil (i.e. having a value/chroma rating of the soil matrix higher than 3) are considered intergrades to Alluvial Soils. The majority of soils have sufficient free iron for the drainage class to be established on subsoil colour and on site. Where difficulties arise, as in some sands, the diagnostic colour parameters adopted by FAO (1974) in defining Gleysols are used as reference. Family separation is made on the particle-size class, loams and silts being combined. Potential acid-sulphate soils and saline soils are also isolated from those which lack these limitations. These parameters also serve to distinguish most soils developed in marine alluvium from riverine Gley Soils, although a further division on the type of parent material is necessary in the case of

non-saline sands. Figs. 24 and 25 summarise the divisions used.

Soils with potential acid-sulphate characteristics are considered to be those which in some horizon within 1 metre of the surface have (1) a dry pH (H_20) of less than 3.5; (2) at least 0.75 per cent total S; and (3) at least three times as much S as carbonate ($CaCO_3$ equivalent). Few data are available on sulphate and carbonate levels and the identification of these soils is normally made on pH combined with jarosite mottling or a mangrove vegetation cover. The classification parameters are adopted from those of the FAO 'sulfidic material and sulfuric horizon' (FAO, 1974: 31).

Salinity is classified on the electric conductivity of the saturation extract at 25°C. Saline soils are considered to be those with more than 4 mmhos conductivity throughout the control section. Nonsaline soils have a conductivity of less than 0.5 mmhos throughout the control section. Soils with intermediate salinity levels are classed as intergrades. This approach recognises the fact that salinity levels in the lower reaches of the major rivers and estuaries can vary widely in response to both heavy rainfall and the brackish water flooding which results from a high tidal range.

Ten Families are named (Fig. 24), eight of which are represented in the Area. Series have been established within them on the particle-size subclass, the type of parent material and the presence of a thin surface peat mantle (Figs. 24 and 25). Although 19 Series have been named, many are confined to west Sarawak, where the variety of parent materials is great. Within the Area, Rajang, Pendam, Tatau and Matu Series are important in coastal situations and Bijat, Sebandi and Pakan widespread in interior riverine floodplains.

Alluvial Soils

The Great Soil Group of Alluvial Soils covers mineral soils which are deeper than Lithosols, are well-drained to imperfectly drained, and are found on present valley bottoms, river floodplains or coastal beach zones. They are developed in riverine, estuarine or marine alluvium which ranges from sand to clay. The deposits are recent and most sites are intermittently flooded in most years. There need not, however, be evidence of rapid accretion in the profile, such as layered deposits, erratic carbon distribution or buried horizons, and such features are commonly not found in the Alluvial Soil of the Area. Associated with these soils are profiles on slightly raised sites, such as levees or coastal beach ridges, which are probably not affected by present flooding, and are not accreting. These soils may show a slight development of a textural or colour B horizon. Provided such horizonation is very weakly expressed it is convenient to include such subrecent soils in the Alluvial Soil Group, as they are closely comparable to recent soils in other respects and it is commonly difficult to distinguish such weak horizonation from depositional layering.

Internal drainage separates the Group from Gley Soils and from intergrades between them. Alluvial Soils have no mottles with a chroma of 2 or less within the surface 50 cms and the value/chroma rating of the matrix within the control section to a depth of 50 cms is 4, 5 or 6. These soils are therefore not Aquents or Aquepts in the USDA taxonomy. Pallid iron-poor sands are rare in this Group in Sarawak. Where they occur, their drainage status is judged on site, water-table levels and comparison with adjacent soils.

Family separation within the Group is based on parent material, origin and particle-size class (Fig. 26). Soils in the Area are developed exclusively in alluvium from acid sedimentary rocks or in quartzose beach sands. Elsewhere, particularly in west Sarawak, a number of Families and Series have been recognised for soils derived from igneous parent materials. These are not represented in the Area and are ignored in this study. Series separation within those Families developed in siliceous deposits is made on the particle-size subclass and the subsoil colour class. Of the seven Series named in Fig. 26 Seduau and Bemang are particularly common in riverine areas and Kabong is widespread in coastal beach zones.

Regosols

The local Group of Regosols is largely equivalent to USDA Quartzipsamments. They are upland, non-accreting soils which are deeper than Skeletal Soils and have a sand particle-size class. A weak textural or colour B horizon may be present in some profiles but is not sufficiently expressed to be considered in the classification. Two Families are recognised (Fig. 27) and are defined on the subsoil colour class. Peninjau Family is related to the Red-Yellow Podzolic Soils, Tika Family to the Grey-White Podzolic Soils. Series division is made between soils developed residually (mainly over quartzose sandstones) and those developed in sandy old alluvium on terrace sites. Peninjau, Sebaya, and Tika Series are therefore coarse-textured soils related to Nyalau, Sabangang and Saratok Series

respectively. No coarse-loam equivalent of the Bintulu Series (developed in alluvial terrace deposits) has been recorded. Very deep Podzols (Kilong Series) are included in Tika Family where the albic A2 horizon extends to beyond 1 metre depth. Such profiles have not been recorded in the Area but are locally present in north and west Sarawak.

Lithosols

Lithosols were called Skeletal Soils in 1966 and have been renamed to agree with systems used elsewhere in the region. They have either a lithic or paralithic horizon (as defined in the USDA taxonomy) within 25 cms of the surface or have more than 50 per cent rock fragments within this depth. Three Families are separated, within which Series are recognised on site and parent material characteristics (Fig. 28). Only Kapit and Lalis Series are widespread in the Area.

Organic Soils

The Group covers the Peat Soils of the 1966 classification and is renamed as some muck Series are now recognised. The Group comprises swamp soils in which a surface mantle of organic materials more than 25 cms in thickness overlies the mineral substratum. Unless artificially drained they are permanently saturated. Organic materials are defined on loss on ignition (Dacknowski-Stokes, 1930), peats having more than 65 per cent loss on ignition, mucks 35–65 per cent. The majority of Organic Soils in Sarawak are derived from swamp forest detritus and comprise peats with more than 90 per cent loss on ignition.

The depth limit of 25 cms allows continuity with the 1966 system (where a 10-inch limit was used) but does not follow the usage of other classifications, which are quite unstandardised. A limit of 30 cms is used by Dudal and Moormann (1964), 50 cms in Indonesia (Dudal and Soepraptohardjo, 1957; Soepraptohardjo, 1976), and 40–60 cms in the USDA taxonomy (USDA, 1975) by FAO (FAO, 1974) and in Sabah (LRD, 1975, following FAO). A deep limit to organic phases of mineral soils may be justified in areas where the organic mantle can be expected to disappear quickly following drainage and mechanical cultivation. The majority of organic soils in Sarawak, however, are close to sea-level and most tracts to which drainage can be applied lie between the 'sponge' of a swamp dome and a strongly tidal river. Efficient deep drainage is difficult to apply. High rainfall also reduces drainage scheme efficiency, both directly and by encouraging rapid regrowth following forest clearance and thus sustaining a microenvironment which limits oxidation. The woody peats include complete tree trunks and there is limited scope for mechanical cultivation methods. For various reasons, therefore, a shallow organic mantle can be expected to persist longer as a feature of the profile in this environment than in some other regions, and it deserves greater emphasis in a local classifcation.

Peats and mucks are considered together at Family level where a primary division is made between shallow and deep peats, (Fig. 29). Shallow peats are divided at Series level on the particle-size class of the mineral substratum (to a depth of 1.25 metres) and other parameters. A division is made between 'residual' and 'alluvial' peats to accommodate certain soils developed in organic beach deposits in the Tanjong Sirik area (Mahat and Luk Series).

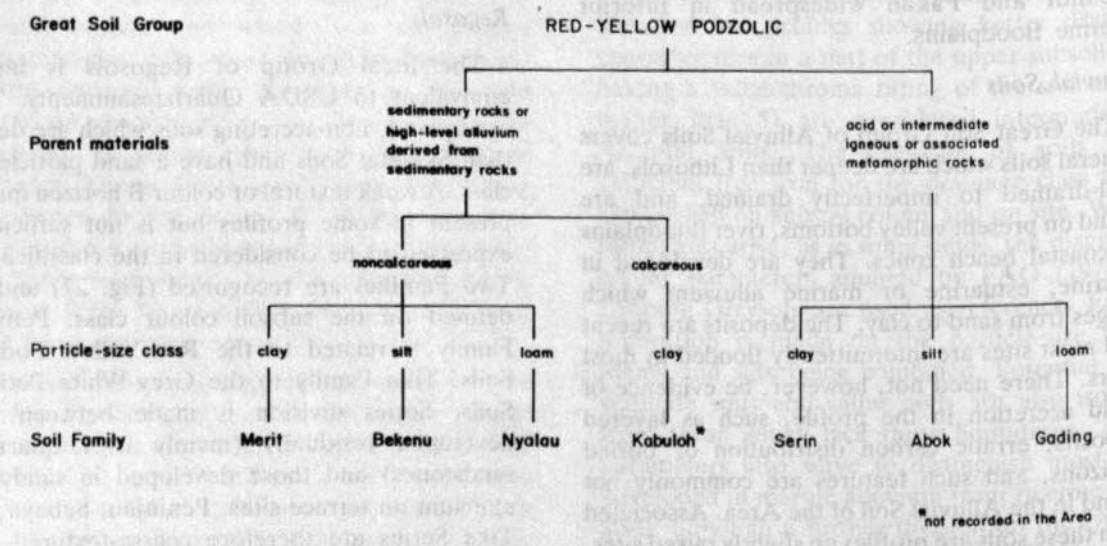


Fig. 17 Family separation in Red-Yellow Podzolic Soils

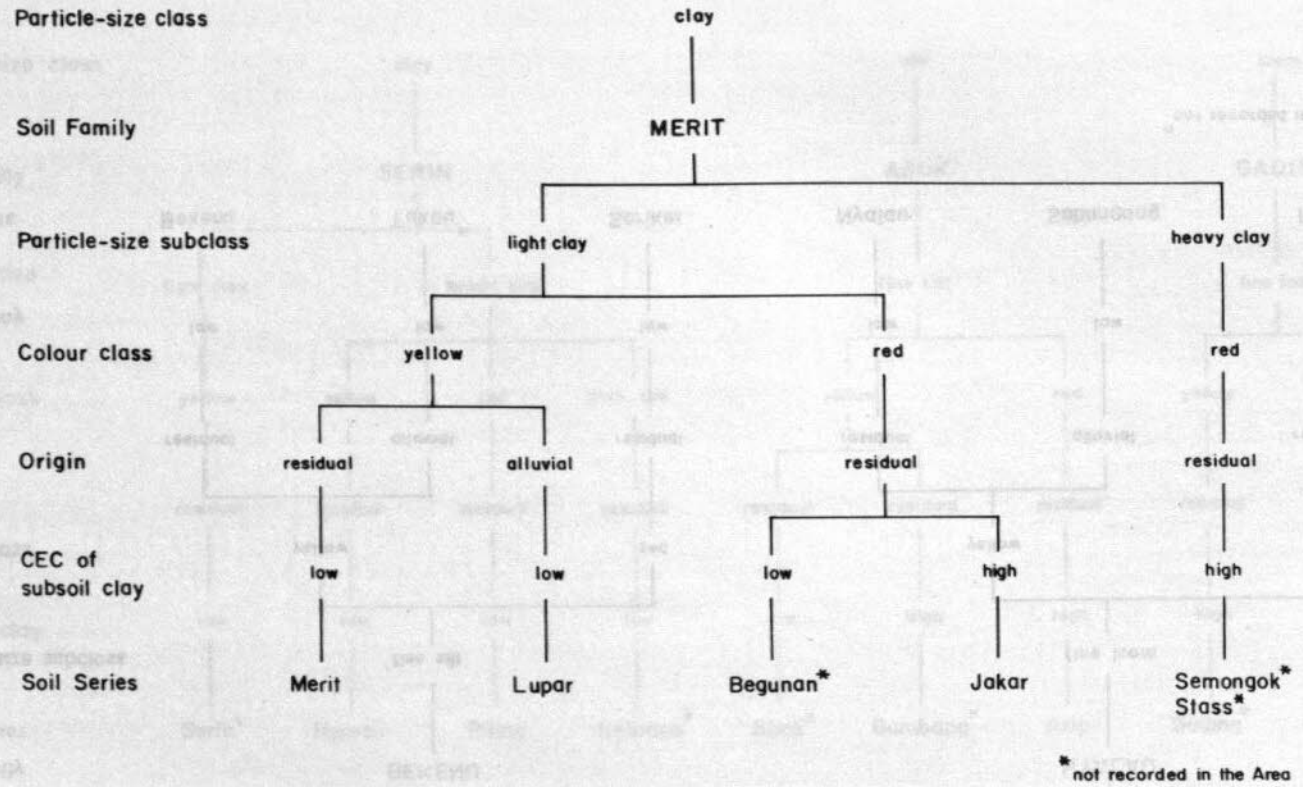


Fig. 18 Series separation within Merit Family

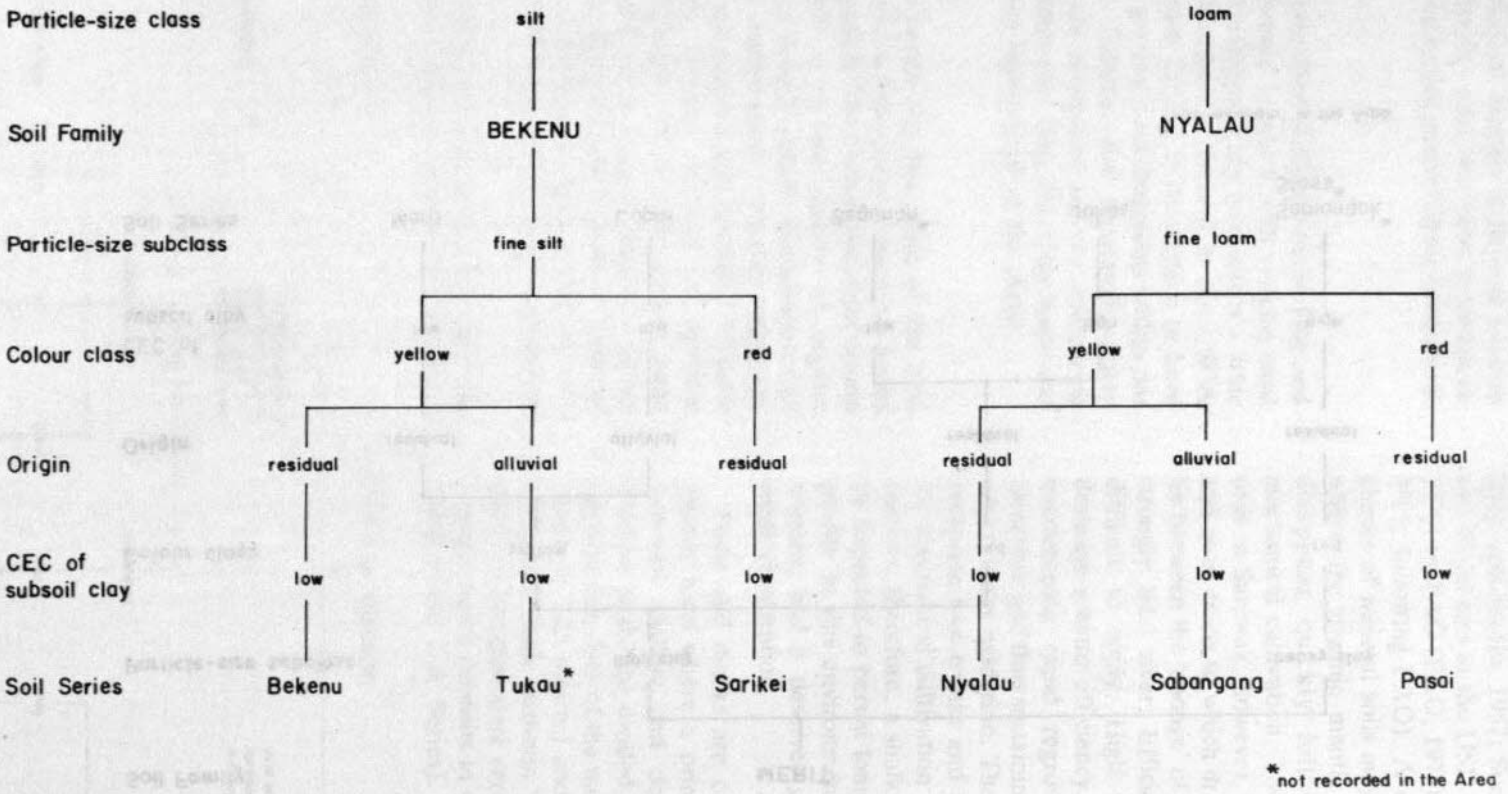


Fig. 19 Series separation within Bekenu and Nyalau Families

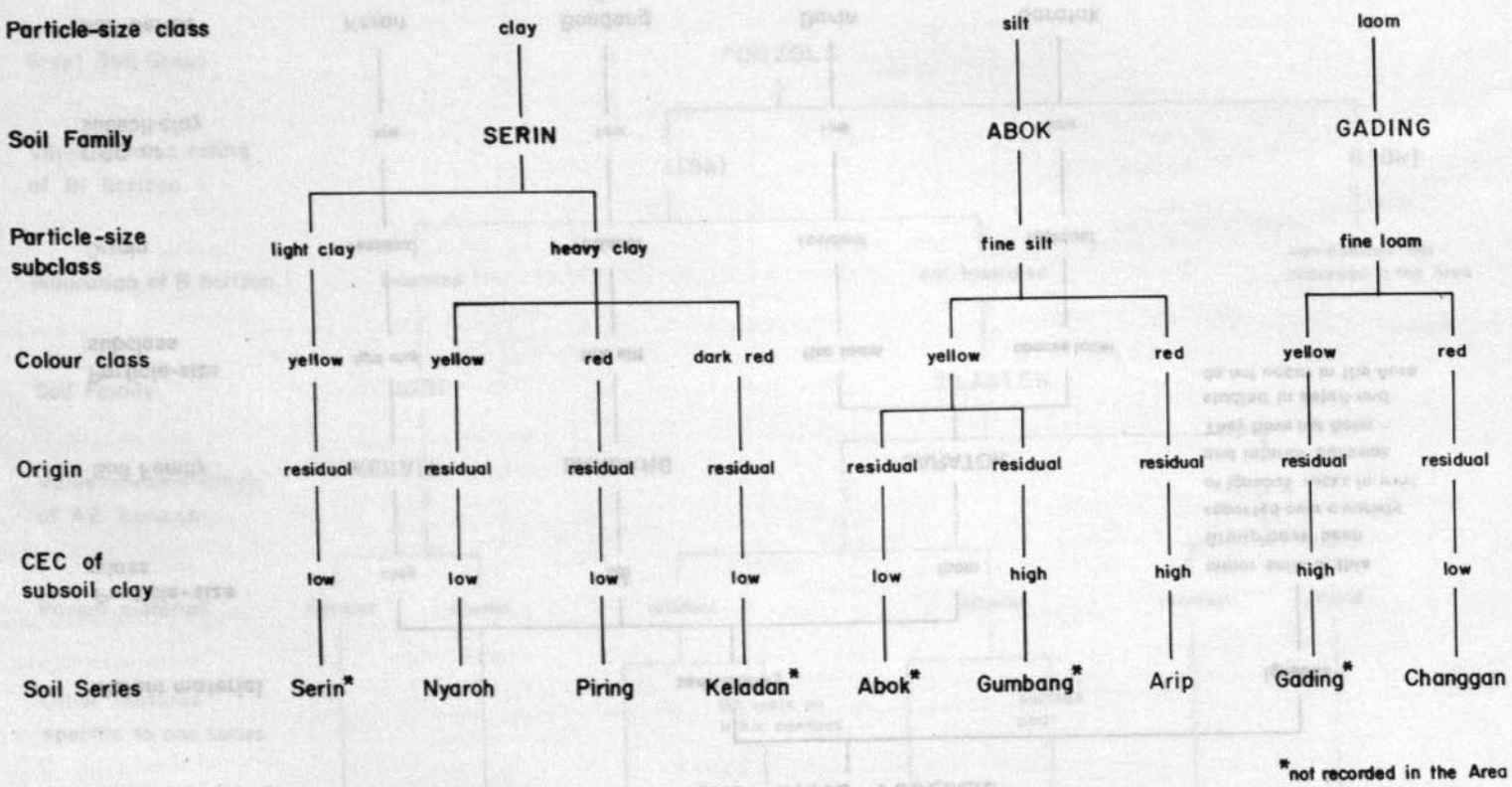


Fig. 20 Series separation within Serin, Abok and Gading Families

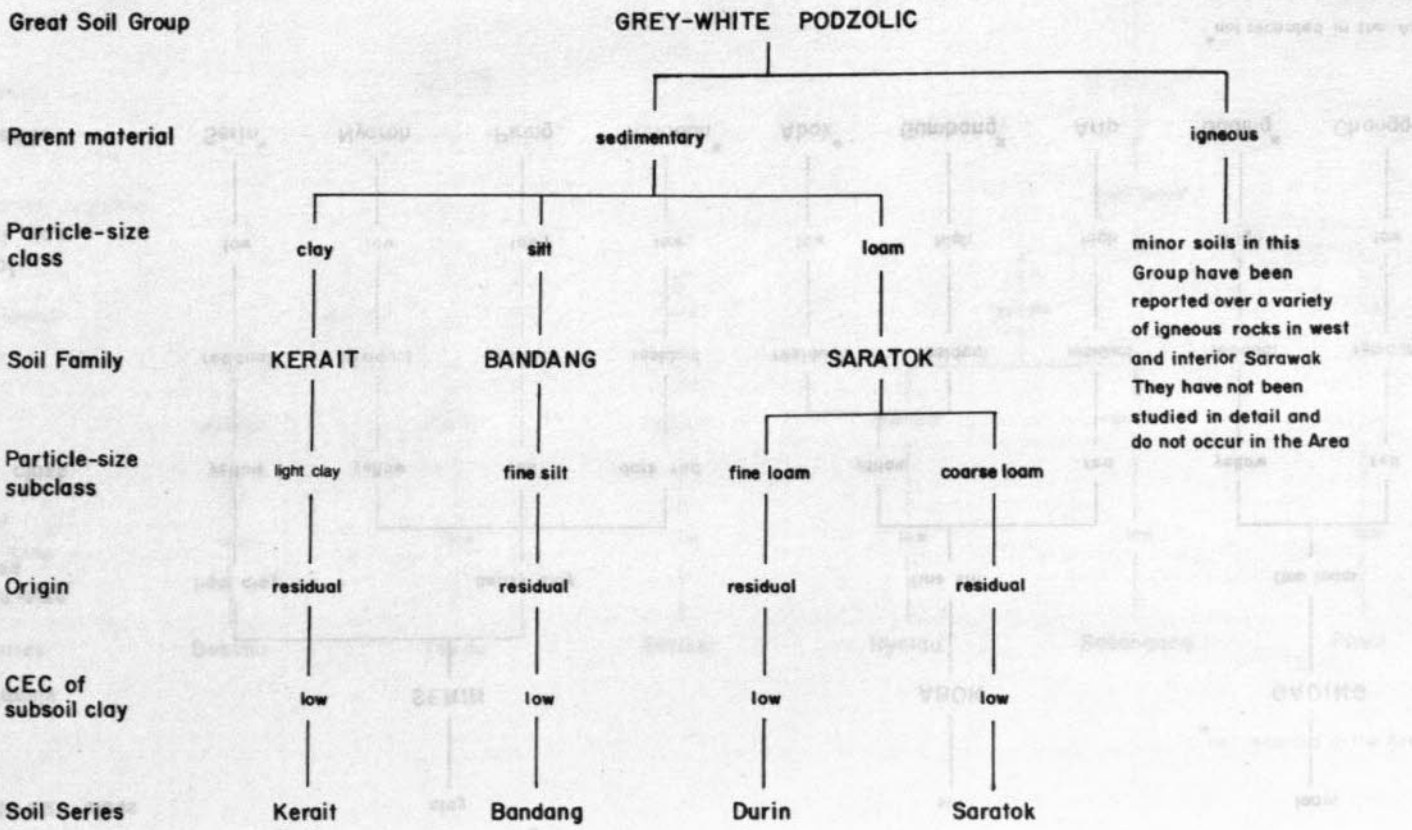


Fig. 21 Family and Series separation in the Grey-White Podzolic Soils

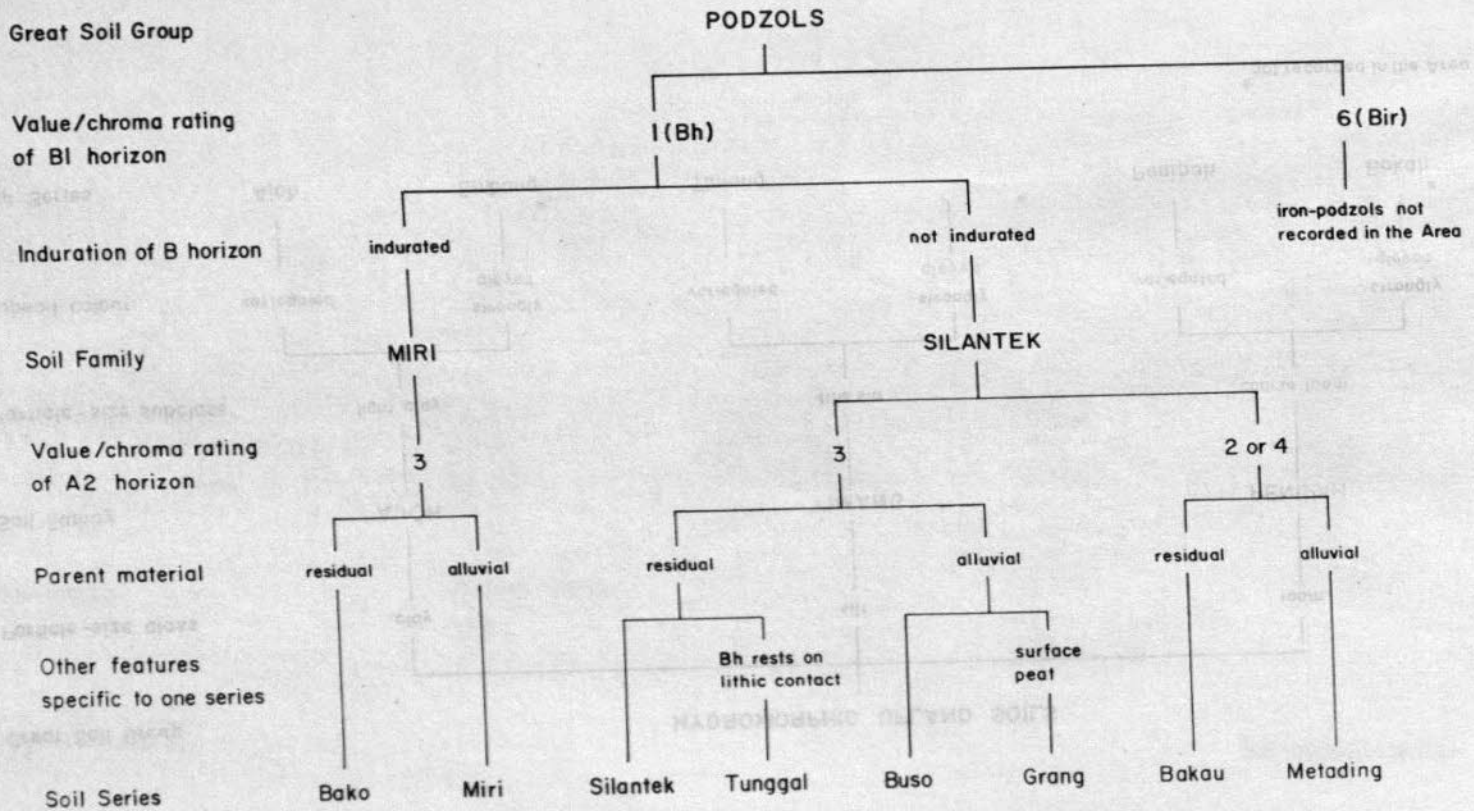


Fig. 22 Family and Series separation in the Podzols

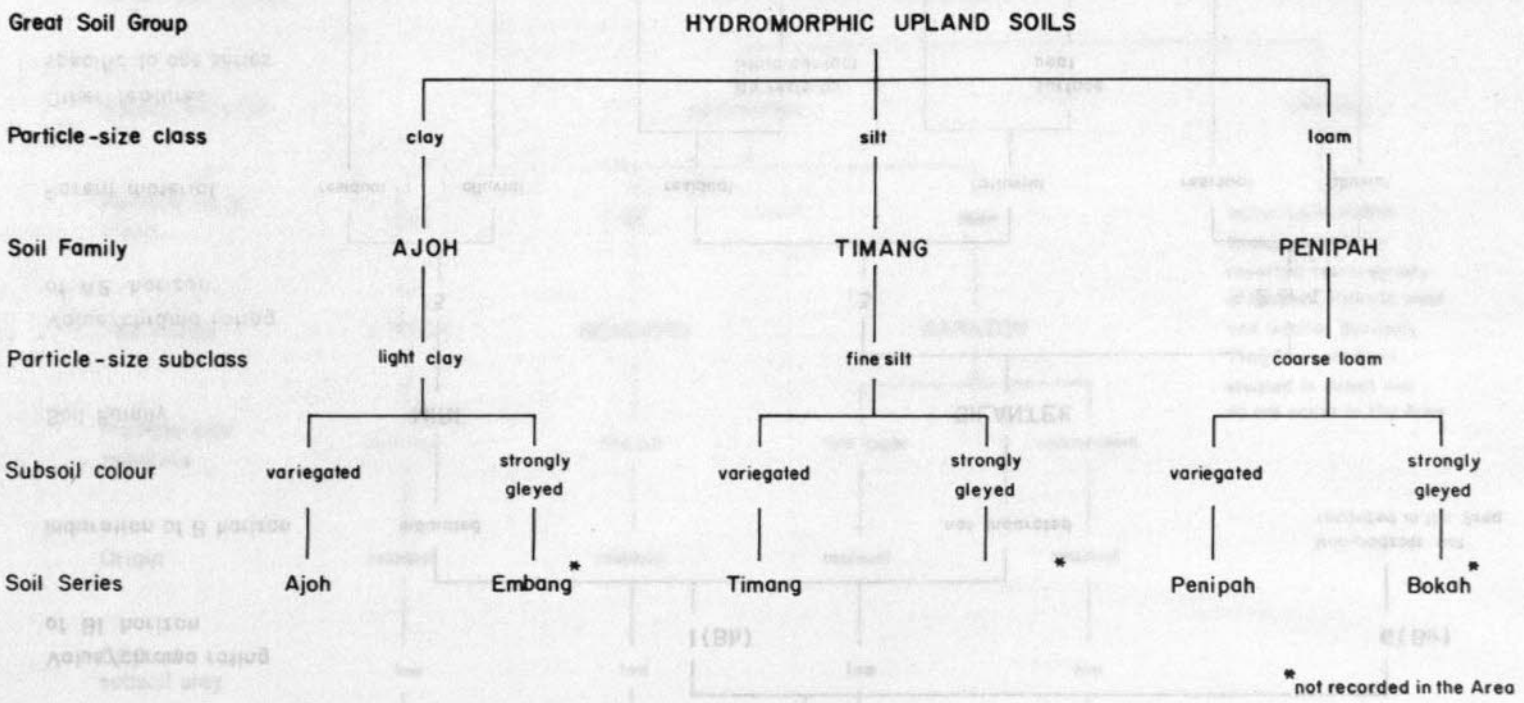


Fig. 23 Family and Series separation in the Hydromorphic Upland Soils

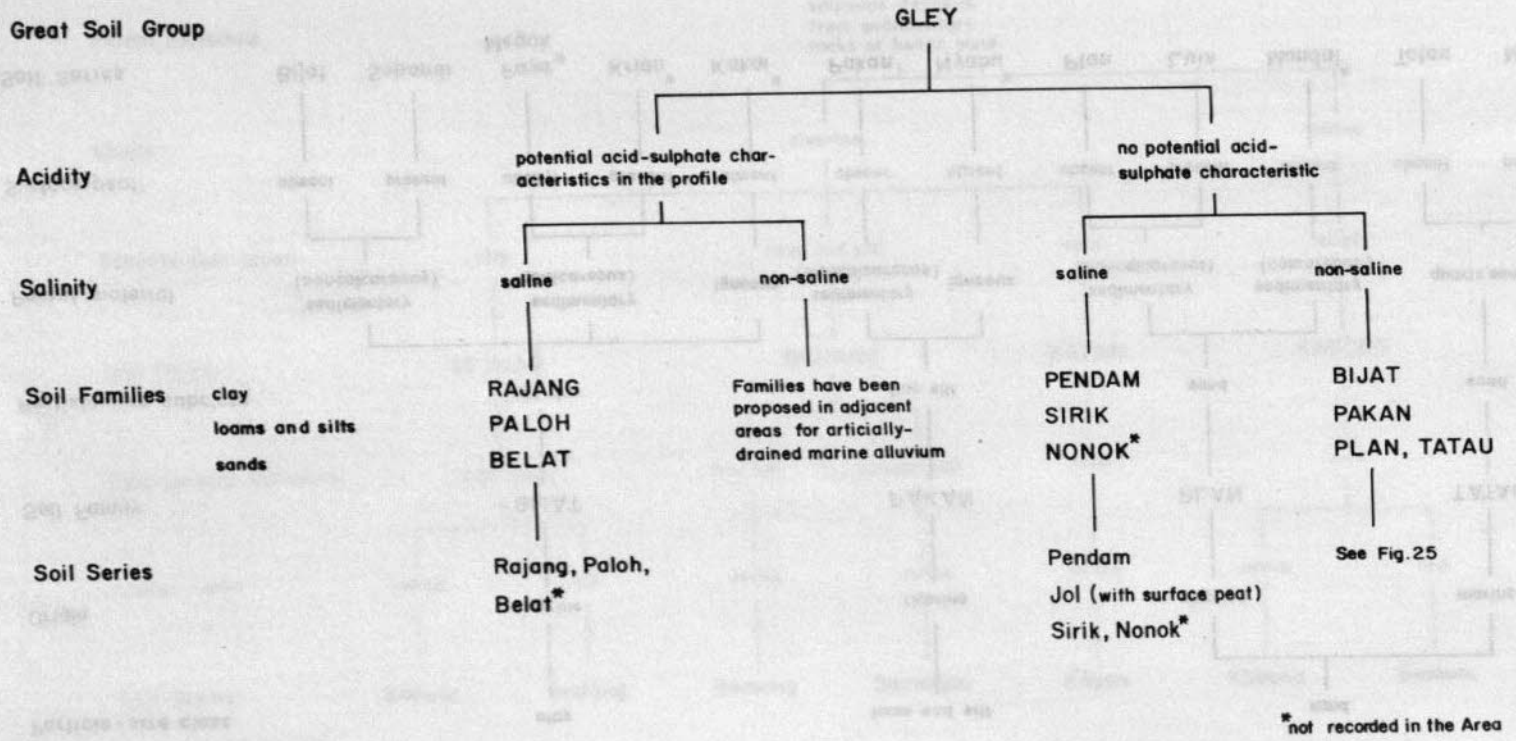


Fig. 24 Family separation in the Gley Soils

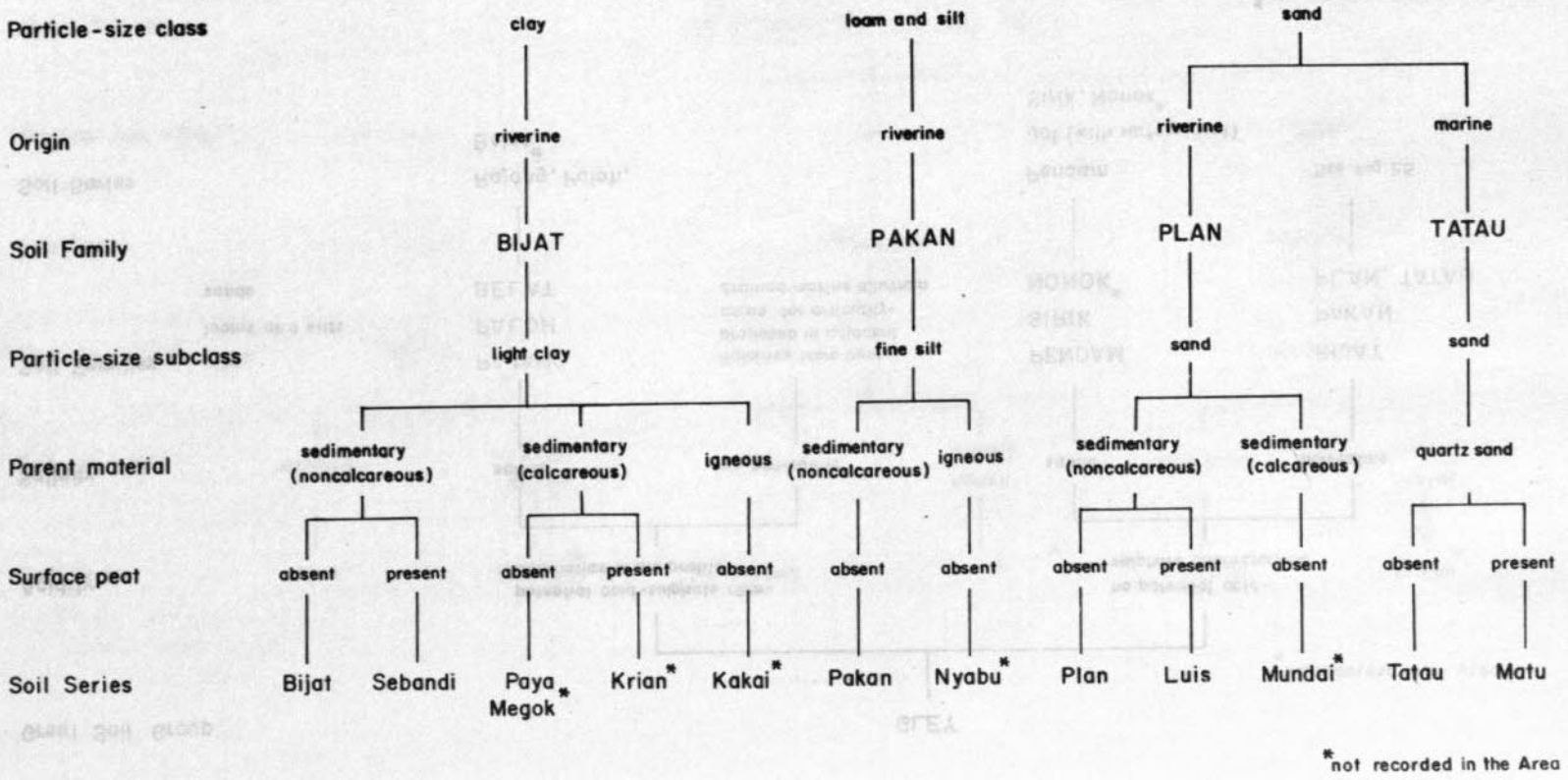
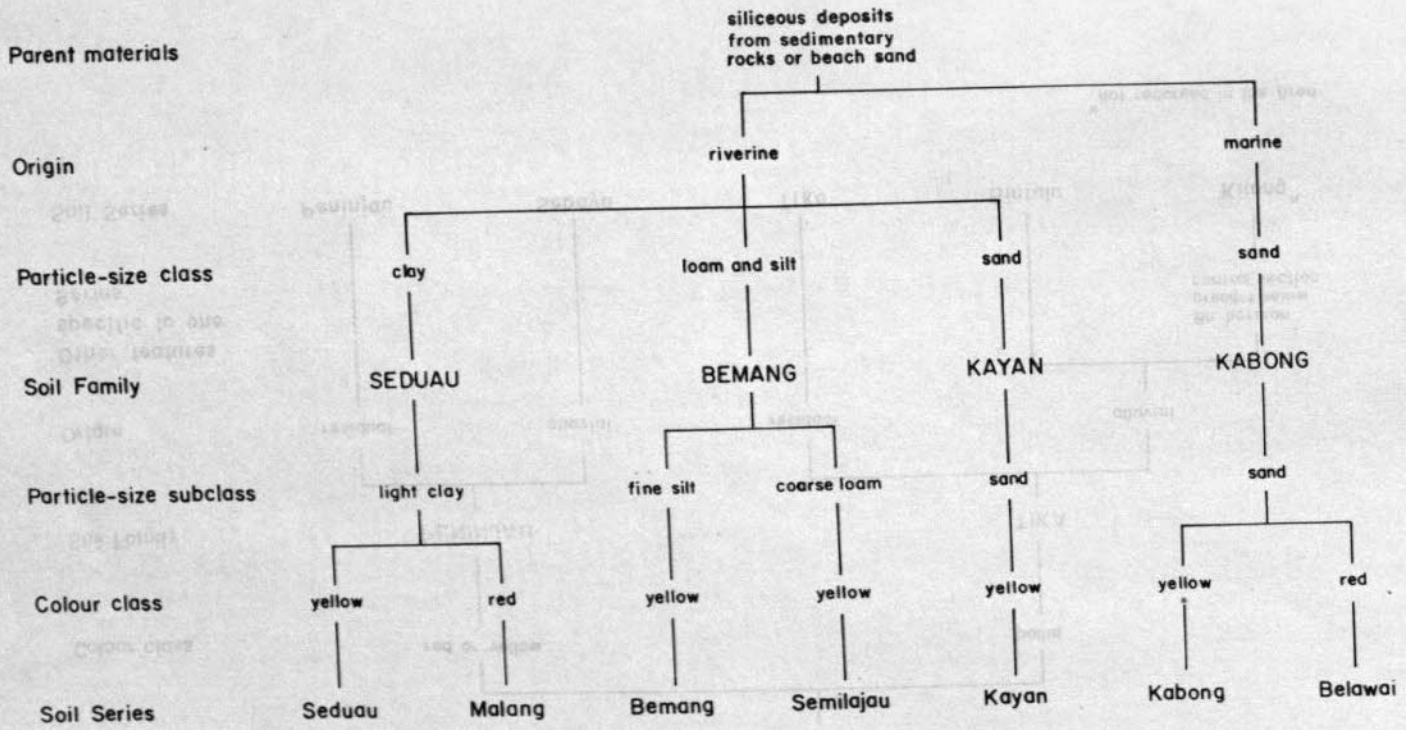


Fig. 25 Family and Series separation in non-saline Gley Soils which lack potential acid-sulphate characteristics



Equivalent Families (Terbat, Ramun, Siar and Sematan) are derived partly from igneous parent materials. They are found elsewhere in the State but have not been recorded in the Area

Fig. 26 Family and Series separation in the Alluvial Soils present in the Area

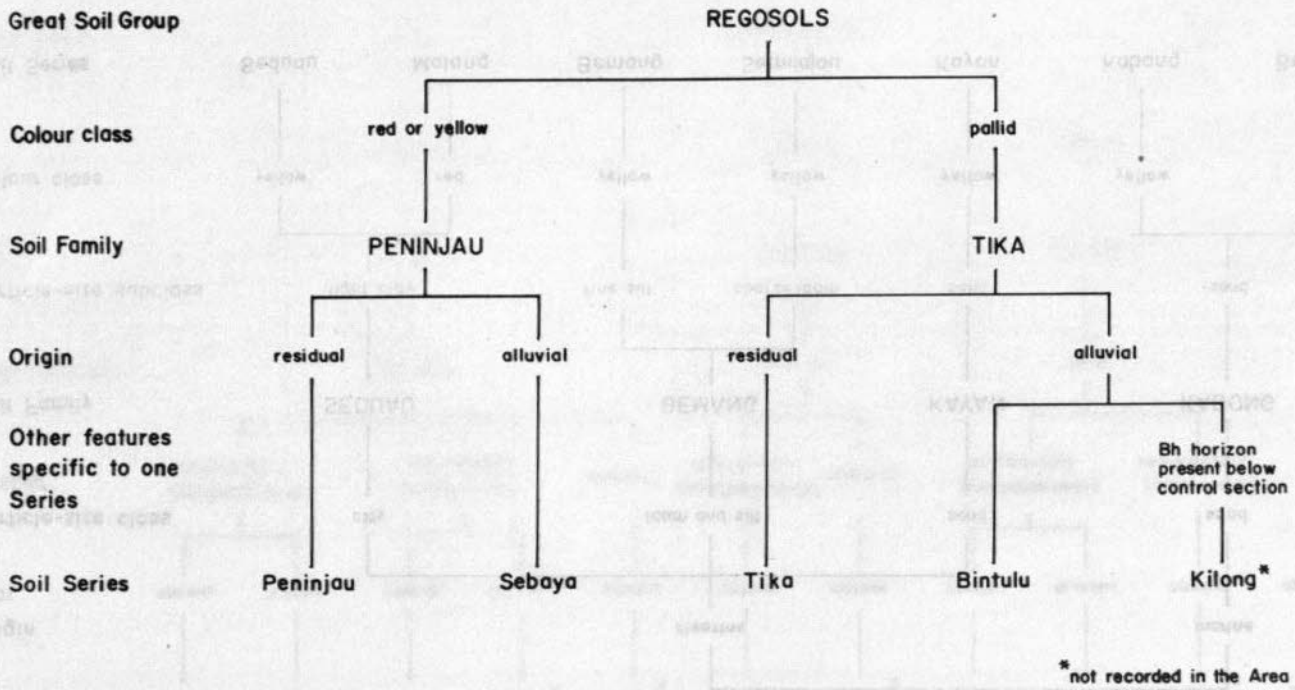


Fig. 27 Family and Series separation in the Regosols

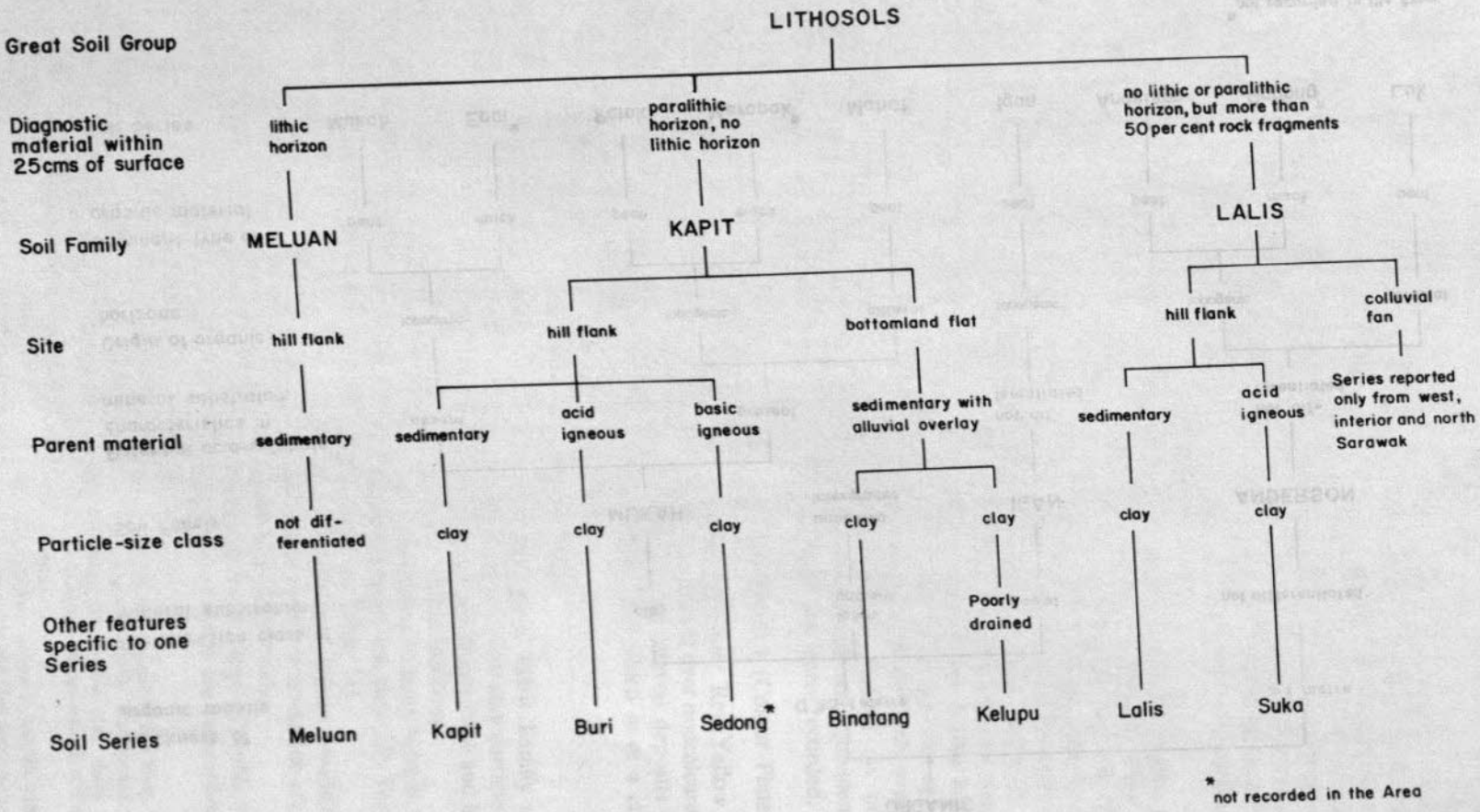


Fig. 28 Family and Series separation in the Lithosols

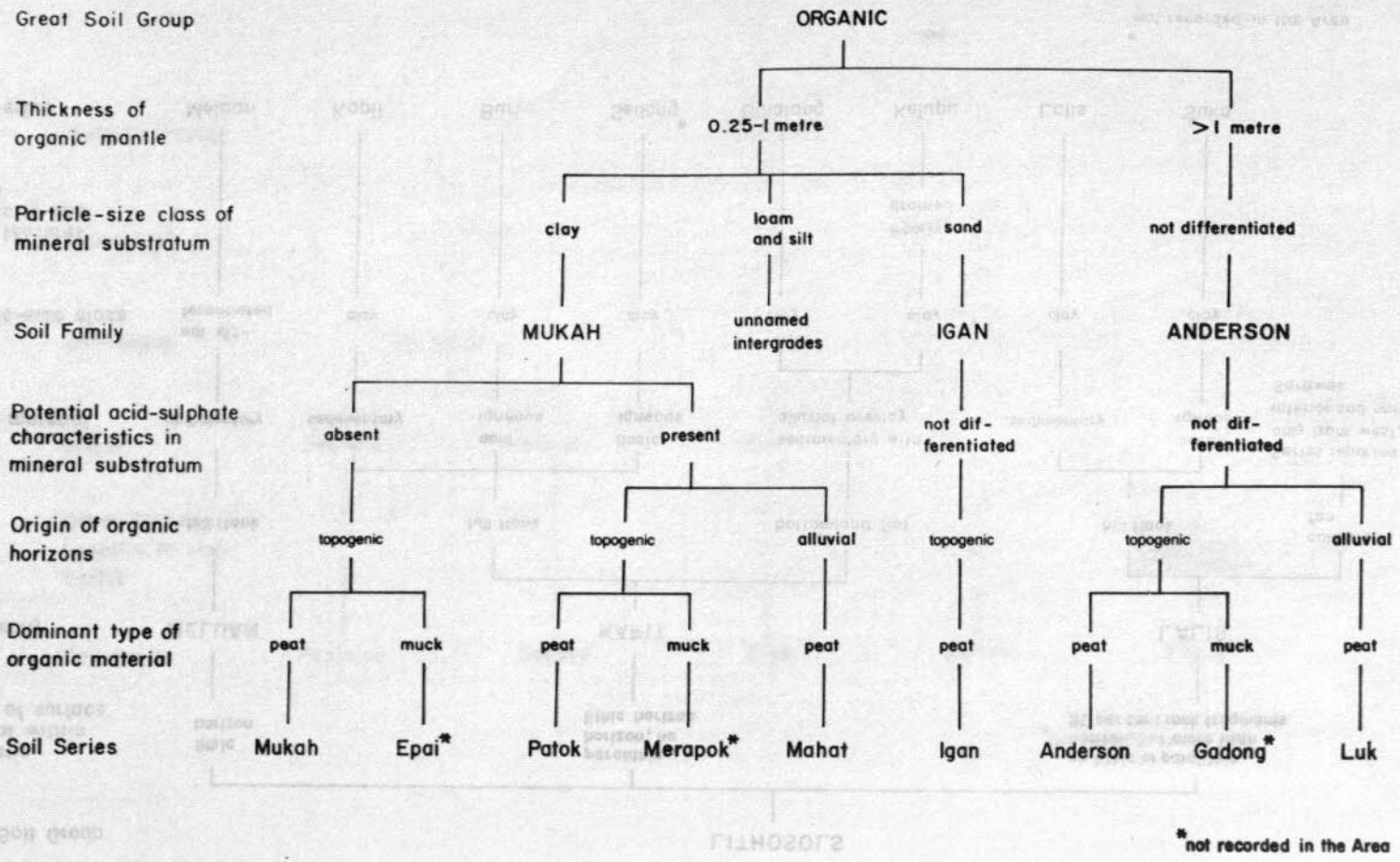


Fig. 29 Family and Series separation in lowland Organic Soils

CHAPTER 8

SOIL FAMILIES AND SERIES

Soil Families and Series which have been recorded in the Area are described in this Chapter. Some reference is made to soils confined to other areas (particularly west Sarawak) where these have been considered in decisions on parameters used in the proposed classification. To avoid repetition, only key Series are described in detail, others being discussed more broadly in relation to them. The Families and Series are discussed in order of Great Soil Groups. The latter are defined in Chapter 7 and these definitions are not repeated.

Red-Yellow Podzolic Soils

Families and Series are separated on parent materials, texture, colour and CEC (Fig. 17-20). A primary division is made between Families developed over acid or intermediate igneous rocks (and their metamorphic associates) and those developed over sedimentary rocks or old alluvium derived from such material. In the 1966 classification this division was attempted on the level of 'Group III' elements extractable in concentrated HCl, it being assumed that these were always higher in soils over igneous than those over sedimentary rocks. This has been abandoned as some sedimentary rocks have very high aluminium levels. Although deep weathering makes identification of parent materials difficult in some situations, igneous rocks can normally be isolated by associations with specific landforms and on available geological data. The differentiation between residual sedimentary soils and those developed in old terrace alluvium can also be difficult as parent materials may be similar and both may now mantle dissected hill land. This distinction is therefore made at Series level and classification confined to the Family where the form of origin is uncertain.

Colour classes are identified within each Family (yellow, red and, in one instance, dark red). In Families with a yellow subsoil colour class both uniformly-coloured profiles and profiles which become redder with depth are found. Series distinction between these forms was considered but was abandoned. The significance of colour in well-drained soils at the lower levels of the system is uncertain and it was considered that this feature was already sufficiently emphasised in the classification. Furthermore, many profiles with uniformly-coloured subsoils are merely deep soils with a weak 'colour B' at 1-2 metres (i.e. below the diagnostic control section).

There is a broad range of subsoil CEC, due to the variety of clay mineralogy, degree of crystallinity and amount of amorphous materials. A very provisional division is made between Series with 'high' CEC figures, these having at least 24 me/100 g clay in all subsoil horizons with low organic matter levels, and Series with 'low' CEC, which do not meet this requirement. (Differentiation of Jakar and Begunan Series is discussed under the former). The majority of soils in the Area have low CEC levels. More comprehensive characterisation of Series on chemical parameters is required but cannot be justified on available data.

All Families established within the Group are at least locally represented in the Area with the exception of Kabuloh (Fig. 17). This appears to be confined to north Sarawak, is developed over calcareous materials and has a pH (H_2O) of 6.0 or more in some horizon below 75 cms depth or immediately above a lithic or paralithic contact, whichever is shallower. It also has a base saturation of at least 35 per cent throughout the control section. Equivalent clay soils over noncalcareous materials (Merit Family) do not meet these criteria. Loam and silt equivalents to Kabuloh Family have not been recorded.

Merit Family (Colour Plates 2 and 3)

Family definition: Red-Yellow Podzolic Soils which are residual over noncalcareous sedimentary rocks or old alluvial deposits derived mainly from them, and which have a clay particle-size class.

Merit Series

Series definition: Merit Family soils which are residual, have a light clay particle-size class, have a yellow subsoil colour class and have a low CEC in most subsoil horizons.

Site: Undulating to steep terrain; all slope facets; slopes normally less than 25°; Terrain Classes 3-6 (defined in Table 11).

Parent materials: Shales, mudstones, siltstones. Some thin bands of sandstone are also possible in interbedded materials.

Profile form: A range of profile forms have been recorded, of which the commonest in the Area is as follows:

A1 — Dark brown loam to clay loam. Very weak granular structure. Friable. Well-rooted. (Less than 10 cms.)

A2 — Brownish yellow clay loam. Massive to weak subangular blocky structure. Friable to firm. (10-30 cms.)

B — Brownish yellow to reddish yellow clay. Massive to weak subangular blocky structure. Firm to very firm. (10-60 cms.)

B3/C — Either hard weathered shale (dusky red, dark grey or pallid) fragmented in a clay matrix or pallid clays

with yellow and red mottling and/or residual rock structure.

A stoneline of iron-enriched rock fragments may overlie the C horizon but, if present, is normally thin. The stoneline may comprise quartz gravel in areas where quartz stringers are common in the parent shales. Profiles are dominantly moderately shallow to moderately deep. The clay increase with depth may be negligible and some profiles have clay textures throughout. Most profiles become firmer in the more clayey B horizon but a minority are friable throughout the control section.

Chemical and mineralogical data: The soils are strongly to extremely acid (Table 8) and a pH of more than 5.4 has not been recorded in the Area. Subsoil CEC is low but variable. Base saturation is less than 20 per cent. Both total P and extractable Ca are low but there are commonly moderate to high levels of extractable Mg. Extractable K is variable, low levels being associated with dominantly kaolinitic clays, high levels with illite and vermiculite. Total iron (4-15 per cent) tends to increase with depth and the A2/B iron contrast is commonly more marked in profiles with colour B horizons, although there is no close correlation between colour and iron levels. Water-dispersable clay is high in the A and very low in the B. Clay mineralogy data are available for Profile 1 and for a few profiles from adjacent areas. Illite and vermiculite are dominant in most soils examined but kaolinite is also present and in some profiles is reported to be the main constituent.

Distribution: Merit Series is dominant or important in Mapping Units 8-12 and in the steeper country of Unit 5. It is also a minor component in many other upland associations. Merit Series is probably the most wide-spread upland soil in the State, outside the steep-land zone in which Skeletal Soils are dominant.

Associated soils: In areas entirely underlain by argillaceous rocks Merit is dominant or is found associated with Jakar Series or, if iron-poor shales are locally present, with Kerait. On steeply-sloping terrain and on some ridge-line tracts elsewhere, Merit grades to shallower Kapit and Lalis Series. Where mixed sedimentary lithology is found Merit is commonly in complex with a variety of Series in the Red-Yellow and Grey-White Podzolic Group. In Unit 16 it is associated with Hydromorphic Upland Soils.

Related Series: Jakar Series has a red subsoil colour class. Soils in the Kabuloh Family are developed over calcareous parent materials. Lupar Series is developed in old alluvium. Other Red-Yellow Podzolic Soils over sedimentary rocks have a coarser particle-size class. Equivalent soils in the Grey-White Podzolic Soils are in Kerait Family and there is provision in the classification for colour intergrades between Merit and Kerait.

Lupar Series

Series definition: Merit Family soils which meet the definition of Merit Series in all respects other than parent materials. Lupar Series is developed in old riverine alluvium derived mainly from sedimentary rocks.

Description: Lupar Series has the profile form of Merit Series except that a colour B is rarely seen and a stoneline, if present, is composed of water-worn gravels. It is this feature which identifies the Series and where a stoneline is lacking or is below auger depth Lupar and Merit can generally not be distinguished. The alluvial deposit rarely occupies a preserved terrace landform and commonly comprised a patchy capping mantling dissected hills near major rivers. Younger terrace clays on terrace remnants a few metres above present floodplain level are noted in a few localities. These are included in the Series at present although subsoil colours are generally a uniform yellowish brown with profuse very fine pale and strong brown mottles. The few analyses from this Series suggest that it is comparable to Merit Series in all major respects, reflecting its development in very similar materials. Lupar Series is particularly important in Soil Association 24 (see also Fig. 36).

Jakar Series

Series definition: Merit Family soils which are residual, have a light clay particle-size class and have a red subsoil colour class. CEC levels are not defined (as discussed below).

Site: Undulating to steeply sloping terrain, typically on rolling dissected hills; all slope facets; slopes normally less than 25°; Terrain Classes 3-6 (Class 2 in Soil Association 16).

Parent materials: Shales, mudstones, siltstones.

Profile form: The profile is moderately shallow at many sites and then has the following form:

A1— Brown to dark brown clay loam. Weak fine blocky structure. Friable. Well-rooted. (Less than 10 cms.)

A2— Strong brown clay loam to clay. Weak coarse or medium subangular blocky structure. Friable or firm. (10-30 cms.)

B — Reddish yellow to yellowish red clay or silty clay. Weak coarse or medium subangular blocky structure. Firm. (10-30 cms.)

C — Red and yellow variegated clay with abundant hard fragments of dark red weathered siltstone or related rocks.

A stoneline of iron-enriched weathered rock fragments may be present but is commonly lacking in shallow profiles. Profile 4 in Appendix IV is typical of the Series. Deep profiles are rare

within the Area. One deep form from the Mukah-Balingian hills is described in Appendix IV (Profile 5).

Chemical and mineralogical data: Jakar is, like Merit, strongly to extremely acid. Topsoil characteristics vary with cultivation history. Subsoil CEC ranges from less than 15 to almost 30 and, because of correlation difficulties with west Sarawak, has not been used as a parameter (see under 'Related Series'). Base saturation is less than 20 per cent except in some topsoil horizons. The soil is low in P and Ca, low to moderate in Mg and K. Data from one profile (4) suggests the clays are mainly illitic but clay mineralogy is likely to be as variable in these soils as in Merit Series. This is also suggested by the CEC range in subsoil samples.

Distribution: Jakar is dominant in Soil Association 9 and important in parts of Association 8. It sporadically occurs in a number of other upland Associations but is mainly important in the west between Saratok and Sarikei, particularly around Jakar.

Associated Soil: In areas where the Series is dominant and mainly comprises shallow or moderately shallow profiles it is commonly in complex with Kapit or Lalis Series. In areas with a deeper mantle it is associated with Merit. If mixed sedimentary rocks underlie the area a variety of other Red-Yellow Podzolic Soils are commonly present, Sarikei Series normally being important. In the Penipah area Jakar is locally associated with Hydromorphic Upland Soils.

Related Series: All other residual soils in the Group developed over sedimentary rocks and having a clay particle-size class have a yellow subsoil colour class, with one exception. This is Begunan Series, established in west Sarawak. It is possible that Begunan correlates with some Jakar profiles from the Area and a division between them may best be made on chemical parameters (including CEC). Unfortunately few analysis of Jakar Series have been undertaken and its range of chemical characteristics is not established, while in west Sarawak Begunan has been described in detail from only one profile. Until more data are available both names are retained in the proposed classification and, in order not to compromise further revisions of the classification, all red clay soils from sedimentary rocks are classed in Jakar within the Area and the CEC level for this Series is left undefined in Fig. 18.

The CEC parameter has been introduced as a definitive feature for Red-Yellow Podzolic Soils mainly with those soils derived from acid igneous rocks in mind. It has proved a useful parameter to distinguish Series recognised in the Area over these materials from similar soils in west Sarawak and has also been helpful in rationalising the classification of the west Sarawak soils to agree with that now proposed. The usefulness of subsoil CEC in characteristing soils of sedimentary rocks is less certain and its employment as a classification parameter will require review when more analytical data are available from a broader range of profiles.

Bekenu Family (Colour Plates 4)

Family definition: Red-Yellow Podzolic Soils which are residual over noncalcareous sedimentary rocks or old alluvial deposits derived mainly from them, and which have a silt particle-size class.

Bekenu and Sarikei Series

Series definition: Bekenu Family soils which are residual, have a fine silt particle-size subclass and have a low CEC in most subsoil horizons. The subsoil colour class of Bekenu Series is yellow and of Sarikei Series is red.

Site: Undulating to steep terrain; all slope facets; typically on slopes of 5-20°; Terrain Classes 3-6.

Parent materials: Sandy shales or, more normally, interbedded argillaceous sedimentary rocks and sandstones.

Profile form: A typical profile form for Bekenu Series is as follows:

A1— Brown to dark brown sandy loam or sandy clay loam. Structureless or weakly granular. Very friable. Well-rooted. (Less than 10 cms)

A2— Brownish yellow sandy clay loam. Massive or weak coarse or medium subangular blocky structure. Friable or firm. (20-50 cms)

B — Reddish yellow sandy clay loam or sandy clay. Structure as above. Firm (20-50 cms)

— A Stoneline of iron-enriched shale fragments in a matrix of the above material. (10-40 cms)

C — Mottled clays or loams from underlying interbedded and steeply inclined shales and sandstones.

The stoneline is normally prominent but is absent from some profiles. The colour B horizon described above may be absent and the subsoil may be uniformly brownish yellow. Most profiles are moderately deep to deep. The mixed nature of the underlying lithology is such that there is commonly a texture contrast between the B horizon and the C material immediately beneath it. Sarikei Series differs from Bekenu Series in having a red subsoil colour class but in other respects is comparable to Bekenu.

Chemical and mineralogical data: These Series are strongly to extremely acid, with a low CEC and low base saturation below the topsoil. Topsoil characteristics are highly variable as most areas of these soils which have been studied have

Colour Plate 1. *Lalis Series*. A Series in the Lalis Family of Lithosols developed over shales. This is a typical profile form in the Durin-Kelupu area, where it occurs on low ridge lines associated with Kapit, Merit and Jakar Series.

Colour Plate 2. *Jakar Series*. A Series in the Merit Family of Red-Yellow Podzolic Soils developed over shales. The profile illustrates the form common in the Penipah-Bedengan area. Farther west near Jakar and Sarikei shallower profiles are more common.

Colour Plate 3. *Merit Series*. A Series in the Merit Family of Red-Yellow Podzolic Soils developed over shales. The profile illustrated has a diffusely irregular boundary to the Colour B horizon. Profiles with more regular horizonation are also common.

Colour Plate 4. *Bekenu Series*. A Series in the Bekenu Family of Red-Yellow Podzolic Soils developed over mixed sedimentary lithology. A weak colour B horizon coincides with the pronounced stoneline which overlies weathered shales. The profile is from the Oya Road Agriculture Station and illustrates a form common along the Oya Road and elsewhere.


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a cultivation history. There are generally moderate levels of HCl-extractable Mg and K in profiles analysed but P is low and extractable Ca may only be present in trace amounts. Total iron may be less than 3 per cent in the A2 and as high as 11 per cent in the B in profiles where a colour B occurs, while many uniformly-coloured profiles have only a slight rise in iron content with depth. The correlation between iron and subsoil colour is not close, however. Clay mineralogy from one Bekenu profile report a mixture of illite and kaolinite.

Distribution: These soils are widespread in the upland zone wherever interbedded shales and sandstones outcrop. These are particularly important in Soil Association 10, 11, 13 and 14 in the Sarikei-Binatang area and in those uplands extending northeast from Sibu to the Balingian drainage basin.

Associated soils: Bekenu and Sarikei rarely occur as a uniform soil mantle and are usually found in complex with other Series in the Merit or Nyalau Families. They may also be associated with Grey–White Podzolic Soils.

Related Series: All other established Series within this Group are differentiated from Bekenu and Sarikei on parent material and particle-size class. No equivalent soils developed over old alluvial materials have been reported in the Area although terrace equivalents to Bekenu Series have been reported from north Sarawak (Tukau Series) and are likely to be locally present elsewhere.

NYALAU FAMILY (Colour Plates 5)

Family definition: Red-Yellow Podzolic Soils which are residual over noncalcareous sedimentary rocks or old alluvial deposits derived mainly from them, and which have a loam particle-size class.

Nyalau and Pasai Series

Series definition: Nyalau Family soils which are residual, have a fine loam particle-size subclass and have a low CEC in most subsoil horizons. The subsoil colour class of Nyalau Series is yellow and of Pasai Series is red.

Site: Undulating to hilly, all slope facets; typically on slopes of less than 25°; Terrain Classes 3-6.

Parent materials: Sandstones; interbedded sandstones and argillaceous rocks where the former are dominant.

Profile form: The commonest profile form of Nyalau Series lacks a colour B horizon, at least within control section depth, and has the following characteristics:

A1 — Brown to dark yellowish brown sandy loam or sandy clay loam. Structureless or weakly blocky. Friable. Well-rooted. (Less than 10 cms)

A2 — Yellowish brown sandy loam or sandy clay loam. Massive or weakly blocky. Friable. (20-50 cms)

B — Yellowish brown sandy clay loam. Weak coarse subangular blocky structure. Slightly firm. (50-100 cms)

B3/C — As above with scattered fragments of weathered sandstone or shale, or pallid patches of sandy loam from sandstone.

Many profiles are deep and some road-cutting exposures show a weak colour B (or C) at depths up to 3 metres. A stoneline may occur at the base of the solum but this is rare and, if present, is almost invariably thin. The less extensive Pasai Series contrasts with Nyalau only in subsoil colour. It is commonly strong brown or reddish yellow throughout and, like Nyalau Series, may or may not have a weak colour B expressed within 1 metre of the surface.

Chemical and mineralogical data: Most profiles are extremely acid. CEC varies greatly in the topsoil but is generally 10—20 me/100 g clay in subsoil horizons, and much lower in some profiles. Base saturation in the subsoil is normally below 20 per cent. These Series are low in total P, Ca and Mg. Extractable K varies from low to moderate. Total iron is 2-10 per cent, being somewhat higher in Pasai profiles analysed than in Nyalau. There is a slight increase in total iron with depth, whether or not a colour B is expressed. Clay mineralogy in dominantly kaolinite in the one profile for which data are available (Profile 10) and data from adjacent areas suggests that this is generally the case in these sandstone-derived soils.

Distribution: Nyalau Series is widespread in upland areas, particularly between Sarikei and Julau, between Sibu and the Oya River, and in the Mukah-Balingian hills. In some localities it is the dominant soil; more commonly it is found in complex with other Red-Yellow Podzolic Soils. Pasai Series is less extensive and is mainly important to the north of the Rajang River (including Oya Road Agricultural Station). Soil Association 11 covers areas in which Nyalau Series is particularly widespread but it is also important in a number of other upland associations. Pasai has been reported in Associations 11 and 13.

Associated soils: Where lithology is mixed Nyalau Family may occur in complex with soils of the Merit and Bekenu Families. They are locally associated with Grey-White Podzolic Soils and, on gently undulating terrain, with Podzols.

Related Series: Soils of Sabangang Series are developed in terrace alluvium. Other soils in the Group which are derived from noncalcareous sedimentary rocks have a finer particle-size class.

Sabangang Series

Series definition: Nyalau Family soils which meet the definition of Nyalau Series in all respects other than parent material. Sabangang Series is developed in old riverine alluvium derived mainly from sedimentary rocks.

Description: The profile form of Sabangang Series is similar to that of Nyalau, the subsoil comprising a friable brownish yellow sandy loam which may or may not show a weak colour B or some clay increase with depth. As in Lupar Series, a stoneline of water-worn pebbles may underlie the solum. Sabangang is an uncommon soil in the Area but was noted on the borders of some major river floodplains where, unlike Lupar Series, it commonly mantles low, well-preserved, subrecent terraces.

SERIN, ABOK AND GADING FAMILIES (Fig. 20)

Soils developed over acid igneous and related metamorphic rocks are confined to the northeast of the Area. Four Series have been recognised and are classified in three Families. In all cases data for these Series are mainly derived from one profile. These are described in Appendix IV (Profiles 23-26) and a summary of selected characteristics included in Table 8. Only a brief description of the profile form is therefore repeated below.

SERIN FAMILY

Family definition: Red-Yellow Podzolic Soils which are residual over acid or intermediate igneous or metamorphic rocks and which have a clay particle-size class.

Nyaroh and Piring Series

Series definition: Serin Family soils which have a heavy clay particle-size subclass and a low CEC in most subsoil horizon. Nyaroh has a yellow subsoil colour class while that of Piring is red.

Description: Piring Series is represented in Appendix IV by Profile 25, Nyaroh by Profile 26. Piring has been mapped in the rolling to steeply sloping ridge country of Bukit Piring (Soil Association 6) on ridge flanks of up to 25° slope and may extend to sleeper sites. Nyaroh was recorded on lower rolling terrain in the same locality where slopes are less than 20°. Parent materials are somewhat uncertain in both cases as saprolitic material was not reached in pitting. The site of Piring Series suggests its development over quartz biotite hornfels. That of Nyaroh has both rhyolite and carbonaceous shales outcropping nearby and, while parent materials are probably acid igneous, strongly metamorphosed sedimentary rocks are also a possibility. Both soils comprise heavy clays with little clay increase at depth. They are massive to weakly blocky. Piring is uniformly yellowish brown while Nyaroh is reddish yellow. The Piring profile described in Appendix IV has a weak colour B horizon and a thin stoneline but these do not occur at all sites and are not considered diagnostic. The profiles are strongly to extremely acid and have low CEC, base saturation and extractable P, Ca and Mg. Total K is also low in the Nyaroh profile analysed but somewhat higher in the Piring profile described. Clay minerals are reported to be kaolinite with some vermiculite and gibbsite in both cases. Nyaroh was recorded only in one locality mapped under Soil Association 7, where it is associated with Merit Series. Piring is confined to the Bukit Piring ridge (Soil Association 6) where it is in complex with Changgan Series and with Lithosols (Buri Series).

ABOK FAMILY

Family definition: Red-Yellow Podzolic Soils which are residual over acid or intermediate igneous or metamorphic rocks and which have a silt particle-size class.

Arip Series

Series definition: Abok Family soils which have a fine silt particle-size subclass, a red subsoil colour class, and a high CEC in most subsoil horizons.

Description: Arip Series if represented in Appendix IV by Profile 24. It has been noted only on the rhyolite ridge bounding the middle Arip valley to the south, occupying both hill flank and footslope sites with slopes of 5-30°. Parent materials are rhyolites or similar rocks. Below a thin topsoil a strong brown sandy clay loam grades to a massive to very weakly blocky sandy clay or clay at depth. Footslope profiles are partially colluvial and may have a thin stoneline of weathered rock fragments at the base of the solum. The profile is strongly to extremely acid. Subsoil CEC is above 30 me/100 g clay in most horizons. Base saturation is low, however, as is total P. There are moderate levels of extractable Ca, Mg and K. No data on clay mineralogy are available but a dominance of illite and vermiculite is suggested by the CEC levels. The Series is confined to Soil Association 7, where it grades on the steepest slope facets to Buri Series.

GADING FAMILY

Family definition: Red-Yellow Podzolic Soils which are residual over acid or intermediate igneous or metamorphic rocks and which have a loam particle-size class.

Changgan Series

Series definition: Gading Family soils which have a fine loam particle-size subclass, a red subsoil colour class, and a low CEC in most subsoil horizons.

Description: The Series is found over granite and granodiorite on the steep flanks and rolling foothills of the Bukit Piring ridge. It is illustrated by Profile 23 in Appendix IV. Below a thin topsoil the profile comprises a strong brown sandy loam or sandy clay loam which grades to a sandy clay at depth. It is weakly blocky and friable throughout the solum. Analytical data are available for only this one profile. It is strongly acid, has a very low CEC below the topsoil, has a low base saturation and very low levels of extractable Mg and K. Total P and Ca are moderately high, however. The clay fraction in this profile is mainly kaolinitic. The degree of variability in the Series is uncertain. Within the Area it is confined to Soil Association 6 and, more locally, Association 7

Grey-White Podzolic Soils

The Group has been discussed above and the Families and Series present in the Area are differentiated in Fig. 21.

Kerait Family (Colour Plate 6)

Family definition: Grey-White Podzolic Soils which are residual over noncalcareous sedimentary rocks or old alluvial deposits derived mainly from them, and which have a clay particle-size class.

Kerait Series

Series definition: Kerait Family soils which are residual, and have a light clay particle-size class and a low CEC in most subsoil horizons.

Site: Gently undulating to hilly; all slope facets; normally on slope of less than 15°; Terrain Classes 3-5.

Parent materials: Typically associated with black or dark grey carbonaceous shales.

Profile form: Where well-developed, Kerait Series is a deep, white or light grey soil with no or only slight mottling. The following profile form is then present:

A1– Grey to dark greyish brown loam or clay loam. Structureless. Friable. Well-rooted. (Less than 10 cms)

A2- White or light grey clay loam or clay Weak medium or coarse blocky structure. Friable. (20-50 cms)

B –White or light grey clay. Firm. Otherwise as above. (50-100 cms)

B3/C–White or light grey clay, with few medium faint pale brown mottles. Massive.

The C horizon may grade at depth to light clays with some dark grey banding following rock structure lines. This then overlies, commonly abruptly and at a depth of some metres, black or dark grey weathered shales which may be either soft and friable or hard and fissile. The above profile form is dominant where carbonaceous shales with low iron levels are found, but Kerait also occurs in where these parent materials are interbedded with shales having a higher iron content. The soil mantle is a complex of Red-Yellow Podzolic and Grey-White Podzolic Soils, and intergrades between them, and the Kerait profile may be distinctly mottled yellow to yellowish red. Provided the dominant matrix colour remains pallid, these profiles are included in the Series. In some Kerait profiles a thin stoneline of quartz gravel underlies the solum. A weak colour B (pale yellow, as against a light grey A2) has been recorded but is not usual in most localities. A concentration of mottling in the B is quite common.

Chemical and mineralogical data: Kerait Series is extremely acid and below the topsoil has a very low CEC (less than 10 me/100 g clay in some profiles) and a base saturation generally below 10 per cent. Total P is low and total Ca is commonly negligible, but there may be moderate levels of Mg and K. Total iron in the subsoil does not reach 4 per cent. Clay mineralogy reported for the one profile analysed (Profile 14 in Apendix IV) is mainly illite and kaolinite.

Distribution: Kerait Series is particularly important in upland areas near Binatang, between Sibu and the Oya River and to the east of the Mukah River, although it is never very extensive and is normally found in complex with other soils. It is an important constituent of Soil Associations 12-15.

Associated soils: Kerait Series may be found in complex with a number of Red-Yellow and Grey-White Podzolic Soils. Particularly common are areas underlain by shale beds with varied iron content and a soil mantle comprising Merit, Kerait and colour intergrades between them.

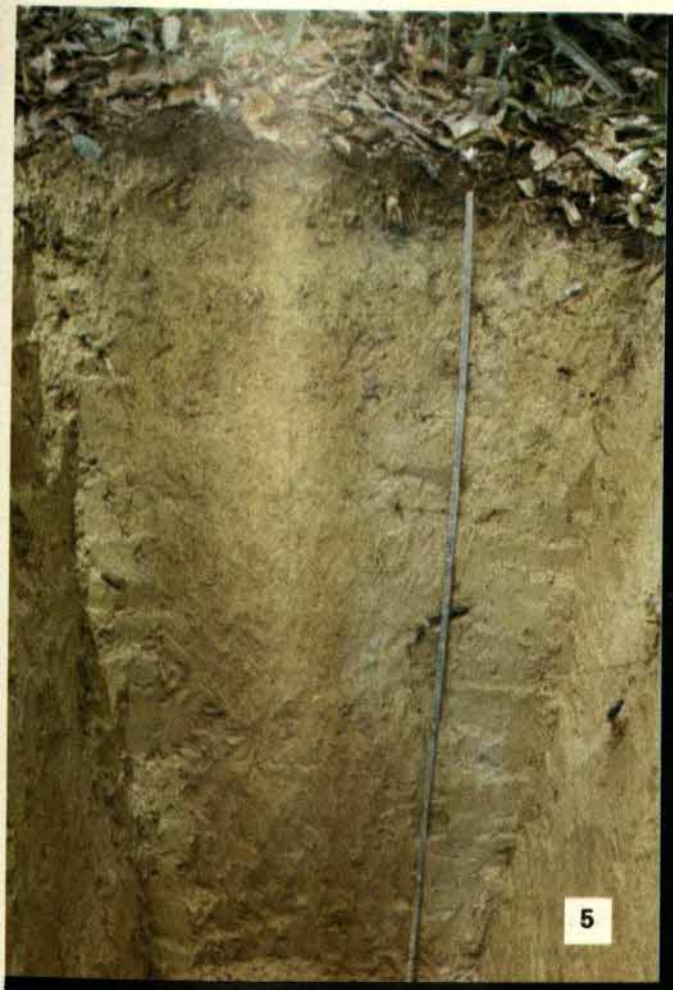
Related Series: Distinctions between Kerait and similar clay profiles in the Groups of Red-Yellow Podzolic and Hydromorphic Upland Soils are discussed in Chapter 7. The Series is distinguished from other soils in the Grey-White Podzolic Group by its particle-size class.

Colour Plate 5. *Nyalau Series*. A Series in the Nyalau Family of Red-Yellow Podzolic Soils, developed over sandstone. The deep uniform profile is typical of the Series although a weak colour B may be present within control section depth.

Colour Plate 6. *Kerait Series*. A Series in the Kerait Family of Grey-White Podzolic Soils, developed over shales. The profile has been cultivated and deep humus staining extending into the upper subsoil. The lower subsoil is a dense clay.

Colour Plate 7. *Saratok Series*. A Series in the Saratok Family of Grey-White Podzolic Soils, developed over sandstones or mixed sedimentary lithology. The uniform, poorly-structured profile overlies a stoneline of quartz gravel.

Colour Plate 8. *Timang Series*. A series in the Timang Family of Hydromorphic Upland Soils, developed over mixed sedimentary lithology. The profile has been cultivated and has a thick weakly humic surface horizon. Weak gleying is evident throughout the subsoil.


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BANDANG FAMILY

Family definition: Grey-White Podzolic Soils which are residual over nonclacareous sedimentay rocks or old alluvial deposits derived mainly from them, and which have a silt particle-size class. Only one Series has been recognised within the Family, and this does not appear to be extensive in the Area.

Bandang Series

Series definition: Bandang Family soils which are residual, and have a fine silt particle size subclass and a low CEC in most subsoil horizons.

Description: Bandang Series is mainly found on gently undulating to rolling terrain (Terrain Classes 3-6) with slopes of less than 15°. It is developed over iron-poor argillaceous sedimentary rocks with subordinate bands of sandstone. The profile is similar to that of Kerait Series except for the texture of the subsoil. Bandang has a higher sand fraction and normally comprises a loam or sandy loam grading to a clay or sandy clay at depth. Profile 16 in Appendix IV illustrates the Series. Chemical characteristics are closely comparable to those of Kerait (Table 8). No mineralogical data are available for the Series but the clays are expected to be mainly illite and kaolinite. On present information Bandang appears to be a minor soil which is locally recorded together with Kerait and Saratok Series in Soil Associations 12-15. It was particularly noted in the lower hills of the swamp fringe zone between Selalang and Durin but granulometric analysis is likely to show that many areas mapped as Kerait on early survey work in other localities should also be considered fine silts of Bandang Series in the present classification structure.

SARATOK FAMILY (Colour Plate 7)

Family definition: Grey-White Podzolic Soils which are residual over noncalcareous sedimentary rocks or old alluvial deposits derived mainly from them, and which have a loam particle-size class.

Saratok and Durin Series

Series definition: Saratok Family soils which are residual, have a low CEC in most subsoil horizons and have a fine loam (Durin) or coarse loam (Saratok) particle-size subclass.

Site: Gently undulating to rolling terrain, all slope facets; normally less than 10°; Terrain Classes 3-4.

Parent materials: Mixed sedimentary rocks in which sandstone beds are dominant.

Profile form: Saratok Series is more extensive than Durin and has the following profile:

A1 – Dark brown or dark greyish brown sandy loam. Structureless. Friable. Well-rooted. (Less than 10 cms)

A2 – Greyish brown to light grey sandy loam or fine sandy loam. Structureless or very weakly coarse blocky. Friable. (20-100 cms)

B – Light grey sandy loam or loam. Otherwise as above. (50-100 cms)

B3/C– Commonly little contrast with above material to some depth. Faint yellow mottling may be present, or residual rock structure.

The clay increase with depth is normally very gradual. A faint pale yellow colour B may be present. A quartz stoneline is seen in some profiles at the base of the solum but is not normally thicker than 10 cms. The subsoil may be mottled but prominent mottling is unusual. Durin Series has the form of Saratok but a slightly higher clay content; subsoil texture are commonly sandy loam over sandy clay loam. Profiles 17 and 18 in Appendix IV illustrate these Series.

Chemical and mineralogical data: These are highly leached and extremely acid soils. The fine earth CEC may be as low as 2 me/100 g although, as the clay fraction is low, the equivalent CEC of subsoil clays may be more than 20. Base saturation is low, as are extractable reserves of P, Ca and Mg, Ca being commonly present in only trace amounts. Total K, however, is generally present in moderate amounts. No mineralogical analyses are available for these soils but chemical data suggests that the clay minerals comprise both kaolinite and illite-vermiculite mixtures.

Distribution: Saratok and Durin are particularly associated with the gently undulating uplands of the swamp-fringe zone. They are particularly important in Soil Associations 14 and 15 and are also locally recorded in areas farther inland in Associations 10-13 where they are often noted in lower slope situations and may be partly colluvial.

Associated soils: These Series have been mapped in association with a variety of Red-Yellow and Grey-White Podzolic Soils but are most commonly found together with other coarse-textured Series, particularly Nyalau. They are also found on very gently undulating sites in complex with Podzols.

Related Series: The particle-size class distinguishes these soils from other pallid profiles on upland sites, Kerait and Bandang being finer-textured and Peninjau (in the Regosol Group) being coarser. Profiles with some faint humus staining in the B occur in which the B does not meet the requirements of a Podzol Bh horizon. These are classed as intergrades, a

Table 8

Red-Yellow and Grey-White Podzolic Soils: Range of data in analysed Series for selected characteristics

Series	*Arip**	*Bandang*	*Bekenu*	*Changgan**	*Durin*
Great Soil Group	Red-Yellow	Grey-White	Red-Yellow	Red-Yellow	Grey-White
Family	Abok	Bandang	Bekenu	Gading	Saratok
Parent material	Rhyolite	Mixed sedimentary rocks	Mixed sedimentary rocks	Granite, granodiorite	Mixed sedimentary rocks
Terrain	Rolling-hilly	Undulating-hilly	Undulating-hilly	Undulating-steep	Undulating-hilly
Internal drainage	Good	Good-imperfect	Good-imperfect	Good	Good-imperfect
Particle-size subclass	Fine silt	Fine silt	Fine silt	Fine loam	Fine loam
Per cent clay (A2)	31	14-21	20-31	27	11-18
..... (B)	33	30-50	26-37	37	19-29
Hue (A2)	10-7.5YR	2.5Y-10YR	10YR	7.5YR-10YR	2.5Y-10YR
..... (B)	7.5YR	2.5Y-10YR	5-10YR	7.5YR	2.5Y-10YR
Value (A2)	5.5	6-7	5-8	5	5-7
..... (B)	5	6-8	5-8	5	6-7
Chroma (A2)	7	1-2	4-8	6-8	2
..... (B)	8	1-4	6-8	6-8	2-4
Consistence (B)	Firm	Firm	Friable-firm	Friable	Friable-firm
Structure (B)	m-wcsab	m-wcab	m-wcsab	m-wmsab	m-wcsab
Thickness of A1 (cm)	5	8-16	3-16	4	5-30
Carbon (A1) %	4	<1-2	<1-7	1-3	1-2
C/N ratio (A1)	17	10-12	11-17	11-12	2-10
pH (H_2O)(A1)	4.1	3.7-4.2	4.1-5.1	5.0	3.4-4.4
pH (H_2O)(A2+B)	4.5-5.1	3.6-4.5	4.1-5.2	4.9-5.7	3.9-4.3
CEC fine earth (A1)	14	4-21	3-13	9	3-9
.....(A2+B)	8-12	4-9	2-5	1-3	1-5
CEC clay (A2+B)**	24-39	19-25	7-26	3-11	9-17
Base saturation (A1) %	12	3-9	10-40	14-16	8-12
.....(A2+B) %	5-11	3-22	2-12	27-34	12-43
HCl-extractable (ppm) :					
P (A1)	150	65-120	60-190	280-360	110
P (A2+B)	70-120	74-120	48-150	200-400	20-80
Ca (A1)	nd	trace-10	trace-300	nd	trace-470
Ca (A2+B)	180-260	trace-260	trace-360	330-1200	trace-320
Mg (A1)	nd	400-500	360-980	nd	80-390
Mg (A2+B)	1300-1800	690-1900	650-1520	0-80	140-1000
K (A1)	nd	1000-1100	760-4140	nd	1100-1300
K (A2+B)	2500-3400	1500-4400	1200-9300	8-18	1100-1400
Na_2CO_3-extractable Fe:			1-4	18	nd
A2	9	nd	3-11	20	nd
B	11	nd			

* data from one profile only
** calculated from fine earth data

Saratok-Silantek intergrade being that most commonly encountered.

PODZOLS

Families and Series in the Podzol Group are for the limited range of Podzols found in the Area - differentiated on the degree of induration of the Bh horizon, the expression of the albic A2 horizon, and the type of parent material. The divisions are summarised in Fig. 22. The emphasis is placed on identifiable profile features rather than the primary distinction between residual and alluvial Podzols adopted in 1966, as the latter is commonly difficult to establish with any certainty. In the proposed classification the Series designation may remain in doubt in some cases but classification at the Family level involves no assumptions regarding parent material. The 'indurated B' employed in the following Family definition has been defined above.

SILANTEK FAMILY

Family definition: Podzols in which the B horizon has a value/chroma rating of 1 and is not indurated.

Silantek Series (Colour Plate 10)

Series definition: Silantek Family soils which are residual over sandstone or other siliceous sedimentary rocks, do not have a lithic contact immediately underlying the B horizon, and which have a strongly bleached A2 horizon with a value/chroma rating of 3.

Site: Gently undulating or gently sloping terrain, slopes normally less than 5°; commonly found on summits and upper slopes of subdued relief underlain by sandstones; Terrain Classes 2-3.

Parent materials: Siliceous, arenaceous sedimentary rocks; generally medium or coarse sandstones or conglomerates. Some profiles are partly developed in a thin mantle of old alluvial or colluvial sands. As such material is difficult to identify in all situations these soils are included

Jakar	*Kerait*	*Merit*
Red-Yellow	Grey-White	Red-Yellow
Merit	Kerait	Merit
Mudstone, shale	Shale	Shales, siltstones
Rolling-hilly	Undulating-hilly	Undulating-hilly
Good	Good-imperfect	Good-imperfect
Light clay	Light clay	Light clay
35–44	14-25	28-44
42–52	32-53	37-50
7.5YR	2.5YR-10YR	10YR
2.5–7.5YR	N-2.5Y	7.5-10YR
5	6-7	5-7
5–6	7-8	5-7
6–7	2-3	4-8
8	0-4	6-8
Friable-firm	Firm	Friable-firm
m-wcsab	m-wcab	m-wcab
5–13	5-8	5-11
1–3	3-4	<1-4
9–14	10-16	9-21
3.4–4.8	4.4	3.6-5.1
3.5–5.2	4.4-4.7	3.5-5.4
7–11	8-9	6-21
4–14	3-5	3-13
10–30	7-18	7-28
8–48	5-35	2-16
3–19	3-9	2-16
50–190	150	59-250
50–170	80-120	40-160
130–320	trace-200	trace-800
70–320	trace-200	trace-560
320–1100	nd	500-1700
380–1200	870-1600	500-3100
480–4800	nd	1500-4300
370–7300	2400-6300	200-7900
6	2	4-5
11	2-3	5-15

Nyalau	*Nyaroh**	*Pasai*
Red-Yellow	Red-Yellow	Red-Yellow
Nyalau	Serin	Nyalaú
Mainly sandstones	Acid igneous and metamorphic rocks	Mainly sandstones
Undulating-steep	Undulating-rolling	Undulating-rolling
Good-imperfect	Good	Good-imperfect
Fine Loam	Heavy clay	Fine loam
14-26	60	19-28
20-31	62	32-36
10YR	7.5YR	5-7.5YR
5-10YR	5-7.5YR	2.5-5YR
5-6	6	6
5-6	5	8
4-8	6-8	6
6-8	8	8
Friable	Friable	Friable-firm
m-wcsab	cab-fab	m-wcsab
2-8	8	5-8
3-9	5	1-3
16-21	14	5-11
3.5-4.6	4.6	4.1-4.3
4.2-5.2	4.8-5.2	4.4-4.7
8-43	18	4-7
4.44	6	4-7
2-19	9-12	13-16
4-14	6	25-30
2-13	7-11	30-50
70-200	150	50-90
35-320	40-440	50-90
trace-400	nd	20-90
trace-200	200-360	120-150
200-420	nd	240-360
290-890	270-500	700-950
540-2200	nd	2600-2800
500-3330	170-600	3700-5000
2-5	12	2-3
2-6	13-14	5-10

in the Series where the C horizon is residuum from country rock. Where the C horizon also comprises alluvial material the profile is classed in Buso Series.

Profile form: The Series is characterised by strongly expressed horizonation.

A1 — Brown or dark reddish brown sandy loam or loamy sand. Structureless. Loose. Much raw litter. (Less than 10 cms)

A2 — White or light grey sand or loamy sand. Structureless. Loose. (10-60 cms)

Bh — Dark brown or dark reddish brown sand or sandy loam. Structureless. Loose or friable. (5 – 20cms).

Bir — Yellow to strong brown sand or sandy loam. Otherwise as above (5–10cms)

C — Pale Yellow to white sandy loam or loam from weathered sandstone. Massive. Friable or firm.

The A2 sand in some localities is hard and unaugerable, either throughout or in irregular patches. All tested samples slake in water, however. The Bh may be firm or patchily indurated, but this is unusual (and a continuously indurated Bh is excluded from the Series by definition). The Bir may be absent or (as in Colour Plate 10) may be represented only by coatings of iron (and humus) on structural surfaces and fossil root channels in the C horizon.

Chemical and mineralogical data: The A1 horizon may have a pH (H_2O) of below 3.5. Subsoil horizons are commonly extremely acid, although some Podzol sands have a pH above 0.5. Other chemical properties vary with the horizon concerned and some are summarised in Table 9. Extractable P, Ca, Mg and K are very low in all profiles analysed. No data are available for clay minerals from profiles in the Area. One comparable profile from west Sarawak (Andriesse, 1972: 306) is reported to have mainly quartz in the A and kaolinite in the B, with anatase and vermiculite also present.

Distribution: Silantek is important in the subdued relief of the hills which form the interior margins of the coastal swamps. It is particularly common in the zone between Sibu and the Mukah-Balingian hills (Soil Association 17) but is also present locally in other areas where sandstones are the main parent rock. It tends to develop where parent materials are siliceous and highly leached, water tables are generally low, and the slope is sufficiently slight to reduce surface

* data from one profile only
** calculated from fine earth data

Table 8 *(continued)*

*Piring**	*Saratok*	*Sarikei*
Red-Yellow	Grey-White	Red-Yellow
Serin	Saratok	Bekenu
Hornfels and related rocks	Mainly sandstones	Mixed sedimentary rocks
Rolling-hilly	Undulating-rolling	Undulating-hilly
Good	Good-imperfect	Good-imperfect
Heavy clay	Coarse loam	Fine silt
56-57	6-20	30-31
62-65	19-23	35-36
10YR	5Y-10YR	7.5-10YR
10YR	5Y-10YR	5-7.5YR
5	5-7	5-6
5	6-8	5-6
6	1-2	6-8
6	1-3	8
Firm	Friable-firm	Firm
wcab	m-vwcsab	wcsab-wcab
8	5-36	5-8
4	1-4	1-3
14	13-17	14-15
3.4	4.2-4.8	3.8-4.1
3.6-3.9	4.1-5.6	4.5-4.6
18	5-10	9-15
8-12	1-6	4-8
8-21	10-27	14-26
9	4-6	15-30
6-10	1-30	21-36
170	35-100	130-180
120-350	20-180	110-140
nd	trace-540	190-250
720-900	trace-430	100-210
nd	90-300	760-950
320-430	90-730	1000-1400
nd	190-1600	3000-3100
1100-1500	1200-3900	4200-9000
nd	1-2	nd
nd	1-3	nd

* data from one profile only

erosion losses and allow the development of a mature podzol profile form.

Associated soils: Silantek is normally associated with sandy Regosols or coarse loamy Podzolic Soils, i.e. Peninjau, Saratok and Nyalau. It is rarely encountered in complex with other Podzol Series.

Related Series: The indurated Bh of Bako, the lithic C of Tunggal and the weakly expressed A2 of Bakau distinguish these residual Series from Silantek. Other Series so far established within the Group are developed in alluvial parent materials.

Tunggal Series

Series definition: Silantek Family soils which meet the requirements of Silantek Series except that the B horizon has a lithic contact.

Description: Tunggal Series has been recorded only on the ridge line of Bukit Tunggal in the northeast of the area, where it is developed over hard conglomerates. Profile 30 in Appendix IV illustrates the profile form. It differs from Silantek only in the depth to lithic material. The humic B horizon is thin and rests directly on weakly weathered hard conglomerate. Structural cracks in the parent rock are infilled with Bh material. The Series is inextensive and does not require further consideration.

Bakau Series

Series definition: Silantek Family soils which meet the requirements of Silantek Series except for the expression of the A2 horizon. The A2 in Bakau is not strongly bleached and has a value/chroma rating of 2 or 4.

Description: Bakau Series Podzols are of minor importance in the Area but have been sporadically encountered in a number of upland areas in association with Nyalau Series. The profile form is similar to that of Silantek Series but, although the nonindurated Bh horizon is well-expressed, the A2 horizon is not. It is either only weakly differentiated from the A1 and is grey or greyish brown with a value/chroma rating of 2 (and bleaching in these profiles may be partly masked by a wash of humus from the topsoil) or it is pale brown to light yellowish brown (value/chroma rating 4) and may in these cases be forming in an environment of somewhat less intense leaching, as the particle-size class is commonly coarse loam rather than sand. Some Bakau profiles may result from human disturbance, although Podzols are generally avoided by farmers, or indicate lateral wash of material from adjacent Red-Yellow Podzolic Soils. The Series is rather hetergeneous and not of great significance in the Area. In terms of the proposed classification it mainly serves to confine the range of Silantek Series to profiles with well-expressed Podzol horizonation.

Buso Series (Colour Plate 11)

Series definition: Silantek Family soils which are developed in riverine or marine alluvium, have a strongly bleached A2 horizon with a value/chroma rating of 3 and which do not have either a surface peat horizon or a lithic contact immediately underlying the Bh horizon.

Site: Flat to very gently undulating subrecent strand lines or marine terrace flats on the coastal plain, or riverine terraces in interior area; slope less than 2°; Terrain Class 2, less commonly 1.

Parent materials: Quartz sands or loamy sands of alluvial origin.

Profile form: The profile form is very similar to that of Silantek Series and is as follows:

A1 — Brown to dark reddish brown sand. Structureless. Loose. Well-rooted. Much raw organic matter. (Less than 15 cms)

A2 — Light grey sand or fine sand. Structureless. Loose. (30-80 cms)

Bh — Very dark brown or dark reddish brown sand or fine sandy loam. Structureless. Loose or friable. (10-80 cms)

Bir — Yellow to strong brown sand or fine sandy loam. Otherwise as above. (10-20 cms)

C — Pallid or gleyed alluvium of varied texture.

There is commonly a patchy wash of humus through the A2 horizon, although some parts remain strongly bleached. Colour Plate 11 illustrates a Buso profile developed on a riverine terrace and shows a well-marked Bir horizon. This is commonly less well-expressed in profiles developed in marine alluvium although the Bh horizon at such sites may be very thick (Profile 28 in Appendix IV). Water-table levels may be in or below the solum.

Chemical and mineralogical data: Some characteristics of Buso Series are summarised in Table 9. It is noteworthy that there is little correlation between horizon colour and either carbon or iron levels. The Bh may have higher iron and not significantly more carbon than the Bir (the horizon designations being given on field appearance). The Bir, if present, was not reached in Profile 28 but Table 78 shows a tendency for carbon to decrease and iron to rise with depth in subhorizons of the Bh. pH levels are highly variable and in profiles close to the coast may be affected by wind-borne salts. In other respects Buso is chemically similar to Silantek, being highly leached and very low in reserve nutrients. No data are available on clay mineralogy from profiles in the Area. One Buso profile from west Sarawak (Andriesse, 1972: 309) is reported to have quartz as the dominant clay mineral in all horizons of the solum.

Distribution: Buso profiles on riverine terraces are uncommon in the Area although they were recorded on the Kanowit floodplain between Julau and Machan and very locally elsewhere. Buso Series developed in subrecent marine sands are widespread, however, both near the coast (Soil Association 21 and 22) and on the interior margins of the coastal plain (Associations 19 and 20). They are also locally present in other mapping units.

Associated soils: In the coastal zone Buso is commonly associated with Metading and Tatau Series, less commonly with Miri. In one locality it is associated with Grang. On riverine terraces it is commonly the dominant soils on the landform unit, if it is present at all.

Related Series: Other Podzols developed in alluvial material and lacking and indurated Bh horizon are Grang, which has a surface peat horizon, and Metading, which lacks a strongly bleached A2.

Metading Series

Series definition: Silantek Family soils which meet the requirements of Buso Series except for the expression of the A2 horizon. The A2 in Metading is not strongly bleached and has a value/chroma rating of 2 or 4.

Description: Metading Series is particularly common in the complex of soils developed in beach sands near the coast, either in association with Buso Series or as a transitional soils between Buso and Tatau. The profile has a moderately well-developed humic B horizon but the A2 is grey, pale brown or light yellowish brown. The Series has been recorded in Soil Associations 21, 22 and 27 on all parts of the coast excluding the Rajang delta itself. Figs. 35 and 37 illustrate areas in which Metading is locally important.

Grang Series

Series definition: Silantek Family soils which meet the requirements of Buso Series with the exception that a surface peat horizon is present. This horizon is not more than 25 cms in thickness (thicker surface organic horizons qualifying the profile for placement in the Group of Organic Soils).

Description: Grang Series is of very minor importance, having been noted at only one site, in Ulu Grang to the west of Selalang. It comprises a continuously waterlogged Buso profile on which surface peat has developed and occupies a swamp-margin site between normal Buso profiles with better drainage and deeper Organic Soils of Igan Series. It is presumed that the general groundwater level has risen in this locality and that the Podzol morphology is now a fossil feature beneath a thin but accreting organic mantle.

MIRI FAMILY

Family definition: Podzols in which in B horizon has value/chroma rating of 1 and is indurated. The definition of an indurated B horizon for purposes of the proposed classification has been discussed above.

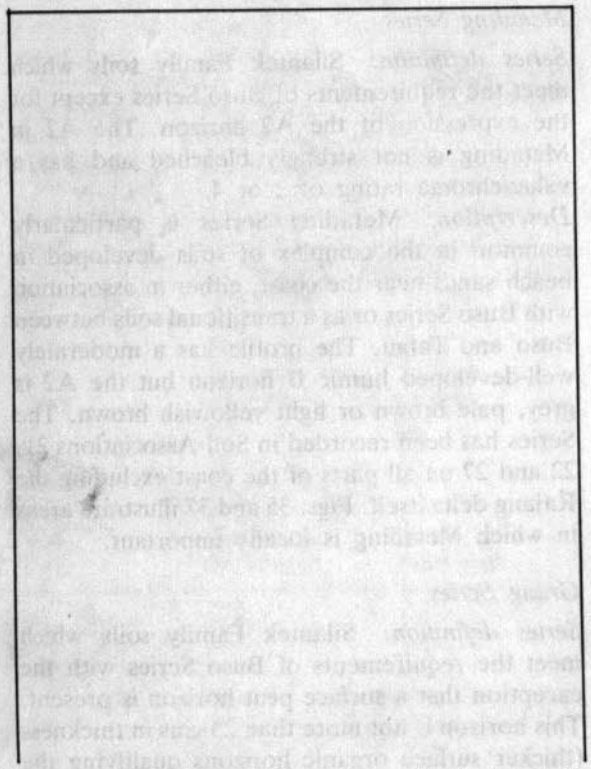
Miri Series (Colour Plate 12)

Series definition: Miri Family soils which are developed in riverine or (more commonly) marine alluvium, have a strongly bleached A2 horizon with a value/chroma rating of 3, and which do not have a surface peat horizon.

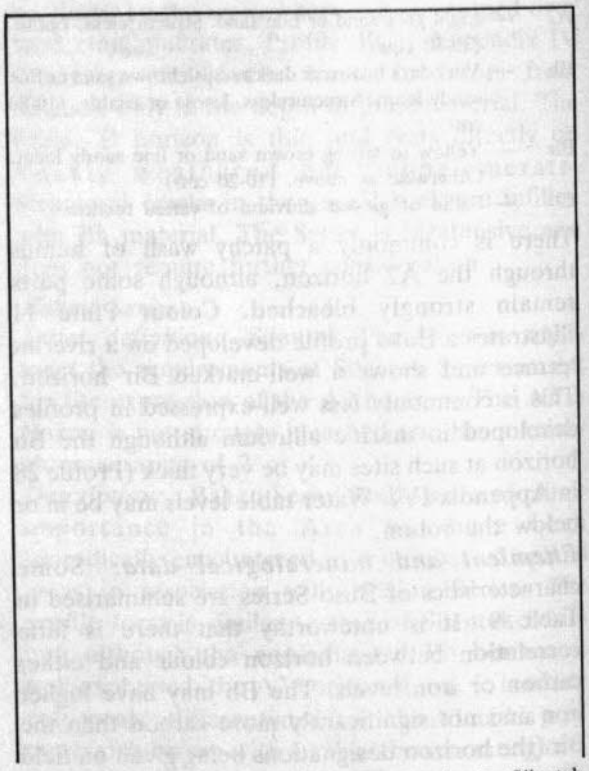
Site: Flat or very gently undulating subrecent strand lines or marine terrace flats on the coastal plain; more rarely riverine terrace tracts in interior areas; slopes less than 2°; Terrain Class 2, less commonly 1.

Parent materials: Alluvial quartz sands.

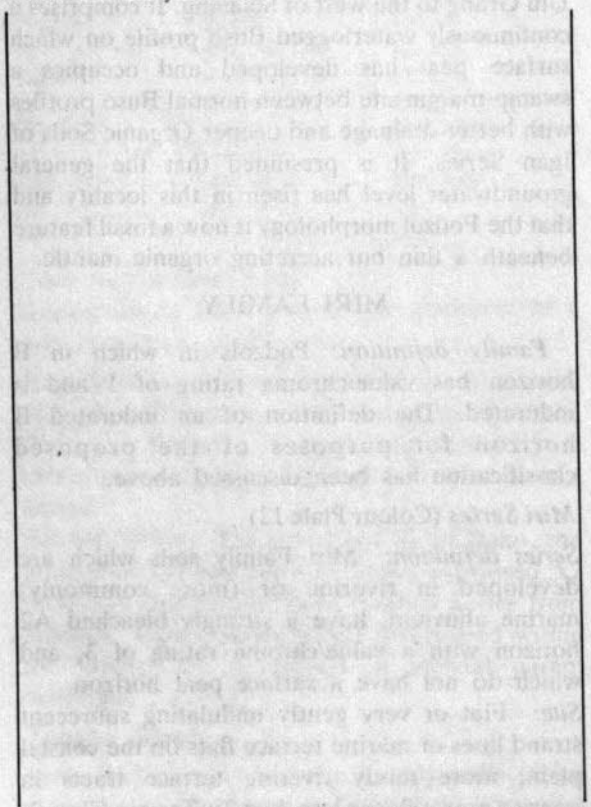
Profile form: There is generally little variation



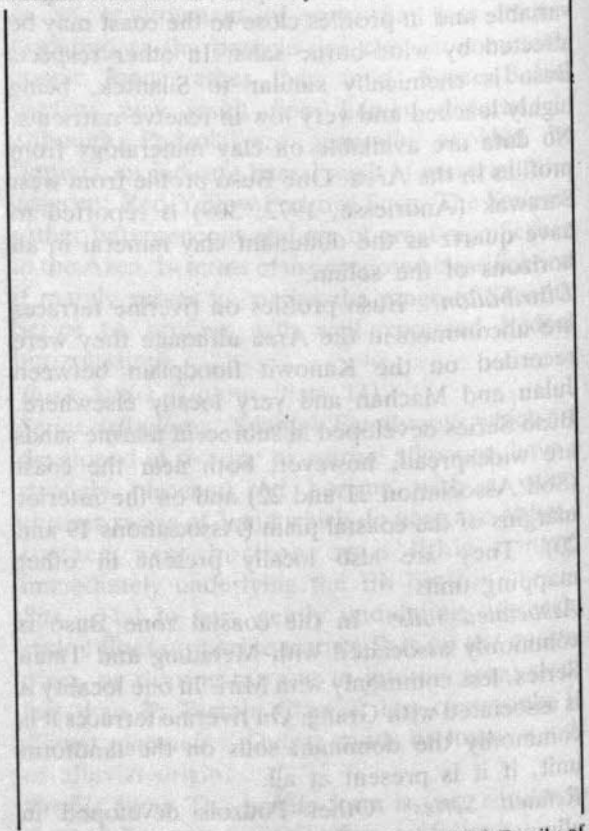
Colour Plate 9. *Saratok-Silcntek intergrade*. An intergrade profile between Series in the Groups of Grey-White Podzolic Soils and Podzols. The weak Bh horizon is apparent in the field but insufficiently strong to qualify the profile for a Podzol classification by the proposed definitions and is also barely reflected in analytical data.



Colour Plate 10. *Silantek Series*. A Series in the Silantek Family of Podzols developed over sandstone. In this well-developed profile, described in Appendix IV (Profile 20), sesquioxide and humus coatings to cracks in the underlying weathered sandstone are clearly seen.



Colour Plate 11. *Buso Series*. A Series in the Silantek Family of Podzols, developed in riverine terrace alluvium. The profile occupies an extensive terrace flat. The Bh horizon is developed in the fine sandy upper subsoil, which overlies a sandy clay in which a weak Bir horizon is present.



Colour Plate 12. *Miri Series*. A Series in the Miri Family of Podzols, developed in fossil marine sands. This profile, described in Appendix IV (Profile 18), illustrates a typical profile form, although the humus staining following root lines in the albic horizon is commonly less pronounced.


9


10



11


12

in the profile form of Miri Series other than depth:

A1 —— Dark brown to dark reddish brown sand or sandy loam. Structureless. Well-rooted. Much raw litter. (Less than 20 cms)

A2 —— Light grey to white sand. Structureless. Loose. (20-80 cms)

Bh —— Black or very dark brown sand or sandy loam. Massive. Strongly indurated throughout or friable in an upper subhorizon becoming strongly cemented at depth. (20-50 cms)

C —— Pale yellow to white sand or sandy loam. Structureless. Friable to loose.

A weakly-expressed Bir horizon may underlie the Bh but this is absent from the majority of the relatively few pitted profiles in which investigations have extended through the indurated horizon. The A2 may be faintly mottled and may have humus tonguing along root channels. At sites significantly above present floodplain level the profile may be excessively drained, particularly where the A2 horizon extends through most of the surface 1 metre. At lower levels drainage is commonly imperfect to poor. A perched water-table may persist above the Bh horizon for some time after rain. In pit exposures a seepage zone is commonly seen at this level and is indicated by humus 'tide-marks' at the base of the A2 horizon, as in Profile 27 in Appendix IV (illustrated in Colour Plate 12).

Chemical and mineralogical data: The profile is generally extremely acid, although the A2 sands may have a pH (H_2O) above 6.0 at well-drained sites near the coast. The profile is very strongly leached and very low in nutrient reserves. Horizon contrasts for some characteristics are given in Table 9. Total iron is particularly low in contrast to the related Buso Series but these differences may reflect the few profiles for which data are available. No clay mineral analyses have been undertaken on Miri Series from the Area's profiles. Heavy mineral data for Profile 27 are given in Table 72.

Distribution: Miri Series is less common in the Area than Buso Series but is locally important on fossil strand lines in the Kenyana area, near Mukah, and to the west of Roban in the south. It is also present at some sites near Saratok and was sporadically recorded in the Rajang delta and on the northern coast. It is mainly mapped under Soil Association 23.

Associated soils: Miri is mainly associated with other alluvial Podzols (Buso Series), sandy Gley Soils (Tatau Series) and shallow Organic Soils (Igan Series).

Related Series: Bako Series has a similar profile form but is developed in residual parent materials. Other Podzols lack an indurated Bh horizon. Profiles in which the Bh is encountered

Table 9

Major Soil Series in the Podzol Group; range of data for selected properties in analysed profiles from central Sarawak and adjacent areas.

		Silantek	*Buso*	*Miri*
Horizon thickness, (cms)	A1	8-13	8-23	11-18
	A2	33-40	8-27	7-35
	Bh	11-24	8-60	6-67
	Bir	4-10	4-8	3-5
Hue	A1	2.5-10YR	5-10YR	5-10YR
	A2	7.5YR-5Y	10YR	10YR
	Bh	5-7.5YR	7.5-10YR	5-10YR
	Bir	7.5YR-2.5Y	5-10YR	7.5-10YR
Value	A1	3-5	3-6	2-3
	A2	7-8	2-7	6-8
	Bh	2-4	2-5	2
	Bir	5-7	3	3-7
Chroma	A1	2-3	1	2-3
	A2	0-3	2	1-3
	Bh	2	2-3	1-2
	Bir	4-6	2-3	4-6
Clay (per cent)	A1	4-6	3-6	6-36
	A2	2-7	3-6	2-4
	Bh	2-16	3-8	2-12
	Bir	2-13	8-12	1-20
	C/IIC	14-28	12-30	12-21
Carbon (per cent)	A1	1-31	<1-3	1-24
	A2	<1	<1	<1-2
	Bh	<1-8	1-4	1-6
	Bir	<1-2	1-4	<1-2
C/N ratio	A1	20-27	16-83	20-23
pH (H_2O)	A1	2.8-4.2	4.2-4.7	3.3-4.2
	A2	3.2-5.7	4.7-5.1	3.8-6.3
	Bh	3.6-5.1	4.5-5.2	3.2-4.3
	Bir	4.2-4.4	4.8-5.1	4.8-5.0
CEC (me/100 g fine earth)	A1	<1-102	1-7	3-34
	A2	<1-3	<1-2	<1-4
	Bh	2-14	1-6	7-26
	Bir	1-8	4-19	5-6
Fe_2O_3(extractable by Na_2CO_3)	A1	<1	<1	<1
	A2	<1	<1	<1
	Bh	<1	1.8-2.1	<1
	Bir	1-2	<1-2	<1

(In all three Series profiles occur in which there is no identifiable Bir horizon)

at more than 1 metre depth are considered as Regosols in the proposed classification (Kilong Series).

Bako Series

Series definition: Miri Family soils which meet the requirements of Miri Series except for parent material. Bako Series is developed residually in upland areas over sedimentary rocks (normally quartzitic sandstone).

Description: The profile form differs little from that of Miri Series other than the C horizon, which comprises residuum from weathered sandstone. The Series is locally important in other parts of the State where it is generally associated with very shallow dipslopes in sandstone country. Within the Area it was only recorded in the Sarupai headwaters in the extreme northeast. It is found there in a footslope position in association with Silantek Series, and is mapped under Soil Association 18.

HYDROMORPHIC UPLAND SOILS

The Group definition has been discussed above. Three Families are present in the Area, each represented by one Series (Fig. 23) which takes the Family name. The Group as a whole is inextensive in the Area.

AJOH FAMILY

Family definition: Hydromorphic Upland Soils which are residual over noncalcareous sedimentary rocks or developed in old alluvial deposits mainly derived from such rocks; they have a clay particle-size class.

Ajoh Series

Series definition: Ajoh Family soils which have a light clay particle-size class, have a control section which is dominantly strongly mottled or variegated, and which lack a gley horizon with a Hue bluer than 5Y within a depth of 75 cms.

Description: Ajoh Series is developed in gently undulating upland flats (Terrain Class 2) in the Pasai and Penipah areas (Soil Association 16). The parent materials are shales, mudstones or siltstones. It is possible that upper horizons at some sites are developed in local old alluvium. The profile comprises, below a thin topsoil, a grey or light clay or clay loam, grading to clay at depth, with profuse yellow or red mottling. Some profiles are variegated white, yellow and red with no dominant matrix colour. In others mottling is largely concentrated in the B horizon. Profile 15 illustrates the Series and Profile 13 a form which, on colour and inferred drainage status, is considered an Ajoh-Merit intergrade. The Series is strongly to extremely acid with a low subsoil CEC, base saturation commonly less than 10 per cent, and low nutrient reserves. The clay minerals are mainly illite and kaolinite in Profile 24, illite and vermiculite, with subordinate kaolinite, in the intergrade Profile 13. In the two localities where the Series was recorded it is associated with other Series in this Group and with Red-Yellow Podzolic soils (or intergrades to them) on slight rises with better drainage.

TIMANG FAMILY

Family definition: Hydromorphic Upland Soils differing from Ajoh Family only in having a silt particle-size class.

Timang Series (Colour Plate 8)

Series definition: Timang Family soils which have a fine silt particle-size subclass, have a control section which is strongly mottled or variegated, and which lack a gley horizon with a Hue bluer than 5Y within a depth of 75 cms.

Description: Timang Series commonly has a subsoil texture of sandy loam, grading to sandy clay loam at depth. Apart from the particle-size class it is very similar to Ajoh Series, described above. It was noted in the Pasai tract of Soil Association 16 and may also be present in the Penipah area, although it was not recorded on brief reconnaissance work there.

PENIPAH FAMILY

Family definition: Hydromorphic Upland Soils differing from Ajoh and Timang Families in having a loam particle-size class.

Penipah Series

Series definition: Penipah Family soils which have a coarse loam particle-size subclass, have a control section which is strongly mottled or variegated, and which lack a gley horizon with a Hue bluer than 5Y within a depth of 75 cms.

Description: Penipah Series generally has a sandy loam subsoil texture which grades to a loam or clay loam at depth. In other respects it does not contrast greatly with the related Timang and Ajoh Series described above. Penipah is equally acid, leached and low in reserve nutrients. It was recorded in the Penipah tract of Soil Association 16 but does not appear to be present in the Pasai area. The Series is illustrated by Profile 19 in Appendix IV.

Classification note - Hydromorphic Upland Soils

The classification of this Group remains very provisional at all three levels of the proposed system. No attempt has yet been made to incorporate the pallid profiles locally important in west Sarawak. The colour parameters used in the Group of Grey-White Podzolic Soils may be appropriate here if west Sarawak soils (mainly

classified as Lubai and Triboh Families in the 1966 system) do not contrast with those briefly described above from the Area in other major respects. Available data, mainly from Andriesse (1972), indicates that other contrasts of importance do exist, however. Except for site, drainage and subsoil colour (factors which are closely linked in these soils) Ajoh, Timang and Penipah show many of the chemical and morphological trends of the Podzolic Soils with which they are associated. Many west Sarawak soils which may qualify for this Group are reported to be more Regosolic. Further, many of the west Sarawak soils are described as being developed in layered alluvial materials and having very strongly contrasting texture profiles, a feature which requires recognition in the classification. Triboh Family has also been extended to cover profiles which are excessively drained. This is contrary to the concept of the Group as defined at present. An extension of the classification to cover these soils outside the Area cannot be satisfactorily attempted without further study of the soils concerned. At present only those parameters which serve to identify the Area's soils have been introduced.

GLEY SOILS

A number of Families and Series have been recognised in this Group, many of which are important in the Area. The Group is discussed above and the proposed Family and Series classification is summarised in Figs. 24 and 25. The following Family definitions distinguish saline fron nonsaline soils and those with potential acid sulphate characteristics from those which lack them. These parameters have been defined for purposes of the proposed classification in Chapter 7.

RAJANG FAMILY

Family definition: Gley Soils which are saline, have potential acid-sulphate characteristics, and which have a clay particle-size class.

Rajang Series

Series definition: Rajang Family soils which have a light clay particle-size subclass, and which do not have a surface peat or muck horizon.

Site: Alluvial deltaic flats, partially tidal; Terrain Class 1.

Parent materials: Marine or estuarine clays and silts.

Profile form: Rajang Series commonly comprises an undifferentiated grey or dark grey clay or silty clay - particularly at sites near the coast or estuary where the profile is inundated by most tides. There is no topsoil development and the profile is saturated and unstructured. Farther from the coast or estuary where the site is only reached by the highest tides some gley mottling may be present in the upper 50 cms, the surface material may have a weak blocky structure and this horizon may be somewhat darker than underlying material, indicating the initial stages of an A1 horizon (although this may not be reflected in higher carbon levels - Table 86). Some jarosite mottling may be present but this is more commonly developed in the better-drained material of surface mounds than in the profile itself. These mounds, built by the mudlobster *Thalassina anomala,* are a feature of the Series, may rise to more than 1 metre above the adjacent soils surface, and give a characteristic microrelief to these areas.

Chemical and mineralogical data: Some chemical characteristics of Rajang Series are contrasted with those of other major Gley Soils in Table 10. Acidity varies greatly but, by definition, dry pH (KC1) is below 3.5 at some level within 1 metre of the surface, although water-soluble sulphate may be present in only trace amounts. The CEC is generally high and the exchange complex is well-saturated, particularly with Mg. Total Mg and K are high, although P and Ca are commonly moderate to low. No clay mineral analyses have been undertaken for profiles of this Series from the Area.

Distribution: Rajang Series is widespread in the Rajang delta and is more locally important in other estuarine and coastal localities in the Area. It has been mainly mapped under Soil Association 30.

Associated soils: Rajang grades laterally to Pendam Series in most areas, and they have been combined for mapping purposes. Locally it is associated with, or replaced by, Paloh Series.

Related Series: Rajang is the only Series at present isolated in the Rajang Family although, as discussed below, further Series differentiation will be necessary. Paloh and Belat Families are distinguished on particle-size class. Other Gley Soils present in the Area do not have potential acid-sulphate characteristics.

PALOH FAMILY

Family definition: Gley Soils which are saline, have potential acid-suphate characteristics, and which have a loam or silt particle-size class.

Paloh Series

Series definition: Paloh Family soils which have a fine silt particle-size subclass, and which do not have a surface peat or muck horizon.

Description: Paloh Series is, on present data, similar in all respects to Rajang Series apart from a somewhat coarser texture. It has been noted in the north of Pulau Bruit, but not elsewhere. It is probably more extensive than the records indicate, however, as very few granulometric analyses have been undertaken on these soils and it is probable that many profiles qualifying for Paloh Series have been classified as Rajang clays on field texture estimates, particularly on early phases of the survey programme when the 1966 classification was in use.

PENDAM FAMILY

Family definition: Gley Soils which are saline, do not have potential acid-suphate characteristics, and which have a clay particle-size class.

Pendam Series

Series definition: Pendam Family soils which have a light clay particle-size subclass and which do not have a surface peat or muck horizon.
Site: Alluvial deltaic flats, partially affected by high tides but generally outside direct influence of brackish water; Terrain Class 1.
Parent materials: Marine or estuarine clays and silts.
Profile form: Where they have not been cultivated Pendam Series profiles are similar to those of Rajang Family in morphology but show some effects of soil-forming processes in the development of gley subsoil mottling, very weakly developed blocky structures and, in some but not all profiles, an incipient surface accumulation of organic matter. Topsoil development, and structure in the upper subsoil, commonly show greater development in fringe areas which have been cleared by local farmers for wet rice and where shallow drains have been dug. Chemical trends are largely comparable to those of Rajang Series (Table 10) but Pendam does not have potential acid-sulphate horizons within 1 metre of the surface. Salinity levels are also lower than most Rajang profiles as Pendam is less affected by brackish water inundation. The Series normally occupies the inner fringe zone of the alluvial belt otherwise dominated by Rajang Family soils and is commonly found between Rajang Series and Organic Soils which back the littoral belt of marine or estuarine alluvium. It is also found as a riverbank soil in the middle courses of some rivers on the coastal plain, in tracts affected by brackish waters of low salinity. It has been mapped together with Rajang Series in Soils Association 30 and is also important in Associations 29 and 40.

Jol Series

Series definition: Pendam Family soils which meet the requirements of Pendam Series with the exception that a surface peat horizon is present. This horizon is not more than 25 cms in thickness.
Description: Jol has the characteristics of Pendam Series with the exception of the surface peat horizon and that, due to the permanently high water-table, profile forms with subsoil mottling or any degree of structural development are not encountered. Jol Series is present in most tracts where Pendam is important, but is generally not extensive. It normally occupies a narrow transitional belt between Pendam Series and soils in the Organic Group.

SIRIK FAMILY

Family definition: Gley Soils which are saline, do not have potential acid-sulphate characteristics, and which have a silt or loam particle-size class.

Sirik Series

Series definition: Sirik Family soils which have a fine silt particle-size and which do not have a surface peat or muck horizon.
Description: Sirik is, in effect, equivalent to Paloh Series, described above in the Rajang Family. It has been noted in the Selalang and Bruit-Matu areas but, like Paloh, is probably more extensive than records indicate, due to the few granulometric analyses undertaken on these marine Gley Soils. No associated Series with surface peat has been recorded, although such soils are likely to be locally present. Profiles with other than a fine silt particle-size subclass have also not been noted, although these may also be present and a fine loam Series is particularly likely.

Classification note - marine Gley Soils

The four families described briefly above are defined only in broad terms and further elaboration of this portion of the proposed classification is obviously necessary. A greater emphasis on the degree of ripening is required and further subdivisions on the seriousness of any potential acid-sulphate limitation (and possibly salinity) would be appropriate. Within the Area there has been little opportunity to investigate changes in these soils following drainage. Some drainage schemes have been implemented in deltaic tracts but soils investigations of these areas were undertaken in advance of the drainage works or during the initial phases of reclamation. Further development of the classification of these soils must therefore rely on work in other parts of

the State where reclamation and resultant soil changes have reached a more advanced stage.

BIJAT FAMILY

Family definition: Gley Soils which are nonsaline, are developed in riverine alluvial materials and do not have potential acid-sulphate characteristics, and which have a clay particle-size class.

Bijat and Sebandi Series

Series definition: Bijat Family soils which have a light clay particle-size subclass and which either lack a surface peat or muck horizon (Bijat Series) or which have a surface peat or muck horizon not more than 25 cms in thickness (Sebandi Series), and are developed in alluvium from noncalcareous sedimentary rocks.

Site: Riverine (or upper estuarine) floodplains and bottomlands; the fringes of basin peat swamps on the coastal plain; Terrain Class 1.

Parent materials: Alluvium from noncalcareous sedimentary rocks. On the coastal plain the Series are extended to include soils developed partly in estuarine alluvium provided that, within the definitions used, it is nonsaline and lacks potential acid-sulphate characteristics. These are included due to the difficulty of separating marine or estuarine from riverine alluvium on other parameters.

Profile form: Bijat has a fluctuating water-table and the upper part of the profile is at some sites profusely mottled towards the surface. More commonly, however, the subsoil is gleyed throughout and has the following form:

A1 — Brown or greyish brown loam or clay loam. Weakly blocky. Friable. Well-rooted. (5–30 cms)

A2g — Grey or light grey clay loam, mottled yellow or red. Massive. Firm or plastic. (20–50 cms)

Bg — Grey or light grey clay, with sparse mottling. Massive. Plastic. (40–60 cms)

Cg — Light grey, white or blue clay, with sparse or no mottling. Massive. Plastic.

Where the water-table is permanently high, no subsoil mottling may be apparent. Normally Bijat Series is only flooded for long periods at the wettest time of year and after an extended dry period the water-table may be below 1 metre. Sebandi Series is permanently saturated and generally lacks mottling in the mineral horizons. A cultivated Bijat profile is illustrated in Colour Plate 15.

Chemical and mineralogical data: The profile is strongly to extremely acid. Subsoil CEC is low or very low and there are few exchangeable bases. There are moderate levels of extractable Mg and K, but low levels of Ca and P, in profiles analysed. Chemical characteristics probably vary significantly in these Series, as they are developed in a variety of situations from a range of alluvial materials. No data are available for clay minerals in Bijat and Sebandi Series.

Distribution: These Series normally occur together and commonly form a transitional belt between Alluvial and Organic Soils. They have been mapped in the middle and lower courses of all major rivers and along many smaller streams. They are particularly important in Soil Associations 25 and 26.

Table 10

Fine-textured Gley Soils; range of data in analysed profiles for selected properties

		Bijat	Pendam	Rajang
Hue	a	10YR	10YR–2.5Y	10YR–5Y
	b	7.5YR–5Y	2.5Y	5Y
Value	a	4–7	3–5	3–5
	b	5–8	3–5	3–5
Chroma	a	1–3	0–2	0–2
	b	0–2	0–2	0–1
Clay, per cent	a	24–47	31–36	33–36
	b	29–53	26–48	32–51
Carbon, per cent	a	<1–6	<1–3	<1–4
	b	<1–8	<1–1	<1–4
C/N ratio	a	6–10	1–2	1–16
pH (KCl)	a	3.5–3.9	3.8–5.1	3.3–5.7
	b	3.5–4.9	3.5–4.1	2.6–3.4
CEC, fine earth	a	3–26	12–31	6–29
	b	3–25	4–21	13–33
Base saturation	a	6–22	29–88	44–100
	b	1–19	43–100	43–100
HCl-extractable:				
P (ppm)	a	60–550	350–820	260–660
	b	50–340	150–310	110–660
Ca (ppm)	a	300–1200	800–1200	500–930
	b	160–300	760–860	330–1500
Mg (ppm)	a	300–3000	5000–8300	1700–6000
	b	730–3000	6100–6300	4700–6400
K (ppm)	a	2300–7500	8000–10300	4700–6400
	b	3700–9400	6300–7100	4800–9200
Water-soluble SO_4, per cent	a	trace	0.4–0.5	trace–0.7
	b	trace–0.1	0.3–0.9	trace–1.0
Conductivity (μmhos/cm at 25°C)	a	<100	500–2500	1000–>20000
	b	<100	1000–2700	1000–>20000

a – A1 horizon or upper layer
b – A2 and B horizons, or middle and lower layers

Associated soils: Where a bottomland tract is entirely poorly-drained Bijat and Sebandi Series may occupy the entire unit. Where a range of drainage conditions are found they are commonly associated with Seduau Series on better-drained sites and Mukah series in adjacent back-swamps, Figs. 31, 32 and 34 illustrate their relationship to landforms and associated soils in selected localities.

Related Series: As Fig. 25 indicates, other Gley Soil which are nonsaline and lack potential acid-sulphate characteristics are either developed in alluvial materials which are not present in the Area (or, in the case of igneous parent materials, are too inextensive to have an important influence on adjacent alluvial soils) or have a coarser particle-size class.

PAKAN FAMILY

Family definition: Gley Soils which meet the requirements of Bijat Family except for the particle-size class, which is either silt or loam.

Pakan Series

Series definition: Pakan Family soils which have a fine silt particle-size subclass, lack a surface peat or muck horizon, and are developed in alluvium from noncalcareous sedimentary rocks.

Description: Apart from the particle-size class, Pakan Series has the characteristics of Bijat Series described above. The Pakan profile normally has a clay loam or sandy clay loam texture in the subsoil and clay horizons are only met at depth. The Series is illustrated by Profile 40 in Appendix IV. As in the marine Gley Soils, few granulometric analyses have been undertaken on the poorly-drained soils of riverine bottomlands and the importance of Pakan Series in the Area is uncertain. It is expected to be present in association with Bijat Series in many areas where the latter is common, and in some floodplain tracts Pakan may be the dominant soil. No loam profiles have been recognised within this Family, nor have Series with surface peat horizons been established. Both undoubtedly occur, however, and named Series will be justified when they are encountered.

PLAN FAMILY

Family definition: Gley Soils which meet the requirements of Bijat and Pakan Families except for the particle-size class, which in the Plan Family is sand.

Plan and Luis Series

Series definition: Plan Family soils which have either no surface peat or muck horizon (Plan Series) or a surface peat or muck horizon not more than 25 cms in thickness (Luis Series).

Description: Plan and Luis Series are of very minor importance in the Area. They comprise poorly-drained sands, generally grey, white or, more rarely, with strongly gley B or BG Hues. The water-table is normally within the surface 1 metre in Plan Series, and in Luis Series on which surface peat has developed is continuously at or near the surface. These soils are only encountered in minor valley bottoms and in gullies.

TATAU FAMILY

Family definition: Gley Soils which are nonsaline, are developed in marine alluvial sands and have a sand particle-size class, and which lack potential acid-sulphate characteristics.

Tatau and Matu Series

Series definition: Tatau Family soils which either have no surface peat or muck horizon (Tatau Series) or have a surface peat or muck horizon not more than 25 cms in thickness (Matu Series).

Description: Tatau sands are generally poorly-drained and in Tatau Series are commonly light grey to pale yellow, with some yellow or brown mottling in the subsoil. Matu Series has a water-table permanently at or near the surface and is completely gleyed and unmottled below the surface peat horizon. Both Series are common in the coastal zone and occupy depression sites between strand line ridges on which Podzols are generally found. Figs. 35 and 37 illustrate localities in which Tatau and Matu are important components of the soil pattern, and Fig. 39 the relationship between these Series and associated soils and their distribution in relation to landforms in the coastal zone.

ALLUVIAL SOILS

The Group of Alluvial Soils is defined in Chapter 7. Within the Area four Families have been recognised on parent material and particle-size class, and seven Series established within them on other criteria. The Family and Series divisions are summarised in Fig. 26.

SEDUAU FAMILY

Family definition: Alluvial Soils which are developed in riverine alluvium from noncalcareous sedimentary rocks and which have a clay particle-size class.

Seduau and Malang Series

Series definition: Seduau Family soils which have a light clay particle-size subclass and a yellow (Seduau) or red (Malang) subsoil colour class.

Site: River-banks, levees and other well-drained riverine floodplain tracts; Terrain Class 1.

Parent materials: Alluvium from sedimentary rocks. Any calcareous source material or localised igneous outcrops do not have a significant effect on these downstream alluvial soils.

Profile form: Seduau Series has the following profile form:

A1 — Brown to dark brown loam or clay. Weak Subangular blocky structure. Friable. Well-rooted. (Less than 10 cms)

B — Yellowish brown clay. Weak subangular blocky structure. Friable or firm. (50–100 cms)

C — As above with light grey mottling increasing at depth.

Imperfectly-drained phases occur and are mottled throughout the subsoil. The upper subsoil may be clay loam, the clay percentage increasing with depth. In some profiles depositional layering is evident but such forms usually only remain in a clay particle-size class if coarser layers are confined to depths near the base of the control section (Profile 32 in Appendix IV being an example). Profiles exhibiting a weak colour B are present but this feature is generally not pronounced. Malang Series has the same form but either a somewhat redder subsoil Hue and/or a well expressed colour B horizon within 50 cms of the surface place the profile in a red colour class. Profile 33 in Appendix IV is an example of the latter. In morphology these Series generally show little genetic horizonation. Profiles in apparently unlayered material which show a colour B and some clay increase with depth are largely confined to levee sites where some effects of leaching can be expected. A Seduau profile from the Pasai River floodplain at Oya Road Agricultural Station is illustrated in Colour Plate 14.

Chemical and mineralogical data: These Series are generally strongly to extremely acid, have a low CEC in subsoil horizons and less than 20 per cent base saturation. Reserve nutrients are variable but there are generally moderate to high levels of extractable K and Mg, and rather lower levels of Ca and P. Carbon remains above 0.2 per cent to below 1 metre in some profiles but not in others.

Distribution: Seduau Series is widespread as a component of the soil association in most major floodplain tracts. In some minor valleys it is the main bottomland soil if the stream is entrenched. Malang Series is equally widespread but is generally less extensive in any locality, being commonly confined to river-bank or levee sites. These Series have been mapped together and are major components of Soil Associations 24 and 25.

Associated soils: In most bottomland tracts Seduau and Malang grade to Bijat Series in adjacent depression sites. Bemang Series is also commonly present and Semilajau may occupy levee sites.

Related Series: These Series are differentiated from other Alluvial Soils developed over similar parent materials by the particle-size class, as indicated in Fig. 26.

BEMANG FAMILY

Family definition: Alluvial Soils which meet the requirements of Seduau Family apart from the particle-size class which, in Bemang Family, is silt or loam.

Bemang Series

Series definition: Bemang Family soils which have a fine silt particle-size subclass and a yellow subsoil colour class.

Description: Bemang Series has clay loam or sandy clay loam subsoil textures. In other respects its range of properties is that of Seduau Series, which it closely resembles. Distribution and range of site are also comparable. Bemang and Seduau occur together on many floodplains and on early survey projects using the 1966 classification were combined under a Seduau Family. No Bemang Family profiles with a red colour class (equivalent to Malang Series) have been noted on semi-detailed investigations but these are also expected to occur.

Semilajau Series

Series definition: Bemang Family soils which have a coarse loam particle-size subclass and a yellow subsoil colour class.

Description: Semilajau Series comprises a yellowish brown sandy loam below a thin topsoil. The subsoil is friable or loose. The profile may, at beyond control section depth, overlie a thick pebble bed. This feature is otherwise unusual in Alluvial Soil of the Area. Semilajau typically occurs as a levee or river-bank soil in interior areas but is never extensive and is not recorded in the lower courses of major rivers on the coastal plain. Equivalent profiles with a red subsoil colour class have not been recorded but may occur.

KAYAN FAMILY

Family definition: Alluvial Soils which meet the requirements of Seduau and Bemang Families apart from the particle-size class which, in Kayan Family, is sand.

Colour Plate 13. *Semilajau Series.* A Series in the Bemang Family of Alluvial Soils, developed in riverine alluvial coarse loams. The profile illustrates a typical profile form, is found on a levee site and, in this instance, has been extensively cultivated for fruit trees.

Colour Plate 14. *Bemang Series.* A Series in the Bemang Family of Alluvial Soils, developed in riverine alluvial fine silts. The profile, described in Appendix IV (Profile 34), was photographed after a few days exposure. The coarse structure which is evident is not expressed in freshly exposed pits. In the 1966 classification the profile was included in Seduau Family.

Colour Plate 15. *Pakan Series.* A Series in the Pakan Family of Gley Soils, developed in riverine alluvial fine silts. The profile is described in Appendix IV (Profile 40). The deep topsoil results from a previous history of wet rice cultivation on this soil. In the 1966 classification the profile was classed in the Bijat Family.

Colour Plate 16. *Luk Series.* A Series in the Anderson Family of Organic Soils, developed in organic debris on present beaches in the Tanjong Sirik area and locally elsewhere. The profile, described in Appendix IV (Profile 49) illustrates a shallow phase, in which the well-sorted organic material overlies poorly-drained mineral horizons at little more than 1 metre depth.


13


14



15


16

Kayan Series

Series definition: Kayan Family soils which have a yellow subsoil colour class.

Description: Kayan Series is the only Series at present recognised in the Kayan Family and is a very minor soil in the Area. Below a thin topsoil it comprises a loose yellow-brown sand. It is largely confined to minor valleys draining areas of sandstone.

KABONG FAMILY

Family definition: Alluvial Soils which are developed in marine alluvial sands, and have a sand particle-size class.

Kabong and Belawai Series

Series definition: Kabong Family soils which have either a yellow (Kabong) or red (Belawai) subsoil colour class.

Description: Marine alluvial soils which are sufficiently well-drained to qualify for this Group are confined to sands immediately behind the present beach or subrecent strand-lines which commonly form complexes in the coastal zone. The soils comprise loose sand or fine sand, ranging in colour from yellow to reddish yellow and strong brown. Most profiles become pallid towards the base of the control section, where the water-table is intermittently present, and weak mottling is found in some profiles at higher levels. White to pale yellow sands locally occur and these are provisionally included in Kabong Series where it can be confidently inferred from the site that the profile is well-drained. Kabong is widespread along all parts of the coast in the Area, with the exception of the Rajang delta. Belawai, its redder associate, occurs with Kabong but is more sporadically distributed. These Series have been mapped mainly under Soil Association 27, together with associated poorly-drained marine sands of Tatau Family.

NOTE ON INTERGRADES

Alluvial Soils typically occupy bottomland tracts in which drainage ranges from good to very poor. The Group is therefore generally associated with Gley Soils and there are repeating transitions between these Groups related to the drainage regime. As stated above, Gley Soils are defined to cover only soils which are poorly-drained throughout the control section, while the Group of Alluvial Soils is restricted to profiles which are moderately well-drained to at least a depth of 50 cms. An intergrade provision between these Groups is incorporated in the classification strategy as this approach best reflects the sequences of profile form most typical of alluvial bottomlands. The Groups have a common division of particle-size classes and subclasses to simplify intergrade placement. The most frequently encountered intergrades between these Groups in the Area are, at Series level, Seduau-Bijat, Bemang-Pakan and Kabong-Tatau, although other possibilities exist.

REGOSOLS

Regosols are of minor importance in the Area as a whole and rarely extensive in those localities where they have been recorded. Four Series have been recognised, in two Families. The classification criteria are summarised in Fig. 27.

PENINJAU FAMILY

Family definition: Regosols which have a red or yellow subsoil colour class.

Peninjau Series

Series definition: Peninjau Family soils which are residual over noncalcareous sedimentary rocks and have a yellow subsoil colour class.

Description: Peninjau Series comprises a deep brownish yellow or yellow loose fine to coarse sand, which is locally encountered in the Binatang-Durin area on uplands underlain by quartzose sandstones. It is there associated with Nyalau Series, to which it is closely related.

Sebaya Series

Series definition: Peninjau Family soils which are developed in old riverine alluvium derived mainly from sedimentary rocks.

Description: Low riverine terraces in the middle Kanowit floodplain (Fig. 36) and locally elsewhere have brownish yellow alluvial sands, which are commonly deep and well-drained and, apart from a slightly coarser texture, differ little from Sabangang Series. The particle-size class dictates a Regosol classification in the proposed system and these profiles are classified as Sebaya Series in the Peninjau Family.

TIKA FAMILY

Family definition: Regosols which have a pallid subsoil colour class.

Tika Series

Series definition: Tika Family soils which are residual over noncalcareous sedimentary rocks.

Description: Tika Series comprises a brownish grey to white sand on moderately undulating uplands underlain by quartzose sandstone. It is commonly associated with Saratok Series, from which it differs mainly in texture, or with Podzols. It is not widespread but has been noted near Sibu and in the Balingian drainage basin where it has been mapped mainly under Soil Association 19.

At some sites profiles have been provisionally classed as Tika Series although a possibility exists that they are developed in old alluvial material and should be more properly considered as Bintulu Series, discussed below.

Bintulu Series

Series definition: Tika Family soils which are developed in old riverine or marine alluvium.

Description: Bintulu Series has the same profile form as Tika but is developed on marine or riverine terrace landforms. The alluvial origin of the material is commonly uncertain as Tika Family soils are characteristically deep and recognisable saprolitic materials are rarely encountered within the surface 1 metre even where the profile is residual. Soils in this Family have only been further differentiated as Bintulu Series where origin is certain, and evidenced by either a well-preserved terrace landform or the presence of pebble beds at depth in the profile. Bintulu has been noted in the Sibu area and in the Balingian drainage basin. It is mapped as a minor component of Soil Associations 19 and 20.

LITHOSOLS

Lithosols are a minor component of many Soils Associations in the dissected lowlands and dominant in the interior, where they cover some 20 per cent of the Area (Table 12). They have received relatively little study as both soil and terrain are major limitations to agricultural development. The differentiation of Families and Series emphasises broad parent material groups and variations in rooting depth (Fig. 28).

MELUAN FAMILY

Family definition: Lithosols in which a lithic contact is present within 25 cms of the surface.

Meluan Series

Series definition: Meluan Family soils which are residual over sedimentary rocks.

Description: Meluan Series comprises a thin mantle of loam or sand (more rarely clay) over hard coherent rock. Most rock types in the Area weather at least moderately deeply and the Series is not widespread. It is mainly confined to steeply sloping uplands underlain by hard sandstones or conglomerates, and Meluan at these sites is commonly associated with rock outcrops. It is important only in Soil Associations 1–3. An equivalent Series over acid igneous rocks may occur in Associations 6 and 7 but was not encountered.

KAPIT FAMILY

Family definition: Lithosols in which a paralithic contact is present within 25 cms of the surface but no lithic contact is present within that depth.

Kapit Series

Series definition: Kapit Family soils which are residual over sedimentary rocks and have a clay particle-size class above the paralithic contact. (The particle-size class does not refer to a control section in Lithosols).

Description: Kapit Series is, with Lalis, the most widespread soil in this Group, and is largely developed over shales. Below a thin topsoil there is an equally thin horizon of yellowish brown to strong brown clay (commonly with some weathered rock fragments) before weathered shale is met at a shallow depth. The C horizon is either soft and easily augerable or is fissile and breaks freely in sampling. Kapit is the main Series in Soil Association 4 and is a component of a number of other Associations in the upland zone.

Buri Series

Series definition: Kapit Family soils which are residual over acid igneous rocks and have a clay particle-size class above the paralithic contact.

Description: As the definition implies, Buri Series has the profile form of Kapit Series but is developed over, in this Area, granites, rhyolites and related rocks. It is confined to Soil Associations 6 and 7 and is of minor importance even in these mapping units. Almost no analytical work has been undertaken on soils of this Group, due to their low priority in the study, but it is possible that available nutrients in Buri Series are in greater supply than in Kapit. Comparison of chemical data from deeper soils over these contrasting rock types does not suggest this, however.

Binatang and Kelupu Series

Series definition: Kapit Family soils in which material above the paralithic contact is of alluvial origin, and has a clay particle-size class; the drainage class is good to imperfect (Binatang) or poor (Kelupu).

Description: On one riverine bottomland in the Binatang headwaters an area was encountered where coherent weathered shales were within 25 cms of the surface but the fine earth above this C horizon comprised a thin veneer of riverine alluvial clay. At some sites the profile was moderately well-drained but at others both the A and C horizons were strongly gleyed. Two Series, Binatang and Kelupu, were established to cover these profile forms but they were not recorded in

any other part of the Area and are of very minor importance.

LALIS FAMILY

Family definition: Lithosols in which no lithic or paralithic contact is present within 25 cms of the surface but which have horizons within this depth in which more than 50 per cent of the horizon comprises rock fragments.

Lalis Series

Series definition: Lalis Family soils which are residual over sedimentary rocks, and have a clay particle-size class in the fine earth above 25 cms depth.

Description: Lalis Series has the shallow undeveloped profile of Kapit Series but is distinguished from it by the character of the C horizon and the greater rooting depth of Lalis profiles. Kapit and Lalis commonly occur together on steeply sloping hill flanks in the interior, but Lalis is also locally dominant in some tracts of the dissected lowlands. It is of particular importance in Soil Associations 4 and 5. Where Lalis mantles steep hill flanks and essentially comprises fragmented shale rubble in a clay matrix it has been suggested, on recent studies in interior Sarawak (Eilers, in prep.), that the profile is largely colluvial or comprises a mantle which may not be accumulating but is subject to continuous downslope creep. This is accepted but the present study suggests (et seq.) that many, and possibly most, upland soils have a colluvial or slope-creep component in their development. In developing an operational soil classification it is not practicable to distinguish such soils from those of exclusively residual origin in all cases and residual and colluvial soils have been combined for purposes of the proposed classification. It is suggested, however, that colluvial soils can usefully be isolated where they mantle a recognisable landform such as a colluvial fan. These are not a feature of uplands in the Area but are reported to be prominent in some parts of interior Sarawak.

Suka Series

Series definition: Lalis Family soils which are residual over acid igneous rocks and have a clay particle-size class in the fine earth above 25 cms depth.

Description: Suka Series has the profile form of Lalis Series but is developed over acid igneous parent materials. It is therefore the equivalent in the Lalis Family to Buri Series in the Kapit Family. It is associated with Buri Series in Soil Associations 6 and 7 but is not found elsewhere in the Area.

ORGANIC SOILS

Organic Soils of varying depth are dominant on the coastal plain and deep basin peat swamps comprise over 40 per cent of the Area's map coverage (Table 12). Studies have been largely confined to the swamp margins where shallow peats and mineral soils are present. The deeper basin peats are of low fertility and present major drainage problems. They are of very low priority in an agricultural development context and consideration in this study has been largely confined to mapping their distribution. Three Families have been recognised, which separate shallow and deep Organic Soils and, in the former, distinguish on the particle-size of the basal mineral material.

The Family and Series divisions in this Group are summarised in Fig. 29. Muck series are named but are largely known from other parts of the State. Soils recorded on the study were almost exclusively peats. Muck profiles are locally present, however, and Epai Series, in particular, is found in many parts of the swamp fringe zone.

MUKAH FAMILY

Family definition: Lowland Organic Soils in which the organic mantle is not more than 1 metre in thickness, and underlying mineral layers to a depth of 1.25 metres have a clay particle-size class.

Mukah Series

Series definition: Mukah Family soils in which the organic mantle is dominantly peat and is mainly topogenic, and in which the mineral substratum to a depth of 1.25 metres lacks potential acid-sulphate characteristics.

Description: Mukah Series typically comprises a surface mantle of fibrous peat overlying gleyed clay. The underlying clay may be of marine, estuarine or lagoonal origin near the coast, and is of riverine origin at interior sites. Unless drained, the Series is continuously waterlogged. The organic mantle may comprise grass residues in areas which have been cultivated for wet rice. More normally it comprises swamp forest debris. This may range from leaf fragments to undecomposed roots, branches and log sections. In general, however, there tends to be a smaller component of very coarse material in the shallow peat soils than in the deeper peats of Anderson Family. This may be due to the lack of opportunity in the shallow peats for fallen trees to sink completely into the organic mantle and the tendency for them to remain partially at the surface and be subject to breakdown under aerobic conditions. The peats are extremely acid

and are low in plant nutrients, as is the underlying mineral material. Mukah Series is widespread near major rivers on the coastal plain and in many of the larger valley tracts in the interior. It is also important on the coastal fringes of the basin swamp zone. Near the coast Mukah is associated with soils of the Pendam, Igan and Tatau Families, among others. In interior riverine tracts it is found together with Bijat Family soils. In all areas it tends to grade to deeper peats of the Anderson Family in backswamp tracts. Mukah is dominant in Soil Association 31 and important in Association 26. It is also a component of a number of other mapping units.

Epai Series

Series definition: Mukah Family soils which meet the requirements of Mukah Series with the exception that the organic mantle is dominantly muck.

Description: Epai Series is locally present in a number of areas but is particularly associated with tracts subject to intermittent flooding and addition of mineral material to the organic mantle. Some peat layers may be present but the organic mantle is mainly muck. In other respects Epai has the characteristics of Mukah Series.

Patok and Merapok Series

Series definition: Mukah Family soils in which the organic mantle is dominantly either peat (Patok) or muck (Merapok) and is mainly topogenic and in which the mineral substratum has potential acid-sulphate characteristics at some level within 1.25 metres of the surface.

Description: Patok and Merapok are equivalent to Mukah and Epai respectively but organic mantle overlies marine clays which have potential acid-sulphate characteristics within a relatively shallow depth. These soils are confined to the coastal zone and have been mapped there together with Mukah Series in Soil Association 31 and other mapping units. Their frequency and distribution are uncertain as no formal chemical survey of the mineral substratum in these soils has been undertaken except on a few recent semi-detail survey projects for proposed drainage schemes. It is at present expected that neither Series is widespread but more detailed work in coastal areas may alter this view.

Mahat Series

Series definition: Mukah Family soils which meet the requirements of Mukah Series with the exception that the organic mantle is of alluvial origin.

Description: Mahat is a minor soil identical to Luk Series (in the Anderson Family, discussed below) except for the depth of the organic mantle. For convenience, Mahat and Luk are discussed together under the latter.

IGAN FAMILY

Family definition: Lowland Organic Soils in which the organic mantle is not more than 1 metre in thickness, and underlying mineral layers to a depth of 1.25 metres have a sand particle-size class.

Igan Series

Series definition: Igan Family soils in which the organic mantle is dominantly peat and is mainly topogenic, and in which the mineral substratum to a depth of 1.25 metres lacks potential acid-sulphate characteristics.

Description: Igan Series has the characteristics of Mukah Series with the exception that the peat mantle overlies sand rather than clay. Igan is largely confined to coastal tracts, in many of which it is quite extensive. It is commonly found in complex with sandy soils of the Tatau Family and has been mapped under Soil Association 32, in which it is dominant, and as a component of Associations 28 and 29. Very occasionally Igan Series was also recorded on bottomlands in the interior. The underlying sands at these sites may be buried riverine alluvium or outwash from adjacent hills. In no case was Igan seen to be extensive at interior locations. No muck equivalent to Igan Series was recorded but it is to be expected that such profiles are also locally present in the Area and would require a Series name when encountered. Profiles in which the underlying sands retain potential acid-sulphate characteristics are less likely.

ANDERSON FAMILY

Family definition: Lowland Organic Soils in which the organic mantle is more than 1 metre in thickness.

Anderson Series

Series definition: Anderson Family soils in which the organic mantle is mainly topogenic and is dominantly peat.

Description: Anderson Series peats mantle the bulk of the coastal plain swamplands. The organic material in the main swamp tracts is commonly 3–6 metres in thickness and three depth phases have been used within the Series: 1–2 metres (moderately deep), 2–3 metres (deep) and more than 3 metres (very deep), the third phase being most extensive. Moderately deep and deep peats generally occupy rather narrow zones on the edges of the basin swamp tract although they cover broader areas on the swamp margins near the coast. The peats are extremely acid, and

comprise forest debris of varied grade up to whole tree trunks. Nutrient reserves are very low, particularly in the interior of the larger swamp tracts. The organic mantle is largely a residual accumulation but some mineral or muck layers may be incorporated on the swamp borders, and result from intermittent riverine flooding into the backswamps. This is unusual in the Area but reported to be typical of the Series in some north Sarawak localities. The basal mineral layers are generally clays, and the Series grades on the swamp tract edges to Mukah Series. In coastal areas, however, Anderson Series is commonly underlain by old marine sands and is there associated particularly with Igan Series. The Anderson Series has mainly been mapped under Soil Associations 34–36 (where the depth phases are isolated) and in Associations 37–40, where deep peat tracts are found in complex with areas of mineral soils.

Luk (and Mahat) Series (Colour Plate 16; Plate 18)

Series definition (Luk): Anderson Family soils in which the organic mantle to a depth of more than 1 metre is of alluvial origin, and is dominantly peat.

Description: Luk Series comprises water-sorted organic material accumulated on and behind present beaches. It has only been recorded in the Tanjong Jol area of Pulau Sirik (Fig. 13) although buried horizon of such material have also been noted in Tatau and Kabong sands at some coastal sites on the northern coast west of Kuala Oya. The organic material consists of raw fragments of coarse sand to fine gravel size, well-graded, and mainly comprising (from reports on a small selection of samples referred to the State Forest Department) comminuted detritus from mangrove forest. The material is probably derived partly from the erosion of riverbank exposures of peats on the coastal plain but may also include waste from sawmills in the lower reaches of Rajang distributaries. The organic mantle overlies marine clays which, at sites investigated, have potential acid-sulphate characteristics. Profile 49 in Appendix IV illustrates the Series and is moderately deep. No deep or very deep profiles have been noted. Shallower profiles in which the organic mantle does not exceed 1 metre depth have been placed in the Mukah Family as Mahat Series. Mahat differs from Luk only in this depth characteristic. In addition to the origin of the organic material, Luk and Mahat contrast with other Organic Soils in drainage and chemical parameters. The organic material is built up as low storm ridges (Plate 18) and in the upper part of the profile is naturally



Plate 18

Pulau Bruit, the beach one mile north of Kampong Bruit, Daro Subdistrict. The beach comprises alluvial organic debris from erosion of riverbank peat exposures, coastal mangrove forest detritus and possibly some sawmill waste. This also forms the soil in the cleared zone backing the beach and this well-drained, sorted organic alluvium is used for rice nurseries, bananas and tapioca. The figures stand at the site of Profile 49 (Luk Series) where the organic mantle overlies marine clay loam at 112 cms. and the water-table was below 60 cms at the time of sampling. See also Colour Plate 16.

well-drained on sites immediately behind the coast. (Water-tables rise towards to the surface in inland tracts and at Tanjong Sirik Luk and Mahat grade inland to the more widespread waterlogged residual peat soils). These coastal soils are affected by wind-borne salts (and probably by intermittent spray and storm wave effects), have an erratic pH, a high CEC and high base saturation. There are particularly high levels of total Ca and Mg in ash analysis (Table 104). These soils, mapped as Soil Association 33, are of very little areal importance but are, in their natural state, of much greater agricultural importance than other Organic Soils and are well-exploited by local farmers in the Tanjong Sirik area.

Classification note – Organic Soils

The Families and Series identified in the Area are defined as 'lowland' Organic Soils to distinguish them from Organic Soils reported at high elevation in interior Sarawak on montane summits and on hill flanks with slopes reported to be in excess of 20°. The high-level Organic Soils have as yet received little study and a local classification of them has not been developed.

The definitions used in this Group assume a simple profile form in which an overlying organic mantle rests on a basal mineral substratum. Profiles in which organic and mineral layers alternate are rare in the Area and have been ignored in the provisional definitions of Families. Where they occur, such profiles can largely be included in established Series on the cumulative thickness of organic materials within a specified depth. A depth of 1.25 metres would be consistent with the classification as at present outlined.

CHAPTER 9

SOIL ASSOCIATIONS

The Area has been mapped in 40 soil associations. The majority of these are compound units involving soils of more than one Great Soil Group. Approximate areas covered by each Association are listed in Table 12. The Soil Families and Series recorded in them are summarised in Table 13. Terrain is classified in the broad groups detailed in Table 11.

SOIL ASSOCIATIONS 1-5

Soil Associations 1-5 comprise shallow soils on steeply sloping or strongly dissected terrain. They are derived from sedimentary rocks and are mainly Lithosols or shallow phases of Red-Yellow Podzolic Soils.

1. *Meluan Association*

The Meluan Association is mapped only in the upper Arip valley (Map 1B; Plate 12). It mantles the scarp formed by thick Nyalau Formation sandstones which bounds the valley to the north. Slopes are 30°-50°. The main soils are Meluan Series and are associated with many rock outcrops and drift boulders. The Association is not farmed and remains under primary forest.

2. *Meluan/Merit Association*

Also confined to the northeast of the Area (Map 1B), the Meluan/Merit Association mantles moderately to steeply dissected terrain (Terrain Classes 5 and 6) underlain by Nyalau Formation sediments. Merit and Bekenu Series are dominant on dip slopes and are moderately deep. Nyalau Series probably also occurs but was not recorded in areas investigated. The dip slope tracts commonly have 10°-25° slopes. Scarp faces have slopes in excess of 30° and are mantled by Meluan Series or have bare sandstone exposures. An outlier of the Association is mapped at Bt. Ransi to the north (south of Bt. Tunggal). Shallow Merit and Bekenu Series soils mantle the eastern flanks of this short ridge, Meluan and outcrops of sandstone and conglomerate the west flank. The ridge line dominantly comprises conglomerate outcrops. Slopes are highly varied but generally in excess of 25° on the ridge flanks. Dissected terrain and the fragmented distribution of tracts with moderate slopes and reasonably deep soils are the main limitation to development. The Association largely remains under primary forest.

3. *Meluan/Tunggal Association*

The Meluan/Tunggal Association mantles the Bt. Tunggal ridge in the northeast (Map 1B). This hogback has flanks of 30°-40° slopes mantled by Meluan Series and sandstone and conglomerate outcrops. These extend over the ridge-line, where hard conglomerates are dominant. The narrow gently-sloping ridge-line also, however, includes tracts of shallow Podzols of Tunggal Series, the solum resting directly on rock and the Bh horizon largely comprising humus infill in structural cracks in the R horizon. Bako Series is also locally present.

The Association is extended eastwards to included Bt. Ladong and the western extremity of the Bt. Keladan ridge on the border of the Area. Bt. Ladong was not investigated but at Bt. Keladan soft sandstones were found to be more widespread than hard conglomerates and deeper

Table 11

Terrain Classification

Terrain Class	*Slope Range*	*Amplitude of Relief*	*Landform Type*
1	less than 5°	Negligible	Bottomland flats and swamp plains
2			Upland flats
3	less than 10°	less than 50 feet	Gently undulating terrain
4	10°-20°		Rolling terrain
5		50-150 feet	
6	20°-35°		Strong rolling terrain
7		more than 150 feet	
8	more than 35°	no limit	Steeply sloping terrain

Podzols of Silantek Series are found in complex with Meluan and with rock outcrops. A Meluan/Silantek Association would be more appropriate for this locality, which has been combined in Association 3 for mapping convenience.

The Meluan/Tunggal Association has very low agricultural potential and has not been farmed.

4. *Kapit/Lalis Association*

The Kapit/Lalis Association is dominant in the interior highland zone covering (a) the headwater areas of the Oya, Mukah and Balingian drainage basins (Map 1B) from which it extends along major ridges into the dissected lowland belt; (b) in much of the Kanowit, Julau and Krian headwaters (Map 1A);and (c) as fragmented tracts of higher uplands from Julau west to the Sabankoi ridge. The Association has been mapped over some 15 per cent of the Area (Table 12). Plates 3, 8 and 9 include portions of it.

In the main interior tracts the Association covers a series of high strike ridges with steeply-sloping and dissected flanks. Terrain Class 7 is dominant with some Class 8. Slopes are commonly 30-45°. Some footslope areas of 20°-30° are present but footslopes are generally not extensive, if present at all. Gentle slopes are largely confined to narrow ridge-line zones. The Association is underlain by Belaga Formation shales and sandstones.

Resistant sandstones may form the spine to the main strike ridges. The soil mantle is variable but generally thin. Shallow phases of Merit, Bekenu and, less commonly, Nyalau Family soils are present but the dominant soils are Kapit and Lalis Series. Weathered shale fragments may litter the surface of steep slopes cleared for hill rice and affected by surface erosion but rock outcrops are few and are generally confined to sandstones exposed in gully bottoms. Meluan Family soils are rare.

The Association grades into other Associations (particularly 4, 10, 11 and 13) which mantle rather less dissected terrain and have somewhat deeper soil mantles but there is rarely an abrupt boundary between them. The Kapit/Lalis Association has therefore been mapped mainly on a terrain basis.

Some parts of the Association have been cleared for hill rice (Plate 3) but the main interior tracts have a primary forest cover (Map 4). Terrain, soil depth and erosion hazard are major limitations to agricultural development but the extension of cultivation into this unit has been more influenced by accessibility than by topography.

5. *Lalis/Merit Association*

The Lalis/Merit Association covers a number of tracts fringing the montane zone in the Lemai Sarupai and Kanowit areas (Map 1B) and north of the Julau River farther west. It comprises dissected terrain with an amplitude of less than 150 feet (mainly Terrain Classes 6 and 7 and dominantly underlain by shales. Slopes range from 10° to 30° but are dominantly 20°-25°. The soils are largely clayey and are rarely more than

moderately deep. In the Lemai and Sarupai areas shallow Merit, Kapit and Lalis Family soils are dominant, with minor occurrences of moderately deep Merit, Bekenu and Nyalau soils. In the Kanowit area, where the Association mantles the fragmented hills and strike ridges bordering the swamps of the Rejang floodplain, shallow Merit and Lalis are the main soils, with some Kapit. Bekenu and Nyalau soils were not noted. Shallow Merit and Lalis are also dominant north of the Julau River where the Association extends to the Pakan area, in complex with Association 4. Near Julau itself Merit Family soils commonly have a prominent quartz gravel stoneline in the subsoil which further limits their useable depth. Portions of the Association are illustrated in Plates 3 and 9.

The Association contrasts with the Kapit/Lalis Association in amplitude of relief and has marginally deeper soils on somewhat less steep slopes. Terrain and soil depth remain important limitations, however. The Association has largely been cleared by Iban for hill rice, and rubber has been planted in some areas on a very small scale. Some tracts remain under forest where better adjacent land is available for planting but most have been used at some time in the past and have a secondary cover.

Soil Associations 6-7

Soil Associations 6 and 7 comprise upland soils derived largely from acid igneous rocks. Red-Yellow Podzolic Soils are dominant, with some Lithosols. Neither Association covers extensive areas.

6. *Piring Association*

The Piring Association comprises the soils mantling the Bt. Piring ridge in the northeast (Map 1B). The soils are derived from granodiorite, granophyre, granite or hornfels. The ridge is a hogback with less than 10° slopes through much of the summit zone but which steepens rapidly to 30°-40° on the flanks. Locally the flanks are even steeper and some on the southern flank comprise almost vertical rock exposures. The ridge is surrounded by a narrow footslope zone of dissected hills.

The soils are varied and the three traverses by which the unit was investigated gave different patterns. In the east Piring Series is dominant on the lower and middle slopes, while Changgan Series occupies the summit zone. In the central traverse, following the main path which crosses the ridge, Piring is dominant on the south and Abok Family soils which probably correlate with Arip Series to the north. No Changgan profiles were recorded. Changgan recurs farther west as the main summit soils, however, and here the flanks have mainly soils of intermediate texture (Abok Family). At its western extremity the ridge grades to undulating hills with 5°-20° slopes and a dominantly Changgan soil mantle. Profile 25 (Piring) in Appendix IV was sampled from the eastern end of the ridge; Profile 23 (Changgan) from the lower hills to the west.

All soils sampled were moderately deep to deep, despite the steep slopes of the hill flanks. There appears to be a rapid transition from a deep mantle to bare rock exposures on the steepest slopes. Lithosols (Buri Series) are present but appear to be inextensive.

The lower hills to the west of the main ridge have been settled and planted, largely with rubber. There has been sporadic clearance of some tracts on the ridge line where slopes are also moderate. Elsewhere the ridge itself has not been planted, steep slopes being a major limitation. The main point of development interest in this unit is as a source of good road metal, which is otherwise rare in the Area.

7. *Arip Association*

The Arip Association is confined to the northeast (Map 1B) and comprises the soils associated with the major ridge which bounds the upper Arip valley to the south (Plate 11). The ridge is formed of rhyolites and other rocks which also form more fragmented hills farther west towards Bt. Piring. These hills have also been mapped in the Arip Association.

The geology is mixed in this unit and the soil pattern complex. The lavas and tuffs which are dominant rest on sandstones and shales which are locally seen to outcrop on the ridge itself. At some points shallow Merit and Kapit profiles from shale, and Meluan soils from sandstone, were noted on the ridge and at one site a light grey coarse sand overlying weathered conglomerate (and classed as Tika Series) was also recorded. In general, however, the soil mantle is derived from acid igneous rocks and represent Series in the Serin and Abok Families.

The main unit of the Association comprises the Arip ridge, with flanks of 25°-40° slopes, a shallow soil mantle and many rock outcrops and large surface drift boulders, and its shelving footslope with slopes of 5°-20°, steepening towards the ridge. The footslope has moderately deep to deep Arip Series soils in localities investigated, while shallow Arip profiles and Lithosols (Buri Series) mantle the steep ridge flanks. On the northern borders of the unit in the upper Arip valley a zone of small limestone outcrops extends for some

Table 12

Calculated area of Soil Association mapping units

	Soil Association	*Square miles*	*Hectares*	*Acres*	*Percentage of Area*
1.	Meluan	1	280	690	<1
2.	Meluan/Merit	18	4,600	11,000	<1
3.	Meluan/Tunggal	2	480	1,100	<1
4.	Kapit/Lalis	916	237,000	587,000	15
5.	Lalis/Merit	233	60,000	149,000	4
6.	Piring	5	1,200	3,000	<1
7.	Arip	12	3,000	7,500	<1
8.	Merit	63	16,000	40,000	1
9.	Merit/Jakar	16	4,000	10,000	<1
10.	Merit/Bekenu	87	23,000	56,000	1
11.	Merit/Nyalau	440	114,000	282,000	7
12.	Merit/Kerait	39	10,000	25,000	<1
13.	Bekenu/Kerait	425	110,000	272,000	7
14.	Bekenu/Saratok	31	8,000	20,000	<1
15.	Saratok/Kerait	9	2,300	5,600	<1
16.	Ajoh/Penipah	8	2,100	5,100	<1
17.	Nyalau/Silantek	57	15,000	37,000	<1
18.	Silantek/Bako	<1	80	200	<1
19.	Tika	2	520	1,300	<1
20.	Buso/Tika	16	4,000	10,000	<1
21.	Buso/Metading	12	3,200	7,900	<1
22.	Buso/Tatau	10	2,700	6,600	<1
23.	Miri	2	560	1,400	<1
24.	Seduau/Lupar	25	6,400	16,000	<1
25.	Seduau/Bijat	106	27,000	68,000	2
26.	Bijat/Mukah	123	32,000	79,000	2
27.	Tatau/Kabong	44	11,000	28,000	<1
28.	Tatau/Igan	19	4,900	12,000	<1
29.	Tatau/Pendam	16	4,100	10,000	<1
30.	Rajang/Pendam	382	99,000	245,000	6
31.	Mukah	122	32,000	78,000	2
32.	Igan	39	10,000	25,000	<1
33.	Luk	4	1,100	2,700	<1
34.	Anderson (moderately deep)	258	67,000	165,700	4
35.	Anderson (deep)	225	58,000	144,000	4
36.	Anderson (very deep)	2,135	553,000	1,400,000	35
37.	Bekenu/Anderson	43	11,000	27,000	<1
38.	Buso/Anderson	28	7,200	18,000	<1
39.	Bijat/Anderson	140	36,000	90,000	2
40.	Pendam/Anderson	76	20,000	49,000	1
–	Disturbed Land*	3	720	1,800	<1

Calculations are based on point-counts from 1:50,000-scale compilation sheets and have been rounded to gross figures.

*Only the main built-up areas (Sibu and Sarikei) are indicated on Map 1.

distance but does not appear to affect the soil mantle.

The outliers of the Association to the west comprise hills with varied slopes (15°-35° being recorded on the flanks) but a largely similar Arip (with some Buri) soil mantle. In some cases, as at Bt. Tubau, coarser-textured soils were recorded which may correlate with Changgan Series although no analytical data are available. On lower hills between these outliers, however, heavy clays of Nyaroh Series were encountered. It is uncertain whether this soil is derived from acid igneous extrusives or from highly-metamorphosed sediments adjacent to them. The former seems most likely.

Baillie (pers. comm.), investigating sample areas in the Arip valley for other purposes, encountered weak red profiles which physically resemble the Keladan Series recorded in west Sarawak. This Association is obviously complex and more detailed work would be required to establish the range of soils present in it.

The Association is largely unfarmed although Plate 11 shows some recent clearances for hill rice extending through the footslope zone up onto the dissected ridge flanks. The footslope tracts appear to have some development potential, although the primary forest cover was of low quality in areas investigated and may reflect a relatively high fertilizer requirement on Arip Series. This is not indicated in available chemical data (Table 63) but requires investigation.

Soil Associations 8-14

Soil Associations 8-14 mainly comprise shallow to deep Red-Yellow Podzolic Soils mantling dissected uplands underlain by sedimentary rocks. Grey-White Podzolic Soils and soil of other Groups are present in most Associations in this group but are never extensive.

8. *Merit Association*

Soils of the Merit Family are important in a number of Associations but are normally encountered in complex with soils of other Families. In a few areas where the underlying lithology is predominantly argillaceous, however, the soil mantle is almost entirely of this Family. Where possible, these tracts have been isolated as a Merit Association.

The Association occurs, firstly, in the upper Arip valley (Plate 11) where Merit Series mantles low undulating hills between the Arip ridge and the Nyalau Formation scarp. Slopes are less than 10° (Terrain Class 3). The profile is moderately shallow to deep and is commonly imperfectly drained. Secondly, it is mapped in the Sarupai-Maong area to the north of the Arip valley. Here the Association mantles rolling hills, mainly of Terrain Class 5, underlain by Tatau Formation shales. Slopes are varied but are commonly of 10°-25°. Soils are moderately shallow and Kapit Series is locally present on the steeper slopes. Thirdly, and in the same northeastern locality, is a zone of low hills (Terrain Class 4) surrounding the Bt. Piring ridge. Classification here is more problemmatical. Soils with the normal Merit Series form are common but are associated with deep uniformly yellowish brown clays similar to the form of Nyaroh Series. Parent materials are uncertain but may comprise sedimentaries which have been heavily metamorphosed by close proximity to the igneous intrusion. Fourthly, the Merit Association mantles parts of the dissected lowlands near Kanowit and Machan (Also Map 1B). Slopes are generally less than 25° and the Association extends over a number of low, gently sloping hills isolated by a bottomland tracts on the fringe of the Rajang swamps. Merit Series is dominant. Jakar, Bekenu and Kerait Series are locally present. Finally, an extensive tract in the extreme south (Map 1A) near Saratok has been mapped in more strongly dissected terrain (Class 5-6) with highly varied slopes of up to 30°. Both Merit and Jakar Series are common here, with Nyalau and Kerait Series recorded locally. There is no clear division between the Association in the Saratok area and adjacent units (Association 11 and 13). The boundary between them has been drawn rather arbitrarily on traverse records. In all five localities the Merit Association has been extensively farmed for hill rice and, except in those tracts in the northeast, for rubber. Some pepper and other crops are also noted in the Kanowit and Saratok areas. While soil depth is variable, the main agricultural limitation other than the rather low nutrient status common to most Sarawak upland soils is that of terrain. This limitation is least in the gently undulating Arip valley and greatest in strongly dissected parts of the Saratok area.

9. *Merit/Jakar Association*

Jakar Series is a component of many Associations but is generally less extensive than Merit Series, its yellow associate. It is dominant, however, in the Jakar area, where a Merit/Jakar Association has been isolated. The boundaries between it and the adjacent Bekenu/Kerait Association are based on traverse records and are somewhat arbitrary. They mantle the same confused terrain (Plate 11).

The topography is here typical of the dissected lowlands, comprising hills with summit areas of 5°-15° slope dropping to flanks of 15°-25°. Terrain

class 5 is dominant; moderately deep soils are locally present in the summit areas but moderately shallow soils on the hill flanks. The main Series are Jakar and Merit Series although Bekenu, Sarikei and Nyalau Series are also locally present.

The unit has been extensively farmed for pepper, rubber, hill rice and other crops. Many of the pepper areas have shallow eroded soils. Soil depth and terrain are important limitations in the unit but, as the landscape around Jakar shows (Plate 13), considerable agricultural use is possible with careful terracing.

10. *Merit/Bekenu Association*

The Merit/Bekenu Association occurs in three localities: the Sarupai headwaters in the extreme northeast, the Kemena drainage basin to the south of the Arip ridge, and between the Mukah and Balingian Rivers bordering the Lemai swamps on their southern edge. The Association is underlain by mixed sedimentary rocks of Belaga and later age. The terrain is varied but is dominantly of Terrain Classes 4 and 5.

Soils are mainly of Merit and Bekenu Series and are moderately deep to deep. A stoneline of iron-enriched rock fragments is common, however, and reduces the rooting depth to some extent. Nyalau Series is locally present in all parts of the Association but is never extensive. In the tract between the Mukah and Balingian basins there are minor occurrences of Kerait, Bandang, Saratok and Silantek Series, and the sporadic inclusion of pallid Grey-White Podzolic Soils in the complex mantle becomes more frequent towards the north. In that locality the shales commonly weather to a pallid clay and Merit profiles commonly comprise a uniformly yellow clay loam over clay which grades to a pale yellow or light grey clay at depth and which lack a stoneline. Portions of the Association are included in Plates 9 and 11.

In the Sarupai-Maong and Kemena areas much of the Association remains under primary forest, reflecting a low population density and a concentration of farming on more accessible land. Clearance for hill rice is extending into these areas, however, and the recent clearances to the south of the Arip ridge in Plate 11 are within this unit. To the south and west of the Lemai basin the Association is extensively farmed for hill rice, although some forest tracts remain on the watershed between the Lemai and Mukah Rivers. Slopes are a limitation in some areas and all soils are relatively low in plant nutrients but the unit offers considerable scope for agricultural development and part of the tract between the Mukah and Lemai Rivers has recently been included in a Government oil palm development scheme.

11. *Merit/Nyalau Association*

The Merit/Nyalau Association covers wide areas to the north of the Rajang River, in the dissected lowlands drained by the Oya and Mukah Rivers, where it extends into ribbons of land with relatively low amplitude in the interior; in the hills which extend towards the coast and form the watershed between the Mukah and Balingian drainage basins; and, less extensively, in the Arip-Sarupai area in the northeast. The main tract is underlain by shales and sandstones of the Belaga Formation; to the east of the Mukah River the unit is associated with younger sediments.

The terrain comprises moderately rolling hills of Terrain Classes 5 and 6 (Plates 2 and 10). Some gently undulating terrain of Classes 3 and 4 is included but is largely confined to areas fringing the swamp plain.

The soils are dominantly Merit, Bekenu and Nyalau Series, either in complex or alternating over reasonably broad distances. On the reconnaissance level data available further subdivision of the unit was not possible but traverse records suggest that moderately large tracts of both Merit and Nyalau Series could probably be separated by semi-detailed survey within the unit. While Red-Yellow Podzolic Soils are dominant in the Association minor inclusions of Grey-White Podzolic Soils, Regosols and Podzols were also found.

In areas draining to the lower Mukah and Balingian Rivers Merit Series is generally dominant, although Nyalau is important in the Anak headwaters and on the lower hills bordering the swamps of the Bawan and Lemai drainage systems. In the Mukah and Oya headwaters Merit and Bekenu Series appear to be dominant but Nyalau becomes more important farther west and south. Nyalau is the main soil mantling the higher hills of the Oya Road Forest Nursery and the nearby Agricultural Station, where Pasai Series is also found. At Sibintek and in the Sekuau area, farther northeast, a Merit-Bekenu-Nyalau complex is dominant. Parent material exposures on the Sibu-Balingian trunk road, which crosses the Association, show that the lithology is varied both in type and in thickness of strata. Dissected hills with a uniformly loam or clay soil mantle therefore grade laterally into hills in which the soil mantle varies greatly in texture over short distances and compound mapping units must be employed even at a semi-detailed level of investigation.

Despite the varied slope the soil mantle in this Association is mainly moderately deep to deep. Moderately shallow soils are generally confined to the steeper gully segments of the terrain. Low inherent fertility and varied slope are limitations to agriculture but the Association is widely used for hill rice cultivation and near the trunk road hill and the main rivers rubber and some pepper are also found. Current oil palm development in the Mukah-Balingian hills is partly based on this Association.

12. *Merit/Kerait Association*

13. *Bekenu/Kerait Association*

14. *Bekenu/Saratok Association*

Soil Associations 12-14 mantle hills of Terrain Classes 3-5 and comprise Red-Yellow Podzolic Soils with subordinate Grey-White Podzolic Soils. Association 12 is largely a complex of Merit and Jakar Series with some Kerait Series. It is confined to the fringes of the 'Sibu Bay' area in the Binatang-Genting and Sg. Salim localities. Association 14 is also of restricted extent and is confined to tracts in the middle Oya. Here soils have a broader range of texture and comprise a complex of Merit, Bekenu and Nyalau Series with subordinate Timang and Saratok Series. Nyalau Series is commonly more extensive than other Red-Yellow Podzolic Soils in the Unit and the Grey-White Podzolic Soils are largely found on lower hills of Terrain Class 3 or footslope sites where they may be mainly colluvial.

Association 13, in contrast, covers a broad tract in the west of the Area, extending from Saratok through the Jakar area to the headwaters of the Assan River. It has also been locally mapped in the Kemena basin in the northeast. Both terrain and soils are confused in this unit and semi-detailed survey of some areas failed to isolate Series mapping units. Fig. 32 illustrates a tract in which the lower dissected hills are mapped under Association 13, while the higher and more steeply sloping tracts are largely combined in Association 4 at reconnaissance mapping scale. In Association 13 Merit, Bekenu and Nyalau Series are dominant but some Kerait, Timang and Saratok soils are also present and the summits of hills formed of resistant shale beds commonly have a shallow Merit, Lalis or Kapit mantle. Jakar Series is common between Sarikei and Saratok. Nyalau, Bekenu and Kerait Series are dominant in the Kemena outlier of the Association but Merit is less extensive there. Saratok and Tika Series were also noted.

Low inherent fertility together with varied slope and erosion hazard are the main agricultural limitations in these Associations but they are heavily farmed for hill rice and, to a lesser extent, for other food crops, rubber, fruit trees and pepper. The Grey-White Podzolic Soils and Regosols are avoided to some extent where they cover large areas but elsewhere they are included in the farmed area. The Association includes the Meradong rubber development scheme (Plate 12), where Nyalau, Bekenu and Saratok Series are dominant, and much of the long-established rubber and pepper smallholding development of the Jakar-Sarikei-Binatang area (Plate 13). Portions of the Association are also illustrated in Plates 4-6.

Soil Association 15

15. *Saratok/Kerait Association*

This mapping unit combines a number of localised Associations in which Grey-White Podzolic Soils are dominant, although other soils also occur. It has been mapped in five areas, each comprising low undulating hills (Terrain Classes 2 and 3) on the hill/swamp borders or as outliers in the interior part of the coastal swamp plain. Near the Kemena River in the northeast a scatter of low hills is mantled by Kerait Series with some Saratok and Nyalau. In the Lemai basin Kerait and Bandang Series mantle long shallow slopes on the swamp fringe in two areas. Saratok and weakly developed Podzols of Silantek Series were also recorded. Both at Kemena and Lemai the soils of the unit are considered to be residual. In the lower Mukah basin, near the mouth of the Sikat River, low rises from the swamp plain are mantled by Kerait in complex with Buso Series. The Podzols here may be developed in old marine alluvium although the site is rather far from the present coast. Near Machan on the lower Kanowit a small tract is mantled by Tika Family sands together with Saratok loams. The sands are believed to be old riverine alluvium (Bintulu Series). The Saratok soils may be residual but the origin of their parent materials is less certain. Finally, near Selalang, terrace flats are mantled by Tika sands and Buso podzols, with Kerait clays on low rises. The Regosols and Podzols here are developed in old marine alluvium. The Kerait profiles are presumed to be residual although this is not certain. There is, however, no instance elsewhere of Grey-White Podzolic Soils developed in alluvial clays on marine terraces.

Slopes are not a limitation in these areas but the Regosols are droughty and the Podzols commonly have slow surface drainage. All soils concerned have very low inherent fertility and they have generally been avoided by farmers. Areas which have been cleared in the past for hill

rice are largely now found under poor regrowth. Parts of the tract near Selalang remains under primary Heath Forest.

Soil Association 16

16. *Ajoh-Penipah Association*

This Association covers two tracts of Class 2 terrain in which Hydromorphic Upland Soils are dominant. Firstly, an extensive upland flat in the Pasai headwaters is briefly crossed by the Sibu-Oya Road and is partly included within the Oya Road Forest Nursery. On the flattest portions of this unit Ajoh Series is the main soil. In more undulating areas, an example of which is given in Fig. 34, somewhat better-drained profiles are found and Merit or Ajoh-Merit intergrades are dominant, together with Kerait. Secondly, an upland flat in the Penipah area east of Mukah, is mantled by Ajoh and Timang Series, with Merit and Jakar clays on low rises. Both areas have slow surface drainage, intermittently high water-tables and low inherent fertility. They are largely uncultivated and areas which have been cleared in the past for hill rice have been abandoned to a poor regrowth cover.

Soil Associations 17-23

The following seven Soil Associations mainly comprise Podzols or Regosols in Association with other profile forms or as a monoseries unit. In some cases a number of field mapping units which cover small areas and have common soil properties have been combined for mapping convenience.

17. *Nyalau/Silantek Association*

The Nyalau/Silantek Association occupies a belt on the swamp margins of the hill zone which extends, with intermittent breaks, from Bawang Assan on the Rajang River to the Bakong headwaters in the lower Mukah. Beyond the Mukah River it is extensively mapped in the Mukah-Balingian hills. Minor occurrences also occur in the Balingian basin. The Association comprises low hills of Terrain Classes 3 and 4 underlain by sandstones with subordinate shales and mantled by a complex of Red-Yellow Podzolic Soils and Podzols. Of the former Nyalau Series is dominant but Bekenu and Merit Series also occur. Of the latter the majority of profiles examined have been classified in Silantek Series although there remains some doubt in many cases whether the profile is developed in entirely residual material. While sandstone structures are commonly seen in the C horizon, the overlying sands in which the solum has developed may represent a thin surface capping of old marine alluvium at some sites. Silantek Series occupies the gently sloping upper slopes and summits. Nyalau Series, or other Red-Yellow Podzolic Soils, are found on the hill flanks or mantle the entire hill unit in localities with somewhat more dissected topograhy and rather steeper slopes. Tika, Saratok and Buso Series were also locally noted.

Except where Podzols comprise the mantle over a large area, this unit has for the most part been cleared in the past for hill rice. Low nutrient status, coarse textures and droughtiness are limitations here, however, and, where investigated, much of the unit appears to have been abandoned to poor regrowth.

18. *Silantek/Bako Association*

A minor area in the Sarupai headwaters comprises a footslope belt mantled by Silantek, Bako and Tika Series. Other minor occurrences of Silantek Family soils in the Lemai and Anak drainage areas have been included in the unit although in these cases the Podzols may be developed in riverine alluvium and be classed in Buso Series.

19. *Tika Association*

Tika Family soils are generally a minor component of the soil mantle and occur in a number of mapping units. One large tract in the Kemena drainage basin has been isolated and a second farther north near the Balingian River. It is uncertain whether the parent materials are coarse sandstones or old riverine alluvium. A minor tract of coarse wet-land sands has also been included in the unit for convenience. It infills a valley draining to the Basai River in the Lemai basin. Parent materials are uncertain here also. It appears likely that they are old riverine deposits and their present poor drainage suggests classification in the Plan Family of Gley Soils. The soils in the Association have low agricultural value and are unfarmed.

20. *Buso/Tika Association*

Seaward of the Nyalau/Silantek Association on the interior swamp margins the undulating hill country drops to a zone of terrace flats comprising old marine sands. The soil mantle is a complex of Podzols and Regosols of the Silantek and Tika Families respectively. The alluvial origin of the parent materials places them in Buso and Bintulu Series for the most part. These soils extend with Association 17 from Bawang Assan to the Mukah-Balingain Hills but while much of the unit west of the Oya River can be isolated on air photographs as a Buso/Tika Association other tracts are more difficult to bound, as they

comprise very low rises in complex with swamp tracts under a common cover of disturbed forest. A compound mapping unit (Association 38) has been necessary in such areas. These soils have very low agricultural value and are not farmed. Some tracts have a Heath Forest cover, others a secondary cover indicating abandoned past clearances.

21. *Buso/Metading Association*

22. *Buso/Tatau Association*

Podzols of Buso Series, together with less well-expressed profiles classed as Metading Series, form the soil mantle in some coastal sand tracts where the sand deposits are somewhat above the permanent water-table. The larger areas of these soils have been isolated as a Buso/Metading Association and occur near Jerijei (Map 1A) and between Mukah and Balingian (Map 1B). In many localities these soils occupy low ridges and intervening depressions have poorly-drained Tatau soils. Where the latter cannot be isolated (at Jerijei, Kabong and between Kuala Matu and Mukah) a Buso-Tatau mapping unit has been employed. Examples of the complex patterns which develop in the coastal deposits are shown in Figs. 35, 37 and 39. The soils of these Associations are infertile but, perhaps due to their accessibility to coastal communities, they have in part been cleared for coconut and vegetable crops. Many tracts are now under a secondary cover, however, and appear to have been abandoned by local farmers.

23. *Miri Association*

Well-developed Podzols with cemented Bh horizons (Miri Series) mantle some marine terrace sand tracts in the west (Map 1A) near Saratok, Roban and Tanjong Mani, and are also dominant in similar deposits near Kenyana (Map 1B). The occurrence near Roban appears to be found in storm-beach material, as there is a high content of pebbles. Elsewhere the sands are better-sorted. Colour Plate 12 illustrates a Miri profile from the Tanjong Mani tract. These soils are infertile and are largely unfarmed.

Soil Associations 24-30

The Associations next described cover the Alluvial and Gley Soils of interior valleys, tracts bordering the major rivers, the Rajang delta and the coastal zone. Where Gley and Organic Soils cannot be separated at the reconnaissance mapping scale a compound unit has been employed.

24. *Seduau/Lupar Association*

In the upstream portions of some major river valleys (particularly those of the Oya and Mukah) there is a narrow but mappable floodplain tract but stream beds are incised and the floodplain soils largely well-drained. High-level terrace remnants are present at some points. Soils in these tracts which are developed in recent or subrecent alluvium are mapped as a Seduau/Lupar Association. Seduau, Malang and (on the river Banks) Bemang and Semilajau Series are the main soils encountered. Kayan Family soils are rare. Lupar and, less commonly, Sabangang Series occur on terrace sites, and Sebaya Series has also been noted on terraces in the lower Kanowit (Fig. 36). The soils of the Association are well-drained, generally deep, and for the most part relatively fertile. They also occur close to major waterways. They have therefore been extensively cultivated for rubber, fruit trees, vegetables and, less commonly, for pepper.

25. *Seduau/Bijat Association*

26. *Bijat/Mukah Association*

The majority of riverine floodplain tracts have a silty or clayey soil mantle. Loams and sands, if present, are generally confined to the river banks themselves and may be associated with a low levee. There is also commonly a progression back from the river bank from well-drained to poorly-drained soils. A common Series sequence from the river bank to the bottomlands behind it is therefore: Seduau (or Malang) – Bijat – Sebandi – Mukah. Semilajau or Kayan may replace Seduau on the river bank itself. Pakan may be dominant in poorly-drained areas rather than Bijat. If the bottomland tract is narrow Organic Soils may not be present and Bijat or Sebandi Series may extend to the foot of adjacent hills. On the coastal plain itself, however, the mineral alluvial soils commonly form only a narrow ribbon adjacent to the river, and the sequence here continues to progressively deeper peats of the Anderson Family. Some interior valleys on the hill/swamp fringes have been infilled by the spreading peat mantle and have a shallow or deep Organic Soil cover. In mapping these soils a distinction has been made between tracts in which there is a significant zone of well-drained Alluvial Soils associated with the bottomland Gleys (Seduau/Bijat) and those where such soils are either absent or form a very narrow river-bank zone, the main soils associated with the river then being Gley and shallow Organic Soils (Bijat/Mukah). The Seduau/Bijat Association is mainly mappable along the Rajang River upstream of the delta, and in the lower courses of the Mukah and Krian Rivers. The lower and middle courses of other major streams generally only have a narrow belt of well-drained alluvium near the river bank itself and have been mapped under the Bijat/Mukah Association.

These soils are of relatively high fertility by Sarawak standards. They are also found close to streams which are both the main arteries of communication and the primary focus for population concentrations. They are therefore extensively used for agriculture. The Gley Soils are cultivated for wet rice (single-cropped and commonly planted on a semi-shifting cultivation system) and vegetables. In the lower Oya and Mukah Rivers, and to some extent elsewhere, sago is also planted on them. The river-bank Alluvail Soils are used for rubber, fruit trees and, near the Rajang River in particular, for pepper.

27. *Tatau/Kabong Association*

28. *Tatau/Igan Association*

29. *Tatau/Pendam Association*

The sand complexes in the coastal zone give a variety of soils. Except where subrecent sands are somewhat above the permanent water-table and Podzol profiles have developed, variations are largely dependent on drainage. In the simplest situation well-drained Kabong Family soils are found immediately behind the beach and a Tatau-Matu-Igan succession forms a zone between them and the deeper Organic Soils of the swamp plain. More normally, however, the sands comprise a series of gentle undulating ridges and swales, in which drainage state varies greatly over short distances. There is then a repeating sequence of Kabong or Tatau soils on the higher and better-drained points, with shallow peats (Matu or Igan) overlying waterlogged sands in the intervening depressions. In some areas sand ridges alternate with clay swales and the latter have soils of the Pendam or Jol Series.

These variations cannot be separated at a reconnaissance level but semi-detailed surveys have been completed in a number of coastal tracts for development scheme planning and, particularly in those localities, some subdivision of the coastal sand complexes is possible. The Tatau/Kabong Association comprises areas in which some of the sands are well-drained (Kabong Family) although the Majority are Gley Soils of Tatau Family. Matu Series is present but deeper peat soils generally absent. The Tatau/Igan Association covers tracts in which almost all soils are poorly-drained and shallow Organic Soils (Igan Family) alternate with Tatau and Matu Series. Where Pendam or Jol Series are important in depression sites, a Tatau/Pendam Association has been mapped. Podzols (Buso and Metading Series) are locally present in these Associations but are not extensive. (Where Podzols are important the area has been mapped under Association 22, above).

Fig. 39 illustrates in section the complexity of the soil mantle in these tracts and the relationship between the profile form and minor changes in elevation. Figs. 35 and 37 show details of the soil pattern in two localities which have been partly mapped under these units. Plate 16 also refers.

Low fertility and generally poor drainage are major limitations in these areas. The coast is relatively heavily settled, however, and the coastal sands have been used for coconut, and for water-melon and other vegetables.

30. *Rajang/Pendam Association*

Soil Association 30 covers the saline marine clays of the Rajang delta and more localised tracts of these soils in other estuarine areas. Rajang and Pendam Family soils comprise the unit. Some shallow Organic Soils and sandy Gley Soils may also be present but are of minor extent. The proposed classification distinguishes Rajang and Pendam soils on potential acid-sulphate characteristics rather than salinity (which was the prime criterion in 1966). On this definition soils of the Rajang Family are dominant in the unit and Pendam soils are relatively restricted.

Although nutrient levels are high in these soils, acidity, sulphide levels and poor drainage are major limitations in the unit. Most areas have not been farmed and remain under a mangrove cover. Some fringe tracts have been cleared for wet rice or other crops in the past and in some of these areas shallow drainage has successfully brought small tracts into continuous use. Other farming ventures have been abandoned, however, due to the difficulties of water control or to the development of acid-sulphate conditions following drainage. Present cultivation in the unit centres on tracts of Pendam Series bordering areas of other more easily cultivated soils.

Soil Associations 31-36

The six following Associations cover the Organic Soils dominant on the coastal plain and in embayments and some interior valleys on the borders of the hill zone.

31. *Mukah Association*

Soil Association 31 largely comprises soils of the Mukah Family. Inland from the coast it typically occupies a transitional position between the Gley Soils near major river courses and the deeper Organic Soils of interfluve areas in the plain. Mukah Series is dominant. Epai Series (Fig. 25) has not been noted but is expected to be locally present. The Association is also mapped in parts of the Rajang delta and in the Matu-Daro area. In these areas the clays underlying the organic mantle are of marine or estuarine origin.

Mukah Series remains dominant but some Patok (and possibly Merapok) soils with potential acid-sulphate characteristics are also present.

The Association remains under peat swamp forest in many places but tracts adjacent to nonsaline Gley Soils are commonly included in blocks cleared for wet rice cultivation. Shallow phases of the Mukah Family are, logically, used to a greater extent than the deeper peats, where mineral layers are below the general rooting zone and drainage improvement is more difficult. Sago is grown on the soils of this Association in many coastal areas.

32. *Igan Association*

Areas mantled mainly by shallow Organic Soils of the Igan Family have been isolated in Association 32. Only Igan Series has been differentiated in this Family. It is a component of a number of coastal soil associations but is mainly dominant in a belt along the northern coast as a transitional zone between coastal mineral soils and the deep Organic Soils of the coastal plain. Along the coastal margins of the swamp plain basal sands extend under the peat blanket for some distance in many areas (Map 3). They have only been isolated in the soil classification, however, where they occur within 1 metre of the surface.

Igan Series is an infertile soil and is generally not farmed except where it occurs in complex with other superior soils. This Association largely remains under peat swamp forest.

33. *Luk Association*

Association 33 isolated the minor areas of Mahat and Luk Series mantling the littoral zone in much of the Tanjong Sirik area. These soils are of no significance in the Area as a whole but are exploited in this locality for bananas, vegetables and rice nurseries, where they are the only soils with reasonably good surface drainage and relatively high nutrient status.

34-36. *Anderson Association*

The Anderson Family, comprising peats deeper than 1 metre, are dominant on the swamp plain and in some interior valleys. They have been mapped in three Associations which distinguish peat depth phases, as follows:

34: peats 1-2 metres deep, (moderately deep)
35: peats 2-3 metres deep, (deep)
36: peats more than 3 metres deep, (very deep)

The soil map (Map 1) indicates that in the coastal zone itself and along the lower courses of major rivers crossing the plain the thickness of the peat mantle tends to become greater over a broad zone and the depth phase Association can, in most areas, be mapped at 1:125,000 scale. On the interior margins of the swamp plain, however, the peat mantle has infilled many stream valleys and it is more common for there to be an abrupt transition from the hill foot to deep peats. In most interior areas Associations 34 and 35 cannot be isolated at this scale. In some localities this is also the case in large-scale mapping (Fig. 38). Plates 8 and 15 illustrate portions of the Association, outliers of which are also included in Plate 14.

The deep Organic Soils have low agricultural potential and have considerable drainage problems. They have largely been ignored for agriculture and remain under peat swamp forest which represents a major timber resource. In areas near Sibu and elsewhere large tracts were, however, cleared for rubber and other crops early in the century. Some of this rubber is still tapped. Anderson Family soils have been incorporated to some extent in a number of drainage schemes in coastal areas but these development projects concentrate as far as possible on shallower peats and mineral soils.

Soil Associations 37-40

Four Associations have been mapped which comprise compound units of contrasting soils which cannot be separated at the mapping scale used.

37. *Bekenu/Anderson Association*

Low hill mantled by Red-Yellow Podzolic Soils occur in some areas in complex with deep Organic Soils on bottomland flats. In two localities (near Binatang and Penipah) these units could not be separated under the forest or old rubber cover and have been combined for mapping purposes. Soils of Merit, Bekenu and Nyalau Families mantle the hills. Other similar areas exist on the swamp fringes near Sibu (Fig. 38 being an example). Where the hill units are believed to be both small and widely scattered they have been ignored and mapped in the Anderson Association.

38. *Buso/Anderson Association*

This Association comprises an extension of Soil Association 20 (Buso/Tika) and has been mapped on the swamp plain borders where low terrace flats mantled by Podzols and Regosols are found in complex with Organic Soils. The unit has been employed in areas in which the forest cover is broken or disturbed (or the air photography

coverage was of low quality) and where the terrace tracts could not be satisfactorily isolated.

39. *Bijat/Anderson Association*

Some interior valley areas, and certain tracts on the swamp plain, were reconnoitred and proved to have a great variety of soils, ranging from Alluvial to Gley and Organic Soils. Association 39 maps those tracts where this complexity exists and where further differentiation was not practicable on the field information available.

40. *Pendam/Anderson Association*

Areas in which marine Gley Soils (mainly Pendam Series) mantle creek banks and finger into tracts of deep Organic Soils (Anderson Family) have been mapped as Association 40 where further differentiation was not practicable. The Association is mainly found in the headwaters of the Lassa River (Plate 17) where the mineral soils form narrow ribbons extending up minor creeks and are developed in material which is believed to have been deposited by backflooding into this highly tidal area.

Table 13

Soil Associations; summary of Soil Series present and main Terrain Classes represented

Soil Association	Soil Series		Terrain Class
	Major	Subordinate or localised	
1. Meluan	Meluan; Rock	Lalis	7–8
2. Meluan/Merit	Meluan; Merit; Bekenu	Lalis; Rock; Nyalau	5–7
3. Meluan/Tunggal	Meluan; Tunggal; Silantek	Bako; Lalis	7–8 (+3)
4. Kapit/Lalis	Kapit; Lalis	Merit; Bekenu; Nyalau	7 (+8)
5. Lalis/Merit	Lalis; Merit	Kapit; Jakar; Bekenu; Sarikei	5–6
6. Piring	Piring; Changgan	Abok; Buri; Suka	7–8 (+3)
7. Arip	Arip	Nyaroh; Buri; Suka Tika; Changgan	4–7 (+8)
8. Merit	Merit	Kapit; Lalis; Jakar; Bekenu; Nyalau; Kerait	4–6 (+7)
9. Merit/Jakar	Jakar; Merit	Bekenu; Sarikei; Nyalau	4–6 (+7)
10. Merit/Bekenu	Merit; Bekenu	Nyalau; Kerait; Bandang; Saratok; Silantek	4–6
11. Merit/Nyalau	Merit; Bekenu; Nyalau	Jakar; Pasai; Lupar; Kerait; Bandang; Saratok; Durin; Tika; Silantek	3–6
12. Merit/Kerait	Merit; Jakar	Kerait; Bandang; Durin; Bekenu	3–5
13. Bekenu/Kerait	Merit; Bekenu; Nyalau; Kerait	Jakar; Pasai; Bandang; Durin; Saratok; Tika; Peninjau	3–5
14. Bekenu/Saratok	Merit; Bekenu; Nyalau; Saratok	Kerait; Bandang; Silantek	3–5
15. Saratok/Kerait	Kerait; Bandang; Saratok	Nyalau; Silantek; Buso; Bintulu	2–3
16. Ajoh/Penipah	Ajoh; Merit; Timang; Penipah	Jakar	2
17. Nyalau/Silantek	Nyalau; Silantek	Merit; Bekenu; Buso	3–4
18. Silantek/Bako	Silantek; Bako	Tika; Buso	3–4
19. Tika	Tika; Bintulu	Plan; Luis	2–3
20. Buso/Tika	Buso; Bintulu		2
21. Buso/Metading	Buso; Metading	Tatau	1–2
22. Buso/Tatau	Buso; Metading; Tatau	Matu	1–2
23. Miri	Miri		2
24. Seduau/Lupar	Seduau; Malang; Bemang; Lupar	Sabangang; Sebaya; Semilajau; Kayan	1–2
25. Seduau/Bijat	Seduau; Malang; Bemang; Bijat; Pakan; Sebandi	Semilajau; Kayan; Lupar; Sebaya; Binatang; Kelupu	1
26. Bijat/Mukah	Bijat; Pakan; Sebandi; Mukah	Anderson (moderately deep)	1
27. Tatau/Kabong	Kabong; Belawai; Tatau	Matu	1
28. Tatau/Igan	Tatau; Matu; Igan	Anderson (moderately deep); Grang	1
29. Tatau/Pendam	Tatau; Matu; Pendam	Igan	1

Table 13 (continued)

30.	Rajang/Pendam	Rajang; Pendam	Paloh; Jol	1
31.	Mukah	Mukah	Sebandi; Bijat; Epai; Patok; Merapok; Igan	1
32.	Igan	Igan	Matu; Tatau; Mukah	1
33.	Luk	Mahat; Luk	Mukah; Anderson (moderately deep)	1
34.	Anderson	Anderson (moderately deep)	Mukah; Anderson (deep)	1
35.	Anderson	Anderson (deep)	Anderson (moderately and very deep)	1
36.	Anderson	Anderson (very deep)	Anderson (deep)	1
37.	Bekenu/Anderson	Merit; Bekenu; Nyalau; Anderson (moderately deep)	Bijat; Sebandi; Mukah; Anderson (deep)	1–3
38.	Buso/Anderson	Buso; Tika; Anderson (moderately deep)	Anderson (deep and very deep)	1–2
39.	Bijat/Anderson	Bijat; Sebandi; Mukah; Anderson (moderately deep)	Seduau; Malang; Anderson (deep and very deep)	1
40.	Pendam/ Anderson	Pendam; Anderson (very deep)	Anderson (moderately deep and deep); Mukah; Jol	1

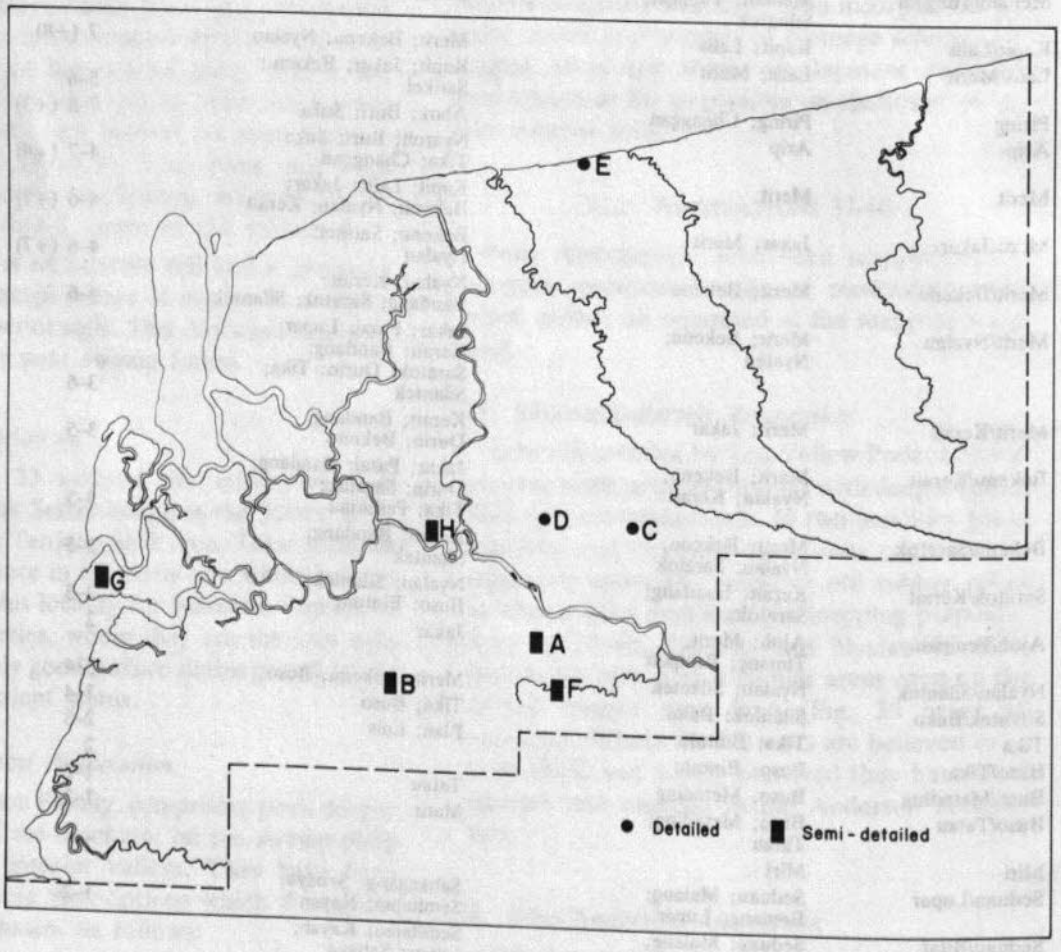


Fig. 30: Location of sample areas

Numbers refer to relevant text figures. Only those illustrated in the text are shown.

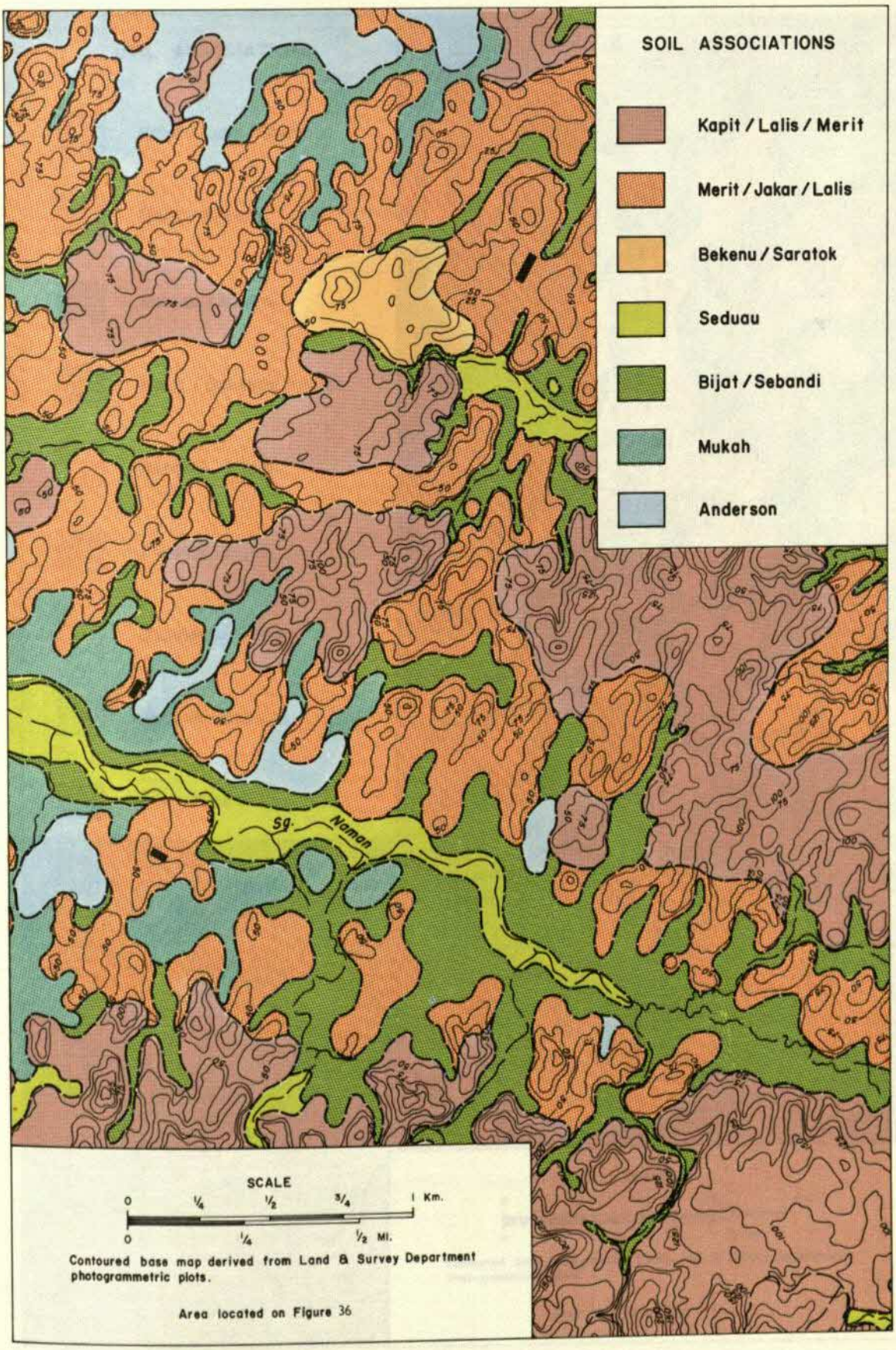


Fig. 31 Sample Area A

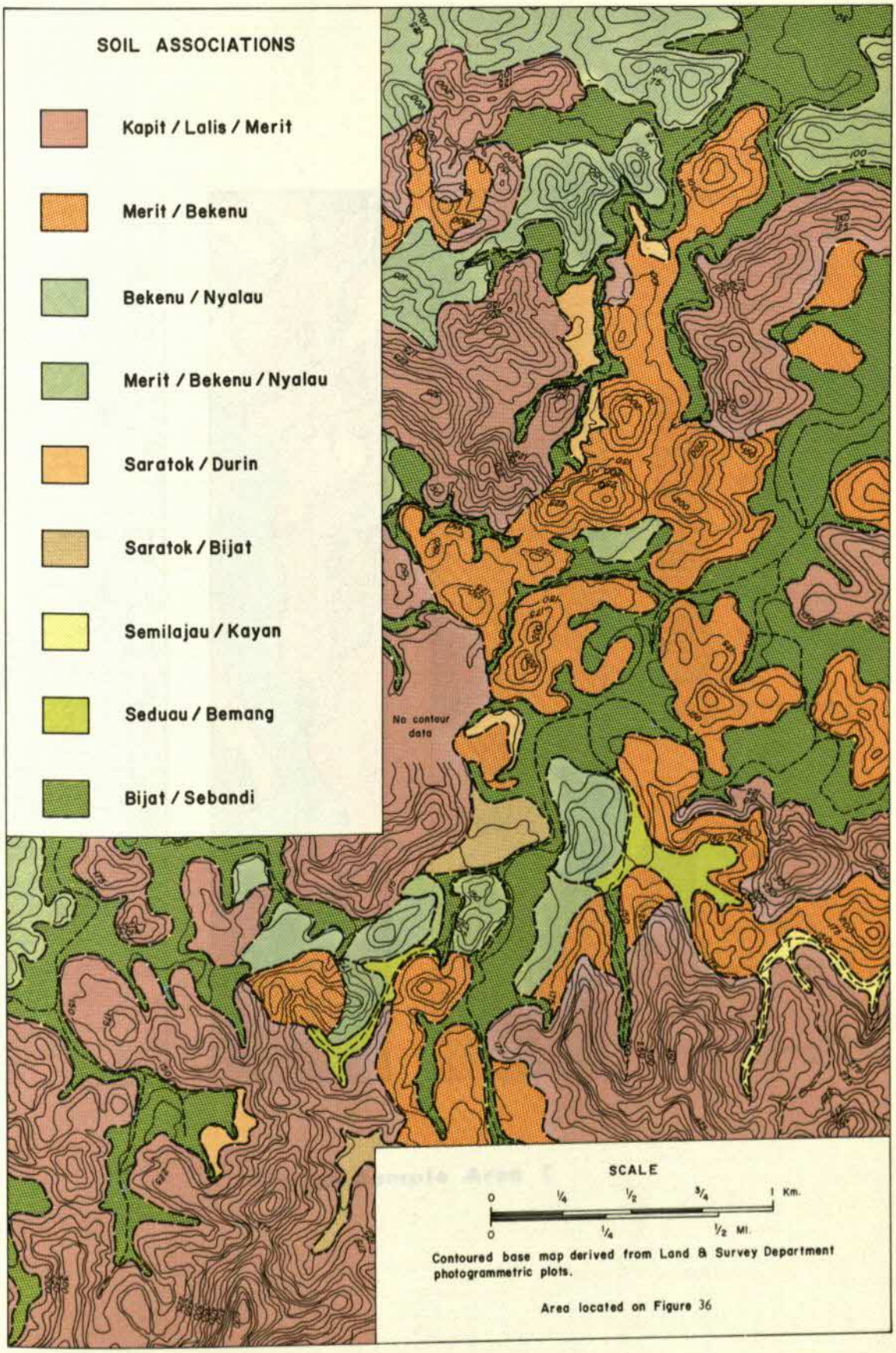


Fig. 32 Sample Area B

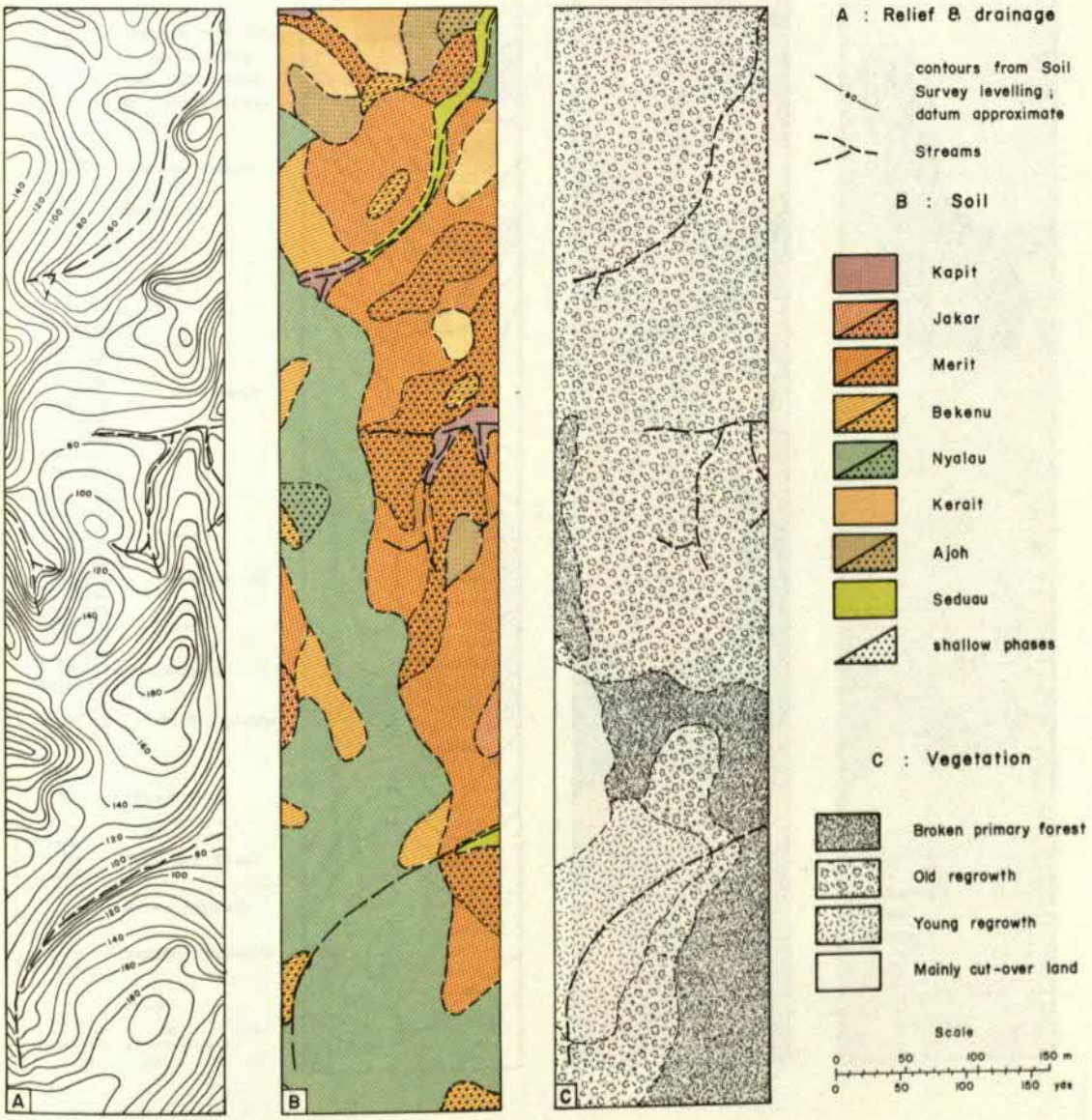


Fig. 33 Sample Area C

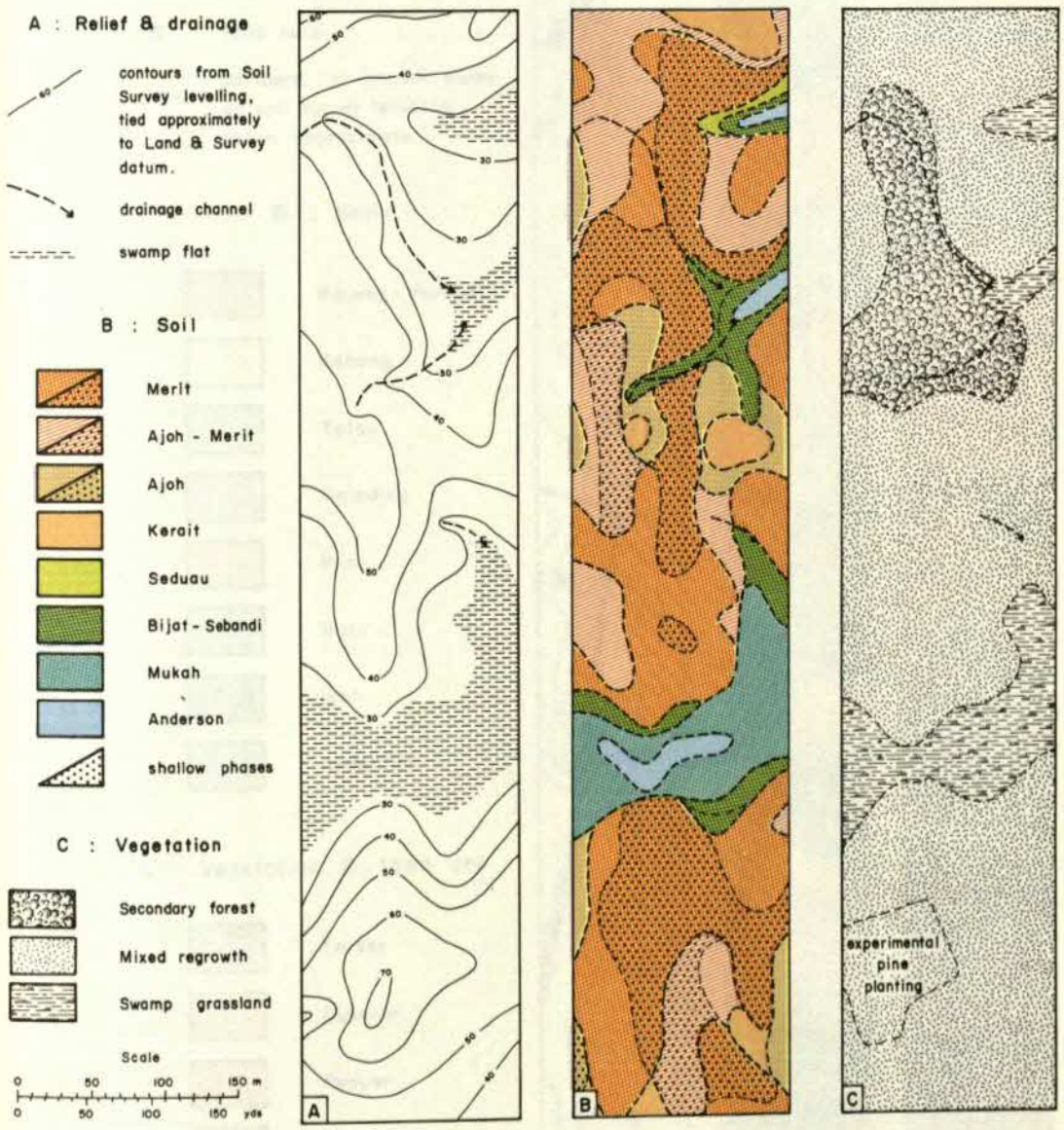


Fig. 34 Sample Area D

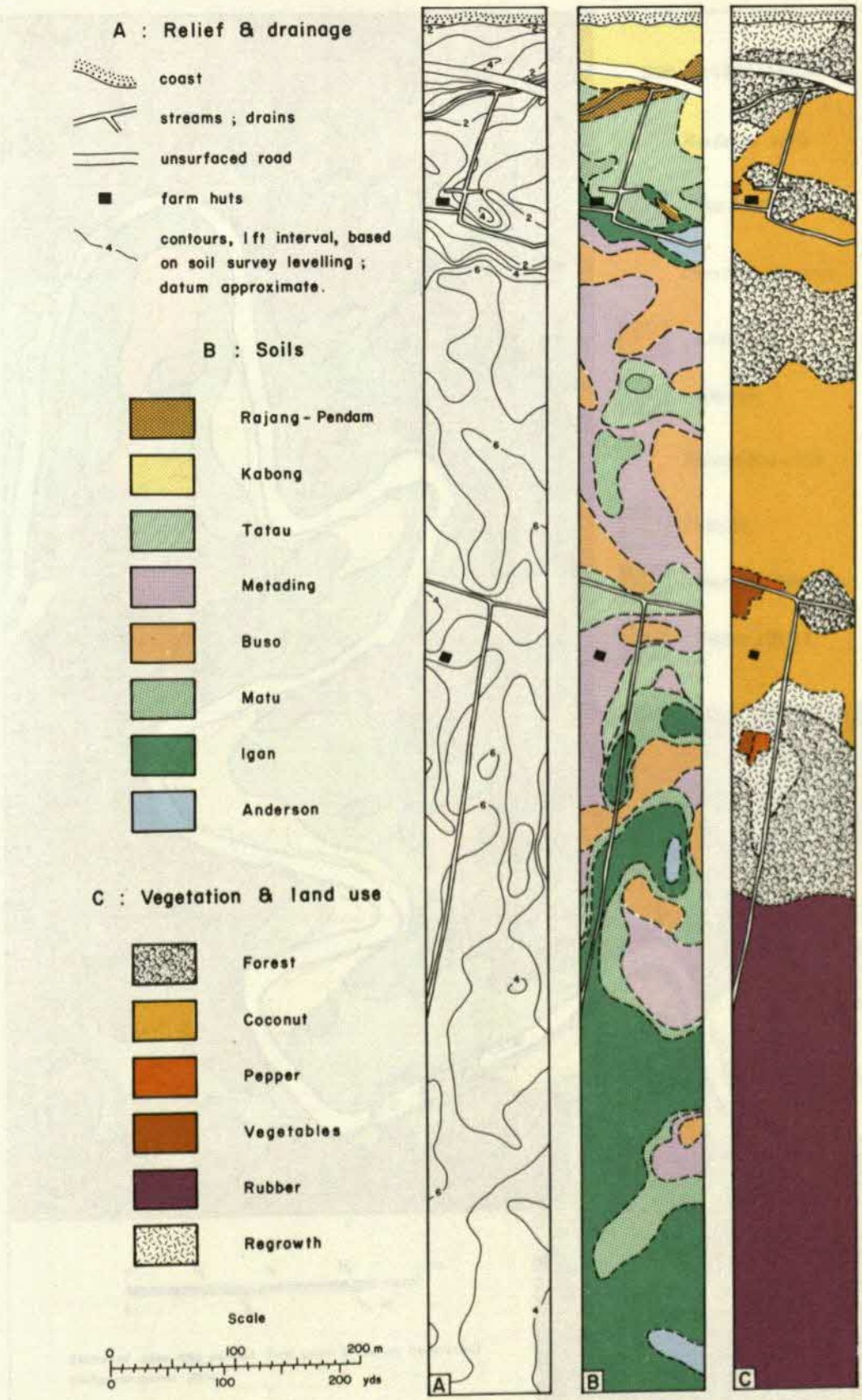


Fig. 35 Sample Area E

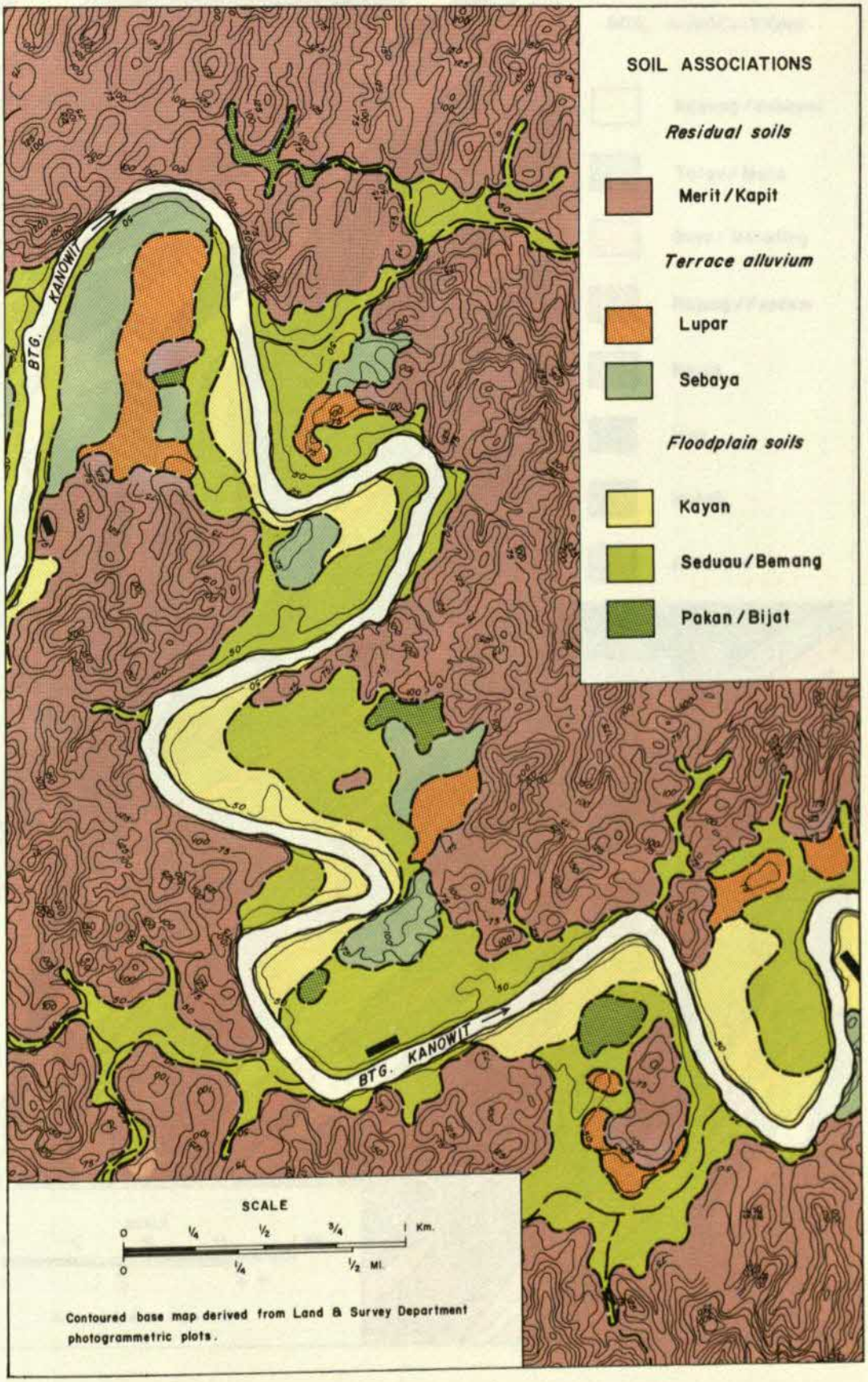


Fig. 36 Sample Area F

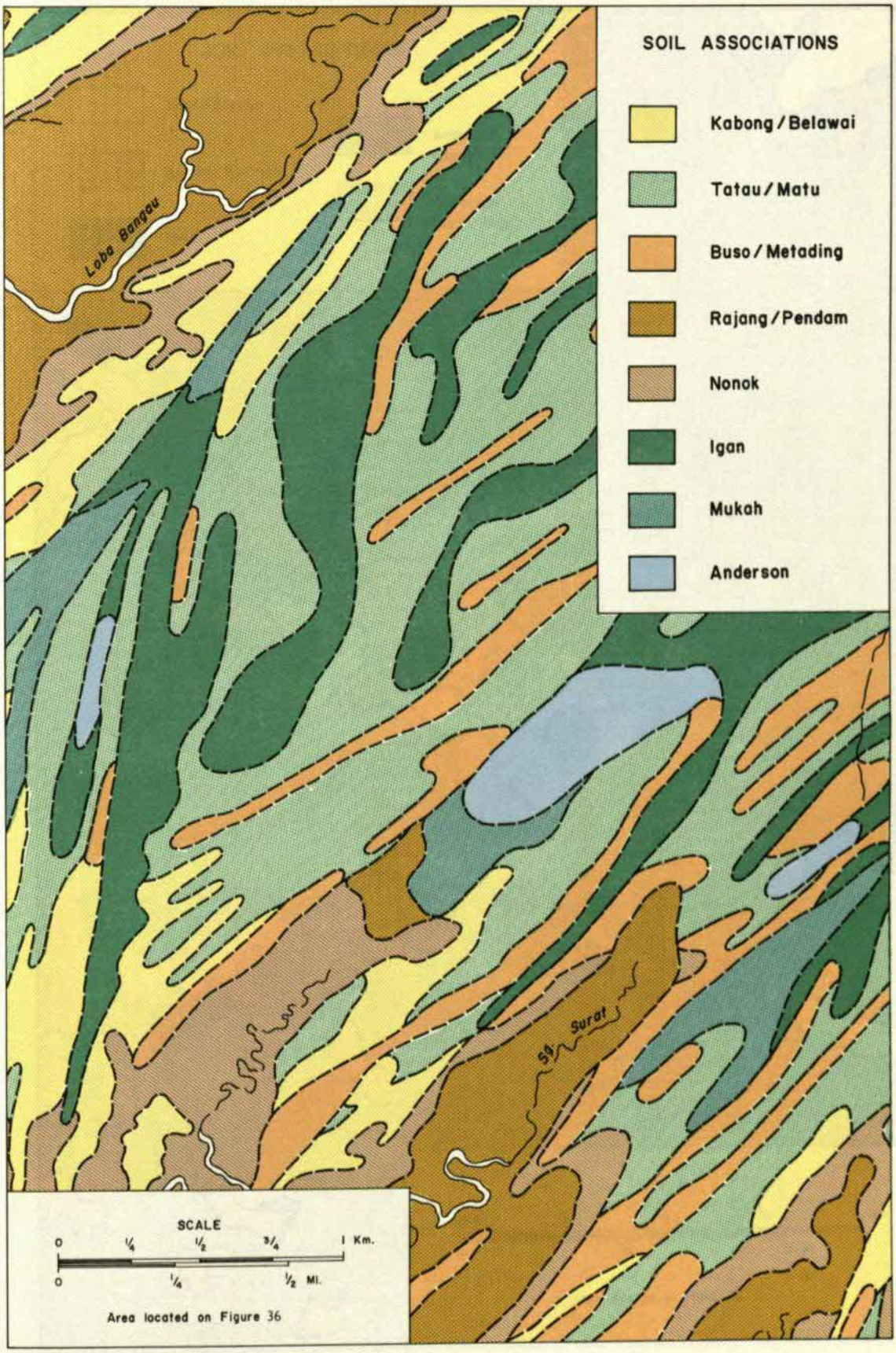


Fig. 37 Sample Area G

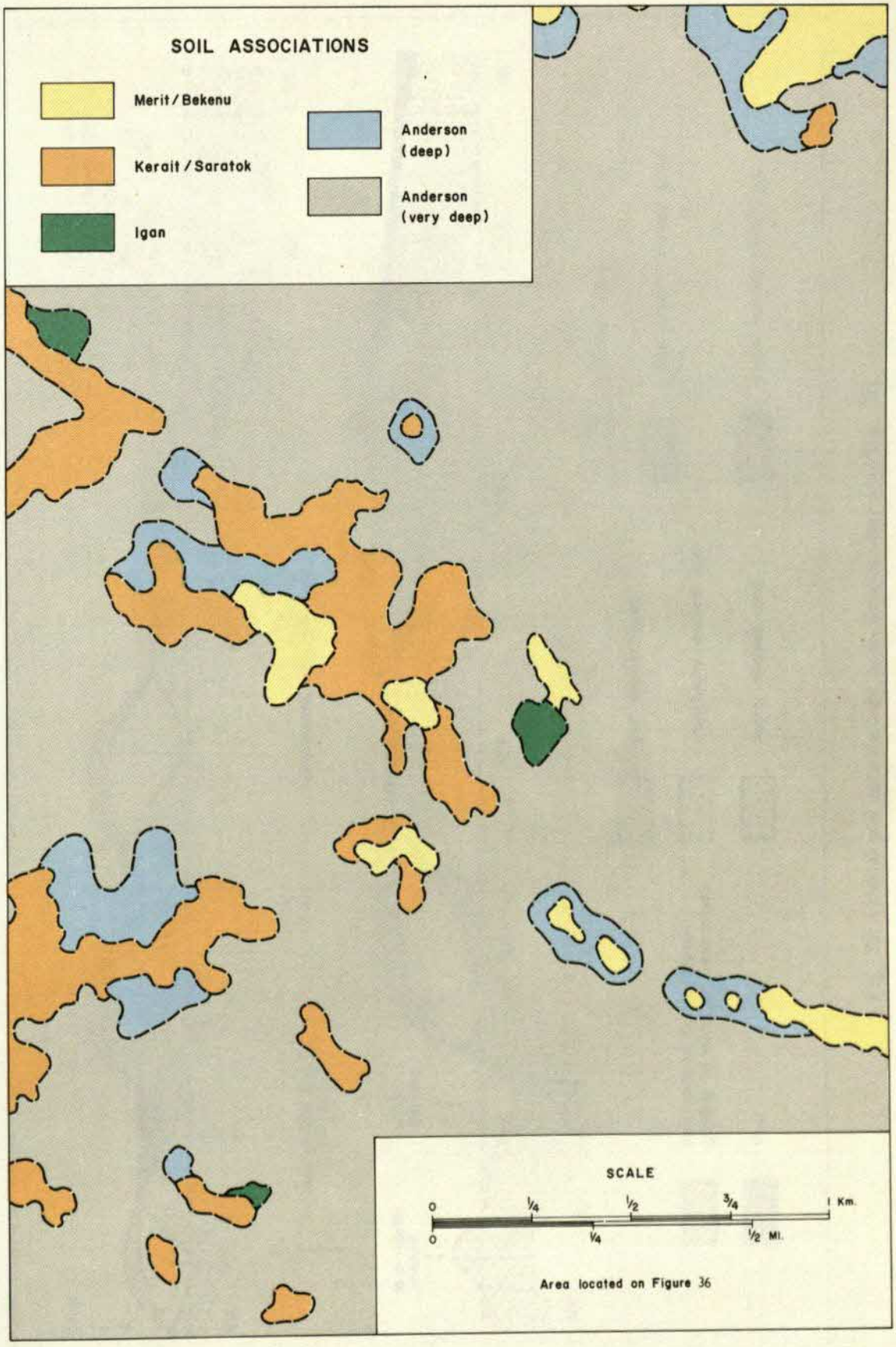


Fig. 38 Sample Area H

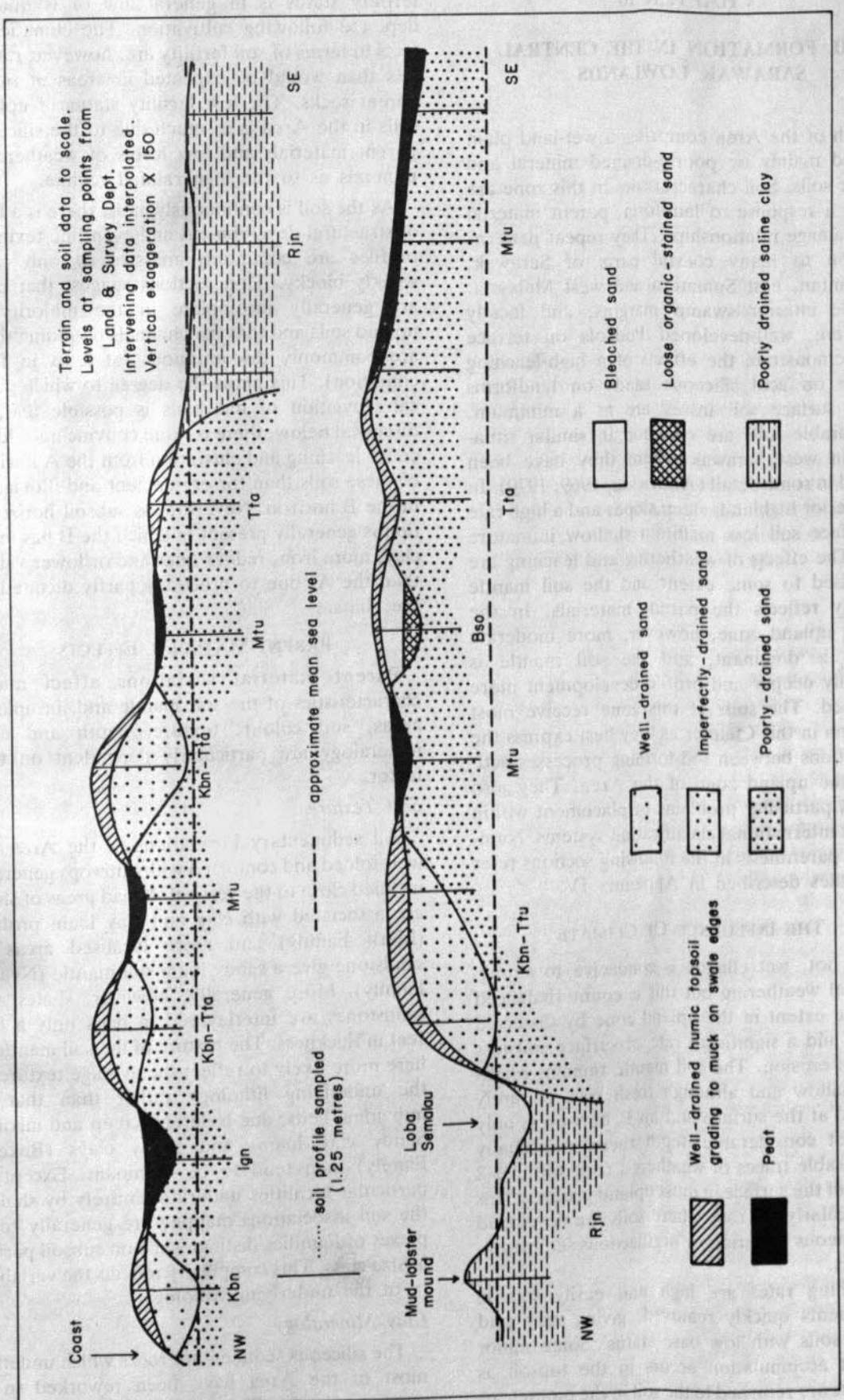


Fig. 39: Coastal soil relationships near Belawai (see also Fig. 37)

CHAPTER 10

SOIL FORMATION IN THE CENTRAL SARAWAK LOWLANDS

Much of the Area comprises a wet-land plain mantled mainly by poorly-drained mineral and organic soils. Soil characteristics in this zone are largely a response to landform, parent material and drainage relationships. They repeat patterns common to many coastal parts of Sarawak, Kalimantan, east Sumatera and west Malaysia. On the interior swamp margins, and locally elsewhere, well-developed Podzols on terrace flats demonstrate the effects of a high-leaching climate on acid siliceous sands on landforms where surface soil losses are at a minimum. Comparable soils are common in similar situations in west Sarawak where they have been studied in some detail (Andriesse, 1969; 1970). In the interior highlands steep slopes and a high rate of surface soil loss maintain shallow immature soils. The effects of weathering and leaching are minimised to some extent and the soil mantle strongly reflects the parent materials. In the central upland zone, however, more moderate terrain is dominant, and the soil mantle is generally deeper and profile development more advanced. The soils of this zone receive most attention in this Chapter as they best express the interactions between soil-forming processes active in the upland zone of the Area. They also present particular problems of placement within current international classification systems. Numbers in parenthesis in the following sections refer to profiles described in Appendix IV.

The Influence Of Climate

The hot, wet climate is conducive to strong chemical weathering but this is counterbalanced to some extent in the upland zone by dissected terrain and a significant rate of surface soil loss through erosion. The soil mantle remains relatively shallow and although fresh rock is rarely exposed at the surface and an R horizon is only found at considerable depth there are usually recognisable traces of weathered rock within 1-2 metres of the surface in most upland profiles. This is particularly the case where soils are developed over igneous materials or argillaceous sedimentary rocks.

Leaching rates are high and easily soluble constituents quickly removed, giving very acid upland soils with low base status. Some minor nutrient accumulation occurs in the topsoil as elements are returned to the soil in the biocycle or brought to the surface by faunal activity, but the fertility status is in general low or is quickly depleted following cultivation. The climatic effects in terms of soil fertility are, however, rather less than would be expected in areas of richer parent rocks. The low fertility status of upland soils in the Area is as much due to the siliceous parent materials and low levels of weatherable minerals as to the high rainfall regime.

As the soil is continuously moist there is a lack of structural development and even fine-textured profiles are commonly massive or only very weakly blocky. Thin sections suggest that peds are generally incomplete in the majority of upland soils and that the channels bounding them are commonly discontinuous (at least in field condition). This limits the degree to which vertical eluviation of materials is possible and, as discussed below, there is more convincing evidence for leaching and eluviation from the A horizon of these soils than for enrichment and illuviation in the B horizon. Nevertheless subsoil horizonation is generally present in which the B has more clay, more iron, redder hues and/or lower values than the A, due to processes partly dictated by the climate.

Parent Material Effects

Parent material variations affect many characteristics of the soil mantle and, in upland areas, soil colour, texture, depth and clay mineralogy are particularly dependent on this factor.

Soil Texture

All sedimentary Formations in the Area are well-folded and contorted with outcrops generally inclined close to the vertical. Broad areas of shale are associated with clay and clay loam profiles (Merit Family) and more localised areas of sandstone give a sandy loam soil mantle (Nyalau Family). More generally, however, shales and sandstones are interlayered in beds only a few feet in thickness. The texture of the soil mantle is here more likely to reflect the average texture of the underlying lithology rather than that of individual beds, due to lateral creep and mixing. Sandy clay loams and sandy clays (Bekenu Family) then tend to be dominant. Except in particular localities underlain entirely by shales, the soil associations mapped are generally complexes of Families distinguished on subsoil particle-size class. This complexity reflects the variability of the underlying lithology.

Clay Mineralogy

The siliceous sedimentary rocks which underlie most of the Area have been reworked in a number of cycles. There are therefore few easily-weatherable minerals supplied to the sand and silt

fractions of the soil mantle. However, feldspars from some sandstones and layer silicates and micas from most shales give a degree of silicate clay development, although the clay fractions of most profiles have a high proportion of amorphous material, the crystalisation of clay minerals is commonly poor, and the clays as a whole are of low activity.

Clay mineral data are available for selected profiles of Merit (2, 4), Bekenu (6, 7) and Nyalau (10) Family soils from the Area. Illite and vermiculite are the dominant silicate clay minerals in soils derived from shales (2, 4) with subordinate kaolinite and (4) gibbsite. Coarser gibbsite crystals may also develop in B and C horizon material (2; Colour Plate 17). Kaolinite is dominant in the one profile developed over sandstone (10). Profiles of intermediate texture developed over mixed sedimentary rocks have either illite (7) or illite and kaolinite dominant.

Data from equivalent soils in north Sarawak and Brunei, and some earlier data from this Area (Dumbleton, 1965; HTS and HO, 1974: 302-303) confirm the importance of kaolinite in sandstone-derived soils but also report it to be dominant in some soils over shale, although there it is partially ordered and some illite and vermiculite are also present. In west Sarawak (Andriesse, 1972: 152; 1975: 84) kaolinite is reported to be generally dominant in all soils developed over sedimentary rocks although some shale-derived soils there may also have mainly illite or vermiculite.

Soils studied from the Area show little contrast in clay mineralogy between horizons, and the clay minerals present are to a large extent a reflection of the parent rocks, kaolinite being derived from feldspars in the sandstones and 2:1 minerals being derived, or inherited, from micas and layer silicates in the shales. The persistence of these trends in the present mantle, however, results from the relatively dissected terrain and erosion rates on upland slopes. The soil mantle is, in terms of clay mineralogy trends, maintained in a rather young stage of development and the tendency towards the dominance of 1:1 clays in a weak-weathering/strong-leaching environment (Crompton, 1962) is retarded.

Soil depth

Chemical weathering is severe but the rate of rock disintegration varies with type. Some quartzose sandstones are resistant but the more widespread greywackes weather deeply and the present soils (mainly Nyalau Family) are developed in a thick mantle of sandy loams and sandy clay loams. Shales commonly have a thin soil mantle and while some rock alteration is found at considerable depths there is residual rock structure and hard coherent rock fragments within 2 metres of the surface. Shales vary, however, and some weather to massive clays with little or no visible rock structure within the surface 3 metres while others are unusually resistant and break to hard fissile fragments with little fine earth, maintaining a shallow soil mantle on all slopes. This is the case in the Julau-Kanowit area (Soil Association 5) where hard shales occur and have many quartz veins. These shales may be slightly calcareous as there is one calcareous exposure near Durin and Wolfenden (1960: 30) reports calcareous nodules in Belaga II rocks in the Kanowit and Katibas headwaters to the south and southeast. The iron-rich shales of the Sarikei-Jakar area (Soil Association 9) also appear to weather slowly and moderately shallow profiles are dominant there also. In that locality, however, such profiles may result from high erosion rates as the area is particularly dissected (Fig. 50) and much of the soil has been exposed to a history of concentrated pepper cultivation.

Stonelines

Many upland soils over sedimentary rocks have a stoneline in the subsoil, separating the solum from the C horizon. In areas where quartz veins are common in the parent rocks this may be largely of quartz gravel but it more usually comprises hard and very altered fragments of rock which have been enriched by iron. The thickness varies but there is a tendency for thick stonelines to be associated with medium-textured profiles (Bekenu Family) developed where interbedded shales and sandstones are dominant, and for the clays and loams developed over more uniform material (shales and sandstones respectively) to have either thin basal stonelines or none at all.

Ironstone concentrations result initially from redistribution of iron in the weathering zone. Road-cutting exposures show that where weathering shales and sandstones alternate iron accumulation takes place at the structural contact and at any joint planes and fracture zones crossing the structure (Plates 19 and 20). Iron is leached downwards from the solum to the weathering zone or from the upper part of the C horizon to lower levels, but examination of such exposures suggests that some of the iron redistribution is lateral, out of the shale and sandstone beds towards the contact zone between them. At a structural surface almost pure iron sheets are found grading back to a zone in which some rock structure is apparent but the material is heavily iron-enriched (Plate 20).

Iron mobilisation is affected by the pH of the weathering solution. At some upland sites this is below 3.5 at a depth of only 2 metres. No full analyses have been published for sedimentary rocks in the Area but pyrite has been reported in all Stages of the Belaga Formation (Wolfenden, 1960: 30, 37, 42). These sediments were deposited in a marine environment and it is probably that, like comparable rocks in west Sarawak for which analyses are available, there is a sufficiently high sulphide level in these sediments to give a very acid weathering environment (below pH 2.5) in which iron is easily released to the weathering solution. Andriesse (1972) considers groundwater movements to be important in the process. Iron is moved to structural gaps or textural boundaries by capillary gradients in the weathering material. These are accentuated where beds of varying texture alternate. Reprecipitation may be induced by less acid solutions which percolate down through the weathering mantle and are concentrated in these zones. Precipitation is also found on the sides of fossil root channel cavities which are prevalent in some shale beds. Such deposits also contribute broken casts to the stonelines of some soils.

There is some precipitation of iron along cleavage lines in massive shale beds but these are usually thin and break easily to small fragments at higher levels when weathering has progressed further. Little or no stoneline development may result. Where massive sandstones occur iron sheets may also be found along the main structure lines but these are commonly spaced widely and the precipitates are consequently fewer although they may be moderately pronounced. They are very marked in some iron-rich sandstones in the Sıkat-Kenyana area and elsewhere but in other areas they are weakly developed. This may be due to the relatively low levels of iron in the sandstones available for redistribution. Alternatively, the weathering mantle may be sufficiently porous to maintain somewhat higher pH levels than in weathering shales and thus lead to less iron mobility. Further, downward percolation of solutions in some porous sandstones may take place over a diffuse front rather than being concentrated in particular channels dictated by rock structure.

The optimum conditions for iron precipitation appear, therefore, to be where shales and sandstones are interbedded. With some exceptions the shales are a relatively rich source of iron, the intervening sandstones give a permeable weathering stratum, the lateral changes in steeply-bedded lithology encourage both a concentration of downward-moving solutions along contact zones and a varied pH in the weathering zones and therefore conditions conducive to both mobilisation and precipitation. As noted above, such mixed lithology generally produces a medium-texture soil mantle. There is thus a logical association between Bekenu Family soils and the presence of thick stonelines of iron-enriched rock fragments at the base of the solum (Plate 21)

The concentration of this material in the soil involves other factors and is considered below. It may be emphasised, however, that the segregation of ironstone sheets in the weathering zone is considered a continuing process and is not necessarily fossil. It has been suggested (HTS and HO, 1974: 76) that they may be the result of a prior weathering cycle, similar to that postalated by Ollier (1959) elsewhere but Alexander (1959: 137) citing the inclusion of crown bottle tops in iron-cemented material at a location in Singapore, has shown that the development of thick iron oxide coatings may be a contemporary process and can take place very quickly. Although, therefore, coatings develop to a considerable depth and are found in root channel cavities which may be of Tertiary age, the ironstone casts themselves are less certainly of this antiquity. The distribution of these features has a bearing on this. For ironstone sheets to develop following the processes described above, the permanent water-table must be at some depth in the weathering mantle, allowing intermittent heavy rainfall to contribute to the weathering solution in concentrated zones along the structural drainage lines. These conditions exist at present in most upland sites. The climate within the region has not, according to present views (Ashton and Ashton, ed., 1972: 50-62) altered significantly since the Tertiary and this weathering process may thus have been important over a considerable geological time. The present distribution of hills and bottomlands, on the other hand, together with the variation in depth to the permanent water-table, results from Post-Tertiary erosional history. The impression is gained in the Area that such iron concentrations in the weathering mantle are confined to present upland well-drained sites. It must be admitted that few exposures of the weathering zone in bottomland flats are available for study and that upland flats with poor drainage (mainly Soil Association 16) are largely underlain by shales, in which ironstone sheets develop less freely. But the available evidence suggests that the distribution of these sheets in the weathering zone is largely related not only to the occurrence of appropriate lithology but also to the present terrain. This would be unlikely if the features were entirely fossil.

Soil Colour

In upland areas white or light grey profiles may alternate with brownish or reddish yellow soils without relation to present topography or drainage conditon. These and other contrasts are a reflection of variations in the parent rocks and, in particular, variations in their iron content. Colour contrasts are especially striking where the soil mantle is developed from shales.

Parent shales exposed in road-cutting or river beds are generally black or dark grey, although greenish grey and reddish grey shales also occur. Where the soil mantle has a white or light grey subsoil this normally grades downwards to a white clay which overlies dark grey or black clay at a depth of 2 metres or more. The colour change is typically abrupt and may take place within less than 1 cm., (Plate 23). Residual rock structure is normally apparent in the lower part of the white weathering zone and no stoneline separates the solum from the C horizon. Where, on the other hand, yellow or reddish yellow soils comprise the mantle they commonly grade directly at depth to hard shale, through a zone of shale fragments in a yellow clay matrix or through a coarsely mottled zone with scattered shale fragments. There may be some ironstone sheet formation in the weathering zone and a thin stoneline may underlie the solum, but neither feature is generally prominent.

Analyses indicate that the red and yellow soils have a higher total iron content than comparable light grey and white soils, and that the colour difference is thus not a reflection of drainage. They also show that there are equivalent differences in the iron content of the weathered rock. No fresh rock was available for anlaysis but it appears more likely that the sediments were iron-deficient before consolidation than that they have preferentially lost iron in an early weathering stage. Three soil/rock relationships are apparent in this context. Firstly there are dark grey to greyish red shales overlain by brownish or reddish yellow clays or clay loams (Merit and Jakar Series). In both the B and C horizons 3-8 per cent Fe_2O_3 was extracted by 6N HCl. Secondly, there are dark grey or black weathered shales abruptly overlain by light grey clays (generally unmottled) which grades upwards to grey, light grey or pale yellow clays of Kerait Series. There is 0.1-1.5 per cent Fe_2O_3 in the dark substratum, similar or slightly higher levels in the pallid zone overlying it, and 0.5-2.0 per cent in the solum itself. Thirdly, there are intermediate forms in which dark grey or black shales with 0.5-2.5 per cent iron underlie yellow or reddish yellow clays (Merit Series, less commonly Jakar Series) with 1-4 per cent iron. The solum is separated from the dark shales by a pallid zone which is commonly heavily mottled and has iron levels similar to that of the weathered rock beneath. Colour Plates 1-3 illustrate the first form and Colour Plate 6 the second.

The iron levels quoted above are summarised from a number of analyses of samples from road-cutting exposures. Together with colour contrasts related to iron content there is a contrast in the weathering type. The shales of the first group are hard and remain as fractured but coherent fragments close to the surface. The soil mantle in many areas is largely skeletal (Colour Plate 1). The shales of the second and third groups weather deeply and are soft and plastic in road cutting exposures. The deep weathering front of the second form allows the development of a pallid substratum in which drainage is commonly impeded.

Certain dusky red or dark reddish grey shales have particularly high iron contents and are associated with red or yellowish red soils (Jakar Series; Colour Plate 2). With this exception the shales have a rather narrow colour range. Wolfenden tried to relate shale colour to degree of iron oxidation from ferrous and ferric iron determinations but concluded that there was no close correlation and 'that while the oxidation state of the iron is important in determining the colour of these sediments, other factors may also have a controlling influence' (Wolfenden,1960: 32, quoting Mineral Resources Division).

The colour of the dark grey and black shales which abruptly underlie a white or light grey weathering product has interested geologists and analyses have been undertaken from sites in west Sarawak, where such shales are common. Full analysis from one site gave closely comparable results for all elements in both white and black materials, with the exception of 0.1 per cent sulphur and 0.5 per cent carbon in the black sample, compared with a nil determination for both in the white (Pimm, 1965: 25). It was concluded that the black colour was due to 'carbonaceous matter and, possibly to a lesser extent, to a finely divided iron sulphide'. Further work reported by Andriesse (1968) showed that the colour in the black shales was not affected by strong oxidising agents but turned white on ignition at 700-750°C. Small black inclusions were also present in the silt-size quartz of this material. It was inferred that the black colour is due to carbon inclusions in clay-size quartz, which is only oxidised in the laboratory when heated to a temperature at which the crystal becomes unstable. It remains to be explained, however, how this breakdown occurs in normal weathering condi-

tions over a front which is commonly quite irregular but normally very abrupt.

Landforms

Steep slopes maintain shallow soils in the mountainous interior and locally elsewhere. Moderately deep soil tend to be found in many such areas on ridge lines and the summits of spurs as slopes are least at these sites and surface losses through erosion reduced to some extent. In general, however, there is little contrast in the depth of the soil mantle on different slope facets in the dissected upland zone (assuming similar soils from similar parent materials) and any variations in this respect tend to be related more to the weathering rate of the parent rocks than to landform type and erosion intensity. Moderately contrasting soil associations over differing parent materials occur on comparable dissected terrain through much of the hill zone, while in some localities where the parent materials are similar over broad areas, soil associations extend with little change in soil characteristics from subdued terrain through to higher country with much greater amplitude of relief and range of slope, the Tanggi area being an example.

As, however, slopes are commonly greater than 10° in upland areas, the landform factor is important in leading to downslope creep, particularly where soils are medium-or coarse-textured. This factor, together with that of faunal disturbance, contributes to the 'averaging-out' process which develops a relatively uniformly-textured soil mantle over heterogeneous sedimentary parent rocks. Examination of the sand fractions of a number of profiles has shown horizon contrasts which suggest varied derivation of the material and which can best be explained by layering of the surface deposits through downslope creep over varied distances, although the distances of lateral transport involved need not be great and would normally be confined to one hill-flank unit. In Profiles 5 and 13, for example, the sand distribution is quite contrasting between horizons and the ratio of fine to very fine sand is particularly erratic down the profile (Tables 52 and 81). In Profile 2 the heavy mineral fraction shows similar contrasts (Table 48). The zircon: tourmaline ratios for each horizon are 0.6, 3.4, 0.6, 0.1; blue tourmalines are largely confined to the lowest horizon and pink zircons to the upper subsoil. In Profile 8 (Table 56) zircon: tourmaline ratios are 2.2, 0.7, 5.6, 7.0, 1.0 and there are horizons contrasts in both the colour of tourmaline and the apparent weathering of zircons. Anatase is also concentrated in the upper subsoil, while brookite is only important below 1 metre, contrasts which are unlikely to be due to authigenesis as all grains are fractured or worn. In Profiles 2 and 8, however, although the mineral suites show much variation the sand ratios through the solum remain quite uniform. Thus even profiles which, on field examination and granulometric analysis, appear to be developed in homogeneous material, may be built up from layers of wash deposits which have reached the site after different degrees of lateral transport. This is particularly evident in topsoil material: the sand ratios in the surface horizons commonly contrast with those of the subsoil (Profiles 4, 5, 6, and 13, for example) although faunal action may be important in this respect also.

The clay: silt ratios of certain profiles also suggest soil bisequency. In Profile 7 (Fig. 23; Table 54) the variability of this ratio is considerable in upper horizons and does not appear to reflect horizon contrasts in dispersability, weathering or clay translocation. This profile may be compared with pallid profiles (Fig. 25) in which the clay: silt ratio is relatively constant despite a marked contrast in total clay levels between the A2 and B horizons. It is significant that the Kerait and Bandang profiles considered in that Figure are, as is generally the case in these families, found on subdued relief in which lateral creep is likely to be at a minimum.

Lateral creep is not necessarily confined to the solum. At some sites ironstone sheets in the weathering zone are seen to bend down-slope before merging into the stoneline at the base of the solum (Plate 22). The evidence for lateral creep and layering of surficial material in which the present soil mantle has developed has obvious implications bearing on the reliability with which one can apply classifications systems where placement of the profile at the highest level may depend on slight variations in clay percentage between horizons.

The importance of the landform factor in limiting the sites at which well-developed podzols are found requires mention. Such profiles are only encountered on the almost level sites of marine or riverine terrace remnants or on some flat or very gently sloping hill summit areas. Given suitable sites the development of these soils appears to then largely depend on the type of parent material and the groundwater regime.

Vegetation And Fauna

A natural forest cover, particularly in upland areas, plays an important role in protecting the soil from erosion by direct rainfall, and by binding the soil mantle together through an inter-locking net of surface and subsurface roots. Following removal of the natural cover the increased rate of

erosion and soil slumping may range from the significant to the catastrophic, depending on slope, soil texture, and the type of cover which replaces the natural vegetation. On the other hand Baillie (1978) considered that even undisturbed mature primary forest, particularly on steep slopes with a coarse-textured soil mantle, may initiate or accelerate soil creep and slumping by its own weight. That landslips can be initiated by wind-throw of large trees on steep slopes has been mentioned above.

In upland soils the root development is concentrated in surface horizons but a number of medium and large roots extend into the upper and middle subsoil. Probing by roots may improve soil structure to some extent but this effect is largely confined to topsoil horizons where fine roots form a dense mat. More important in lower horizons are the cavities left by the decay of larger roots, which become filled with material from overlying horizons either by gravity or through transport by soil fauna. Many of the cavities visible in upland subsoil horizons are probably initiated by root penetration. As well as aiding the extension of faunal activity to lower horizons and leading directly, or indirectly through faunal action, to some redistribution of organic matter down the profile, subsoil probing by tree roots is probably responsible for some of the irregular boundaries to 'colour B' horizons noted in upland soils (Colour Plate 3).

Soil creep aids in mixing subsoil material and concentrating stoneline gravel but tree fall and faunal action are also important in this respect and faunal activity may be of prime importance at some sites. Large trees in primary or old secondary forest have strong buttress roots and, when wind-thrown, the root complex adjacent to and below the trunk is thrown with the tree rather than breaking. The dished depression which is left may be over 5 metres broad and up to 1 metre deep in the centre, the soil mantle having been bodily ripped out (Plate 24). Large blocks of relatively undisturbed soil may be seen adhering to the root complex at the base of the fallen trunk. Much of this will fall back into the depression but where slopes are moderately steep downslope creep of material above the depression will be accelerated. Windthrows are common on both flat and sloping land but their frequency per acre (or per site) is probably low, particularly in inland areas under shifting cultivation where regenerating forest is cut for further planting as soon as it approaches maturity. This factor may therefore be of limited importance in periodically cultivated land.

The extent of faunal activity is apparent in thin section. Sections were examined from nine upland soils over sedimentary rocks. In three profiles (4, 6 and 13) the resorting of material in tubular structures, following the passage of burrowing fauna was a major characteristic of all subsoil horizons studied, and these extended to depths of 60 to 82 cms. in different profiles. Using the terminology of Brewer (1964) these can be described as striotubules, being tubular structures of skeletal grains and plasma without recognisable aggregates but with semi-ellypsoidal directional arrangements tangential to the tubule walls (Colour Plates 19, 26 and particlarly 27). All profiles concerned were clays or fine silts. No striotubule structures were noted in two fine loam profiles (Nyalau Family) which were sectioned and mesofauna may be less active in these soils.

The wide range of fauna which is present in soils has been reviewed in general terms by Thorp (1949). The types of mesofauna concerned in reworking subsoils in the present Area were not directly established but field evidence suggests considerable variety. Worm casts are common on the surface at many sites (particularly under forest). Small cavities with the remains of the nests of wasps or bettles are exposed in some profile faces (usually within 50 cms of the surface but some at lower levels). Termite species are present, although these do not build the large mounds which are characteristics of termites in parts of the drier tropics. Low surface mounds or semi-spherical nests built on saplings or low creepers are both seen. A subterranean nest of a (presumed) termite species is illustrated in Plate 25. It is almost spherical, some 25 cms in diameter, and is free-hanging in the root mat within a larger chamber. The chamber walls are thinly coated with a dark skin similar to that of the nest surface and the chamber appears to have been excavated from a fossil root channel to accommodate the nest itself. The previous root channel extends from the surface to the chamber and continues beneath it. The example is from a later study by the writer in Sabah (Scott, 1978) in a soil correlating with Bekenu Series (Tanjong Lipat Family in the Sabah classification) but similar subterranean nests have been observed (Hatch, pers: comm.) during excavation of terraces in Merit Series near Simanggang. Finally, it may be noted that there are some species of burrowing snakes in the Area and that the writer brought up a live specimen in an auger sample on one occasion from a depth of some 35 cms.

The passage of worms and other fauna leaves cavities in the material. The majority of larger pores in those subsoil samples examined in thin

section are associated with striotubule structures. Pores are generally small and relatively sparse in adjacent less-disturbed material. Faunal action may therefore increase the ease of water movement into and through the profile and thus accelerate lateral creep and selective lateral leaching of material. But the main sorting effects of this activity are probably vertical. Mesofauna such as worms injest material selectively and deposit some of the finer material at the soil surface. Burrowing fauna such as beetles also avoid the coarser fragments in mining the soil and there is a tendency for coarse fragments to settle downwards after their passage. Over a period the coarser soil material within the zone affected by fauna tends to be concentrated at lower levels and faunal activity is probably the main agency at many sites by which ironstone fragments and quartz gravel (which are generally the only gravel-size hard material to persist following rock weathering in areas of sedimentary rocks) are concentrated at the base of the solum as a stoneline.

Downward sifting of coarse material during lateral creep is also important at many sites and this is the explanation for stoneline concentration offered by Andriesse (1972) for similar features in west Sarawak, and by Leamy and Panton (1966: 60) for stonelines in Peninsula Malaysia although those authors favour a process involving colluvial deposition. Stoneline development by successive colluvial deposition of differing materials (layering) has been proposed in many other areas (e.g. Parisek and Woodruff, 1957; Ruhe, 1959) particularly where a footslope zone is well-developed. Such landforms are not, however, developed in the Area. Nor is it easy to consider lateral creep a primary agency in stoneline concentration at all sites in the Area as, where a stoneline is present, it is normally continuous over the whole hill unit and its depth and thickness in summit profiles do not differ greatly from those on lower slope sites. Where the stoneline is irregular it is commonly markedly so, and is unrelated to the slope or landform facet. While the irregular stonelines such as that shown in Plate 21 are difficult to explain, it does appear that resorting of material within the solum at such sites is more vertical than lateral and that faunal sorting is likely to be a major process involved. Some workers (e.g. de Heinzelin, 1955) have emphasised the importance of faunal sorting but mainly in areas where termite activity is a major soil-modifier. The profiles with stonelines described by Ollier (1959) resulting from termite sorting in Uganda are very similar to those of the Area.

Thin stonelines of coarse quartz sand are seen in some pallid profiles on almost flat sites at depths of less than 10 cms. Invariably the soils are imperfectly drained and it can be expected that faunal activity is here more confined to surface layers. At well-drained sites, faunal activity appears to be important throughout the solum in many soils and this is relevant to other physical characteristics. The tendency for textural contrasts between upper and lower subsoils to be minor, for the clay increase with depth to be gradual rather than abrupt in most Families, and for the colour boundary between the paler upper subsoil and any 'colour B' horizon to be rather diffuse may be partly due to the homogenising influence of the fauna on the finer mineral fractions within the solum.

Time

The time factor is difficult to evaluate as the varied parameters by which the maturity of a profile can be judged reflect processes which operate on independent time scales. The main point requiring emphasis in connection with most upland soils is their relative youth. Surface losses through erosion tend to keep pace with rock weathering. Except where the parent material weathers particularly rapidly the soils remain rather shallow. Clay mineralogy remains to a great extent a reflection of the parent material. Pedogenetic horizonation has developed to some degree but this is possibly less a sign of soil age than a comment on the rapidity with which some soil processes, such as the translocation of sesquioxides, tend to operate in this extreme environment.

The Podzols, particularly those on marine terraces on the coastal plain, are those with most developed morphology and are probably the oldest soils of the Area in absolute terms. The flat sites and the coarse texture mean that surface erosion losses are negligible; the landform has been more or less unaffected since it was uplifted and as groundwater levels presumably dropped at that time the development of a Podzol mantle may well have taken place fairly quickly after that event. An absolute age of at least 4,000 years may therefore be relevant to Podzols on the lowest terrace remnants. Those on higher terraces may be older, although this is less clear as higher terraces are likely to have a history which has been more complicated by dissection and erosion than those immediately above the present swamp level. The age of these terraces is also somewhat uncertain, as has been discussed above.

Other mineral soils on the coastal plain, together with the majority of soils in interior riverine areas, are in a youthful stage, either

because they are developed in presently accreting or recently deposited alluvium or because development is retarded by continuously poor drainage, or both.

The peat swamp mantle which dominates much of the plain is in a continuous state of youth as fresh material is constantly being added to it. It can, in fact, be considered that the processes involved in the development of this mantle are geogenetic rather than pedogenetic and that the swamp 'soils' need not be considered in this context. They are of interest, however, from the viewpoint of time because, like the terrace Podzols, it is possible to suggest absolute dates for their initial development. Radio-carbon figures indicate that a similar age to the lowest terrace deposits is relevant, and it can be taken that for at least the last 4,000 years peat soils similar to those now mantling much of the plain have been present in some parts of it and that the main trend since that time has been extension of the mantle and increase in its thickness.

Red-Yellow Podzolic Soils

The Red-Yellow Podzolic Soils comprise the most widespread Group of non-accreting well-drained mineral soils in the Area other than the shallow juvenile soils which mantle steep slopes in the interior. They have therefore received more study than other upland soils and a broader range of data relevant to process is available for them than for soils of other Groups, although the data have been gathered over an extended period and are rather unstandardised. Data for specific profiles are tabulated in Appendix IV. Some supplementary data are given in this section. As information from a number of profiles is necessary to adequately characterise the processes involved, use is also made of averaged data for the main soil Families. This further serves to reduce the effect of horizon variability due to layering following downslope creep.

The discussion mainly concerns the soils over sedimentary rocks (Merit, Bekenu and Nyalau Families) as these are dominant in the Area. These are therefore considered first and available data on the few soils derived from igneous rocks in the Area is briefly discussed at the end of the section.

Leaching and silication

The soils are strongly affected by leaching and those soluble constituents not fixed in clay lattices are quickly lost. The parent materials are low in bases, however, and the parent materials have few easily soluble components. Exchangeable cations are highest in the top-soil, to which some are returned in the biocycle, but base saturation is commonly below 10 per cent in all soils families and averages less than 30 per cent even in surface horizons (Table 15). A number of workers (Hardon, 1936; van Schuylenborgh, 1957; 1958; Tan and van Schuylenborgh, 1959; 1961a; 1961b; Mohr, et al., 1972: 255 et seq.) have stressed a causal relationship between base-poor soils and acid humus accumulation with low mineralisation and high C/N ratios, low pH, the dominance of humic and fulvic acids, and the chelation and mobilisation of sesquioxides (particularly iron) resulting in residual silication. Andriesse (1975; 130 ff) also notes these trends in considering selected profiles from west Sarawak, the profiles concerned being similar to those under discussion here but remaining under primary forest. Most of the upland soils from the Area which have been analysed have a history of agricultural use and there is thus a considerable variation in pH, topsoil development and C/N ratios. A positive relationship between topsoil pH and C/N and ratio is apparent but, on a set of 46 profiles, was only significant at the 5 per cent level. The mobility of iron, residual silication of the solum and the importance of a podzolic process is evident, however, from silicate data for soils in this Group over both sedimentary and acid igneous parent materials. These data are considered below.

Sesquioxide mobility may result only in translocation within the solum. The degree of total loss of constituents from the solum by leaching and silication is difficult to estimate but some indications may be given by the titanium trend. It has been suggested that titanium may become slightly mobile at very low pH and in the presence of organic complexes (Mohr, et al., 1972: 465 et seq.) but there is general agreement that titaniferous minerals (rutile, anatase, ilmenite, brookite) persist in the most weathering environments (Jackson and Sherman, 1953; Karim, 1953). The interpretation of the Ti trend in soils over sedimentary rocks is complicated, however, by the low levels which are found and the danger of giving significance to minor variations which may be due to layering in the initial material. Ahmed and Sim (1973) have studied titanium trends in a number of profiles from west Sarawak (including representatives of Merit and Bekenu Families), as has Andriesse (1975) for Merit and Nyalau profiles. The TiO_2 in the fine earth of almost all profiles examined was found to be lower in the C horizon than in the A and B. An exception was a Nyalau profile in which the C horizon was probably not reached. TiO_2 in the clay fraction was more erratic although here also the majority of profiles has less titanium in the C than in any horizon of the solum below the A1.

Table 14

Average granulometric analyses of fine earth in main soil families derived from sedimentary parent materials.

Family	*Horizon*	*vcs-fs*	*vfs*	*si*	*Clay %*		
		%	*%*	*%*	*mean*	*range*	*s*
Merit	A1	14	18	34	35	27 – 43	7.2
(7 profiles)	A2	13	22	29	36	27 – 44	5.0
	B	16	28	29	45	35 – 52	5.2
	B3 or C	7	17	31	45	44 – 45	0.4
Bekenu	A1	8	26	37	28	22 – 36	7.1
(4 profiles)	A2	6	39	26	26	20 – 31	6.1
	B	8	24	35	33	31 – 37	2.2
	B3 or C	nd	nd	nd	nd	nd	nd
Nyalau	A1	42	18	18	22	16 – 29	4.7
(10 profiles)	A2	40	19	18	22	14 – 28	4.2
	B	39	17	17	27	20 – 36	4.9
	B3 or C	40	14	22	24	20 – 30	4.0
Kerait	A1	8	44	30	19	13 – 23	5.3
(3 profiles)	A2	8	42	29	21	14 – 25	4.2
	B	4	29	27	41	32 – 58	14.6
	B3 or C	2	19	27	52	51 – 54	1.5
Saratok	A1	30	31	18	15	10 – 18	4.1
(4 profiles)	A2	33	35	17	14	11 – 18	2.7
	B	32	33	16	23	19 – 29	4.7
	B3 or C	27	31	17	25	21 – 29	5.4

Table 15

Average trends for selected chemical parameters in fine earth of main soil families derived from sedimentary parent materials

Family	*Horizon*	*pH (H_2O)*	*C %*	*C/N*	*CEC*	*Ca*	*Mg*	*K*	*BS %*	*P (HCl;ppm)*
						me/100g				
Merit	A1	4.0	2.9	12	14	0.8	0.5	0.5	19	143
(7 profiles)	A2	4.1	0.9	9	9	0.6	0.1	0.2	14	112
	B	4.3	0.5	7	9	0.6	0.1	0.2	13	104
	B3 or C	4.4	0.1	2	9	0.6	0.1	0.2	15	83
Bekenu	A1	4.2	4.1	14	8	0.5	0.6	0.4	29	178
(4 profiles)	A2	4.8	0.7	9	4	0.1	0.2	0.2	20	110
	B	4.5	0.5	8	4	0.1	0.1	0.1	11	100
	B3 or C	nd	nd	nd	nd	nd	nd	nd	nd	nd
Nyalau	A1	4.0	4.0	17	20	0.6	0.4	0.3	15	131
(10 profiles)	A2	4.3	0.7	11	5	0.6	0.1	0.2	25	74
	B	4.5	0.2	9	4	0.5	0.1	0.1	22	71
	B3 or C	4.6	0.1	6	4	0.5	0.1	0.1	16	74

Kerait	A1	4.7	2.8	14	9	1.9	0.2	0.3	30	142
(3 profiles)	A2	4.5	0.6	9	5	0.4	0.1	0.1	10	86
	B	4.7	0.2	4	5	0.2	0.1	0.1	6	83
	B3 or C	4.7	0.1	2	6	0.2	0.1	0.1	8	146
Saratok	A1	4.0	1.8	12	8	0.5	0.2	0.1	13	83
(4 profiles)	A2	4.3	0.7	15	4	0.3	0.1	0.1	10	48
	B	4.6	0.4	11	5	0.2	0.1	t	17	43
	B3 or C	4.1	0.1	4	7	0.4	0.2	t	22	27

Table 16

Silica sesquioxide and titanium trends in fine earth of Merit, Nyalau, Kerait and Saratok Families (average of 3,3,4 and 3 profiles respectively)

Family	*Horizon*	SiO_2	Al_2O_3	Fe_2O_3	*Si:R*	*Si:Al*	*Si:Fe*	*Al:Fe*	TiO_2
Merit	A1	77	13	3.2	9	10	68	6.2	0.76
	A2	76	15	3.9	8	9	52	5.6	0.72
	B*	72	17	4.3	6	7	46	5.9	0.75
	B/C	62	25	6.7	4	4	26	5.6	0.71
Nyalau	A1	85	9	2.6	11	13	70	5.5	0.67
	A2	83	12	3.2	10	12	71	5.5	0.71
	B*	81	12	3.6	10	12	60	4.8	0.81
	B/C	75	16	3.8	8	9	60	6.1	0.60
Kerait	A1	85	6	0.7	23	24	318	13.1	0.78
	A2	86	8	0.8	18	19	274	14.2	0.91
	B	75	15	2.4	7	8	83	10.2	0.92
	B/C	63	22	2.7	5	5	62	12.6	0.81
Saratok	A1	89	3	0.5	54	62	493	10.7	0.46
	A2	87	4	0.7	42	50	380	10.5	0.51
	B	85	8	1.0	18	19	344	17.7	0.58
	B/C	86	8	0.9	17	18	293	16.1	0.57

*excluding horizons with ironstone accumulations

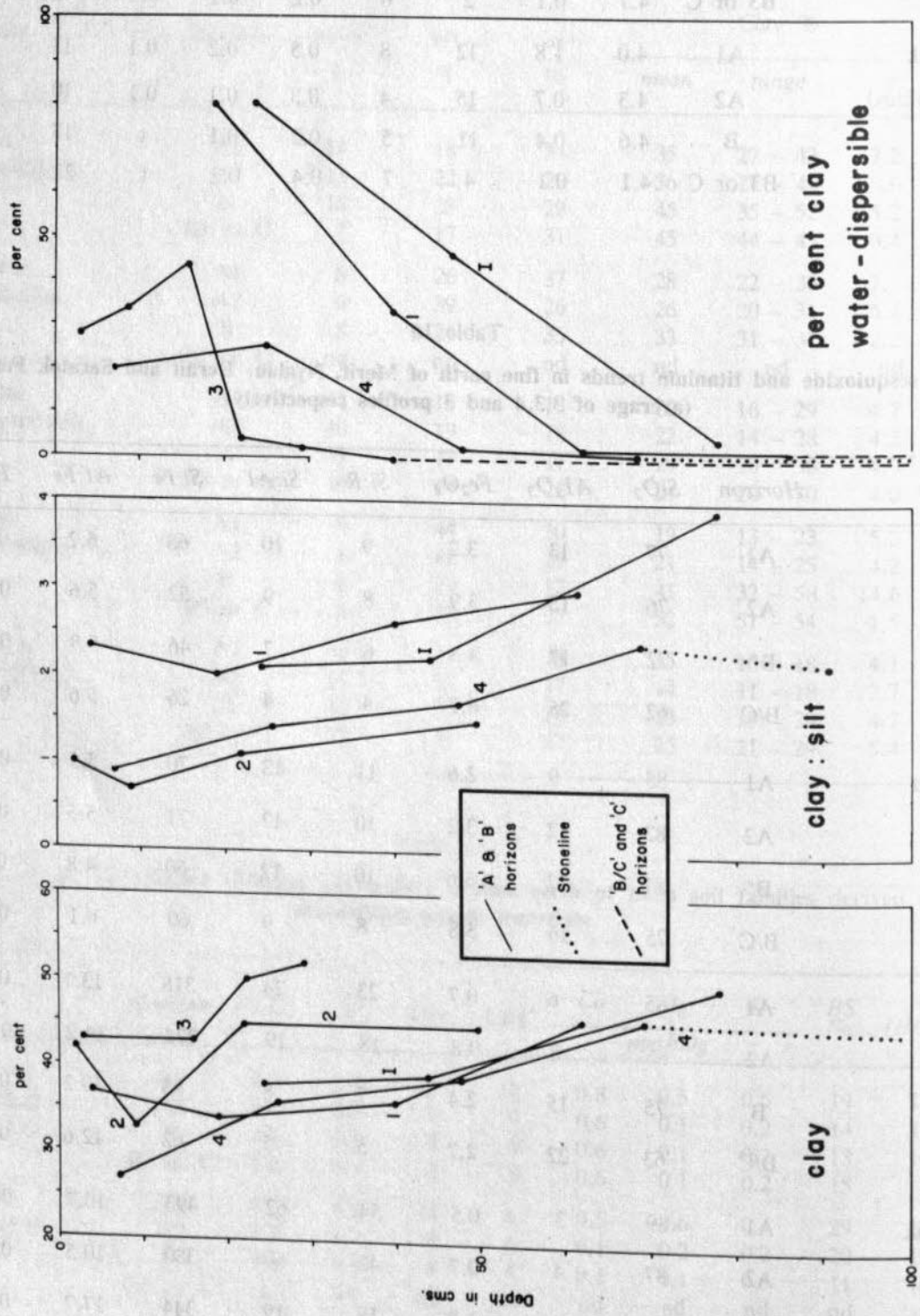


Fig. 40: Clay trends, Merit Family

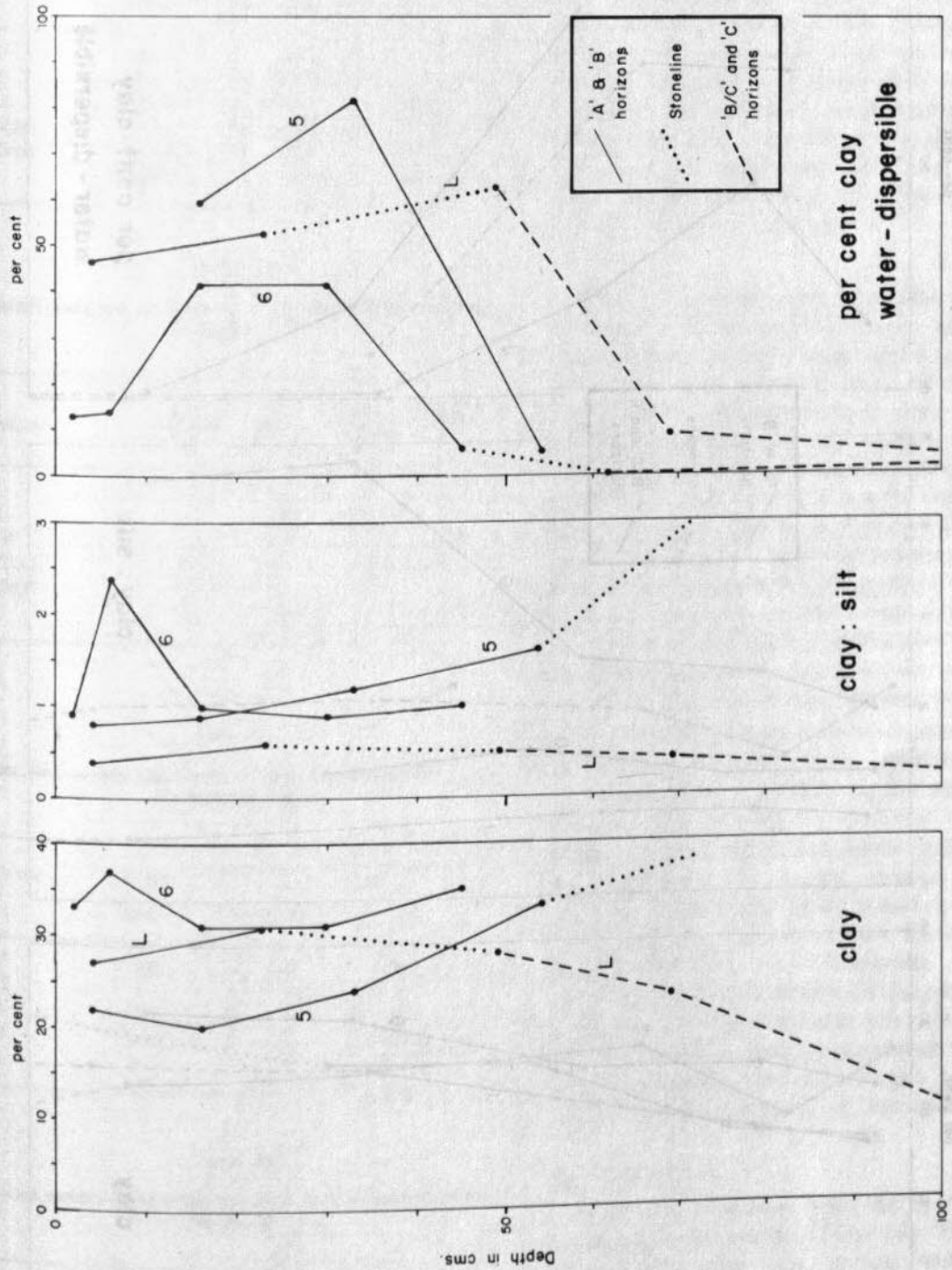


Fig. 41: Clay trends, Bekenu Family

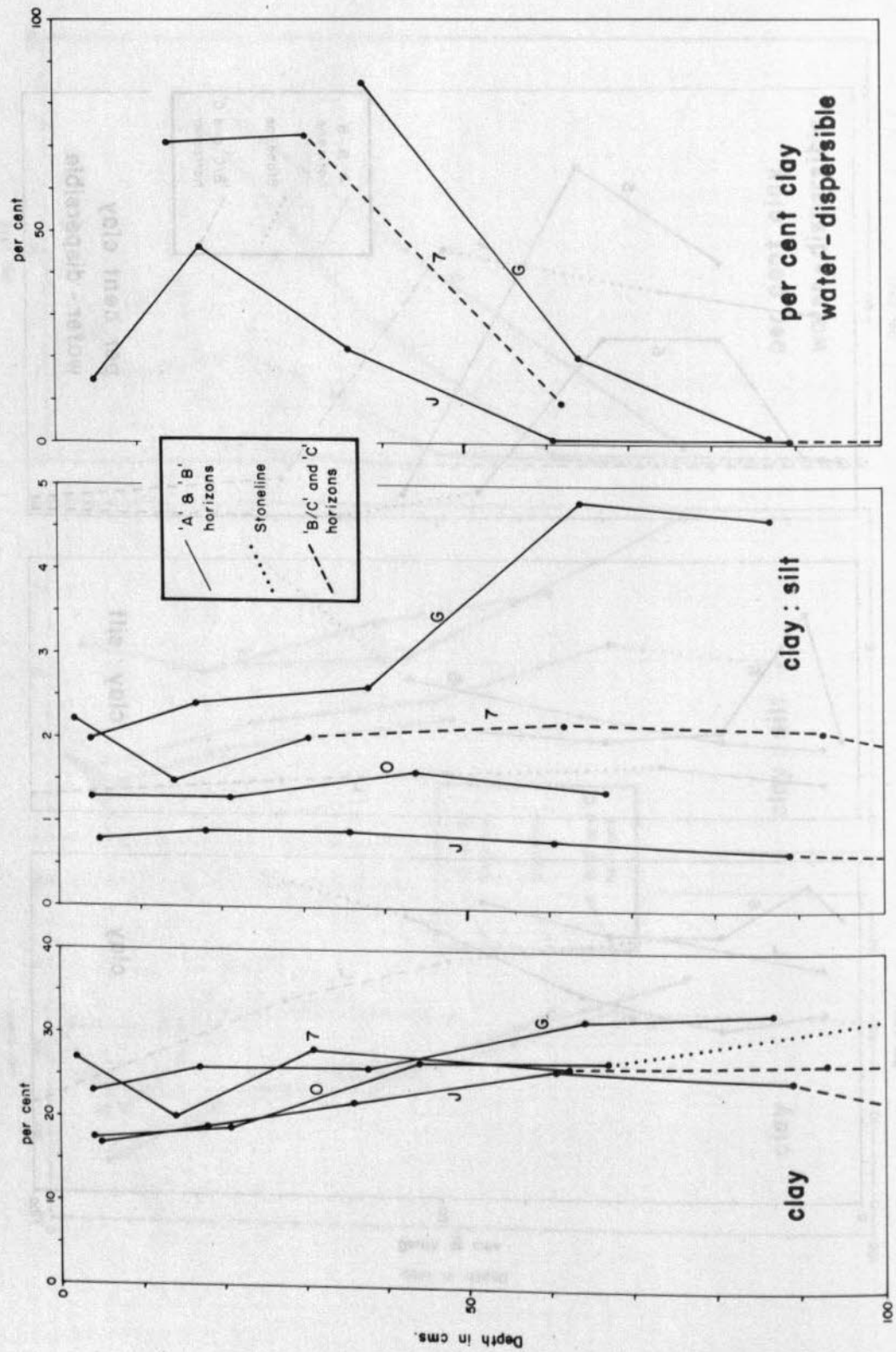


Fig. 42: Clay trends, Nyalau Family

Table 17

Silica, sesquioxides and titanium in clay fraction of a Merit clay loam (Profile 3)

Horizon	*Depth* (cms)	*Clay* (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	TiO_2 (%)
A1	0-3	42	44	28	7.3	0.83
A2	3-15	33	45	30	7.2	0.96
B21t	15–28	45	45	31	7.1	0.92
B22t(s)	28-41	45	44	32	7.8	0.86
B23t(s)	41-58	44	44	31	7.4	0.79
C	58-97		44	31	6.1	0.75

Table 18

Selected molar ratios for the clay fraction of a Merit clay loam (Profile 3)

Horizon	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A1	2.2	2.6	16	6.1
A2	2.2	2.6	17	6.5
B21t	2.1	2.5	17	6.8
B22t(s)	2.1	2.4	15	6.4
B23t(s)	2.1	2.5	16	6.5
C	2.1	2.4	19	8.0

Table 19

Silica, sesquioxides and titanium in the clay fraction of a Jakar silty clay (Profile 4)

Horizon	*Depth* (cms)	*Clay* (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	TiO_2 (%)
A11	0-5	43	45	28	10.1	0.81
A12	5-13	43	45	28	9.9	0.79
A2	13-18	43	44	29	10.8	0.72
B2t	18-25	50	42	29	11.4	0.65
B3	25-33	52				

Table 20

Selected molar ratios for the clay fraction of a Jakar silty clay (Profile 4)

Horizon	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A11	2.2	2.8	11.8	4.3
A12	2.2	2.7	12.2	4.4
A2	2.1	2.6	10.8	4.2
B2t	2.0	2.5	9.9	4.0
B3				

Considering profiles with the Area, average TiO_2 levels for key horizons are given for Merit and Nyalau Families in Table 16. Levels are slightly higher in the solum than the C horizon. Data from selected Merit (Table 17) and Jakar (Table 19) Series profiles show a similar trend. The data suggest that there is some residual accumulation of titanium and therefore some total loss of constituents from the solum, but these losses appear to be rather small. Data from R horizon, if available, would possibly show greater contrasts but probably not significantly so: analyses of comparable rocks from adjacent areas suggest that initial TiO_2 levels do not normally exceed 1 per cent.

While the general trend is towards silication, Andriesse (1975) suggests that a desilication phase may be an initial stage of the weathering process in soils related to those of the Area. There are no profiles in the present study for which unaltered parent rock is available and which could be compared with C horizon material but it is considered that if such a process operates its effects are small. The range of SiO_2 in C horizons are 59 – 64 and 78 – 84 per cent in soils over shale and sandstone respectively and this is within the expected range for unaltered rock. Desilication would be expected to lead to excess aluminium and the presence of gibbsite, but in none of the profiles for which clay mineralogy data are available is gibbsite present in more than small amounts. Nor are there indications of an increase in free aluminium in the C horizon. In this connection, however, the presence of sand-size secondary gibbsite in the B and C horizons of Profile 3 may be significant, the crystal structures being confined to the larger channels and cavities and being particularly associated with fracture zones in disintegrating rocks fragments. No clay mineralogy data are available for this profile but a comparison of the aluminium levels in the clay and fine earth with the clay percentage (Table 17 and 50) indicates that gibbsite must be largely confined to the sand and silt fractions.

Mobility of iron

Total iron increases from the A to the C horizon in most profiles (Table 16). This partly reflects increasing clay content with depth. Determination of total iron in the clay fraction of fine-textured profiles (Tables 17 and 19) confirms that the clay of the B has more iron than that of the A, although contrasts are not marked. Profile 3 (Table 17) for which data are available for the C horizon, shows that the B clays have markedly more iron than that of the C (in at least some

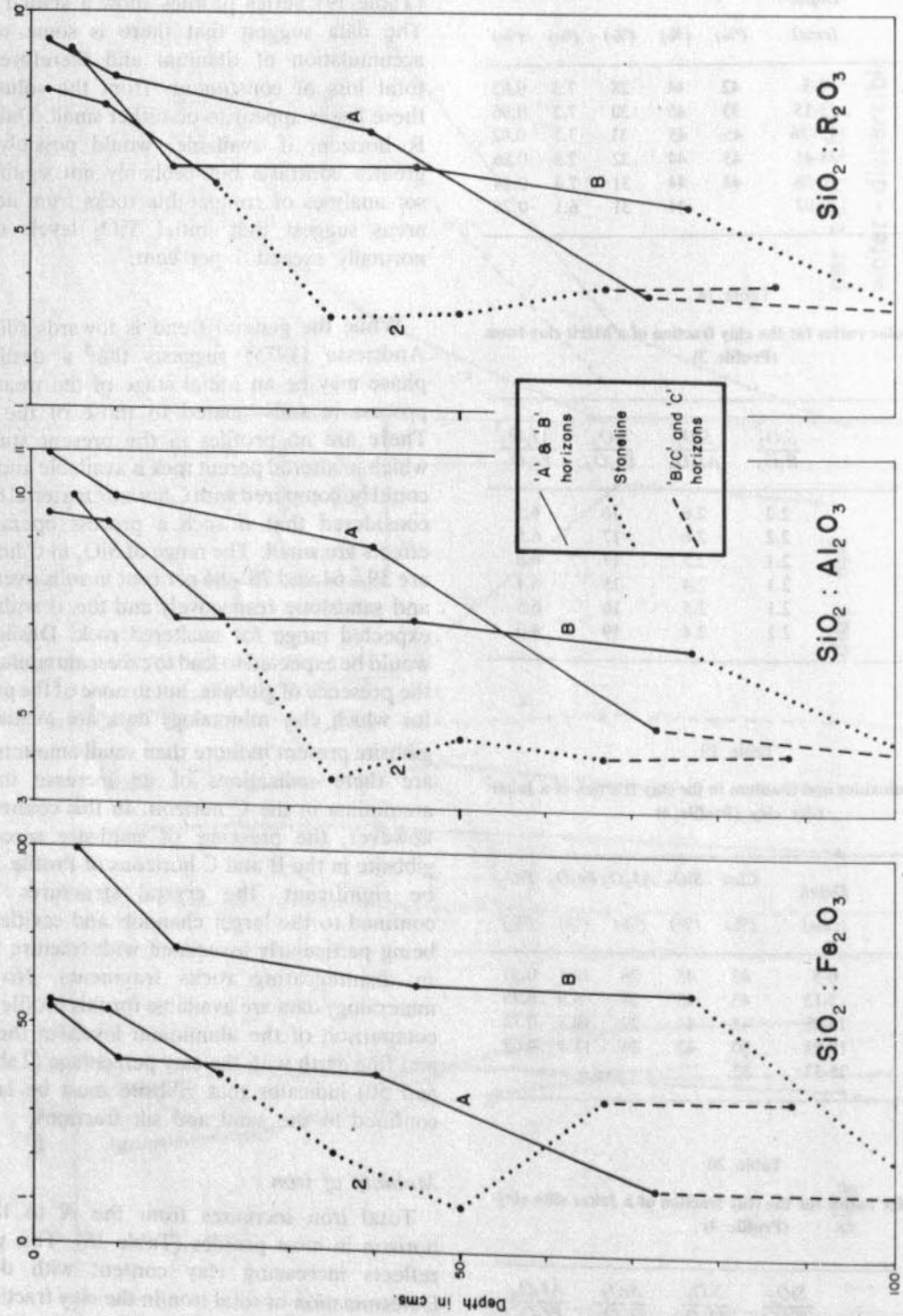


Fig. 43: Silica: sesquioxide ratios, Merit Family

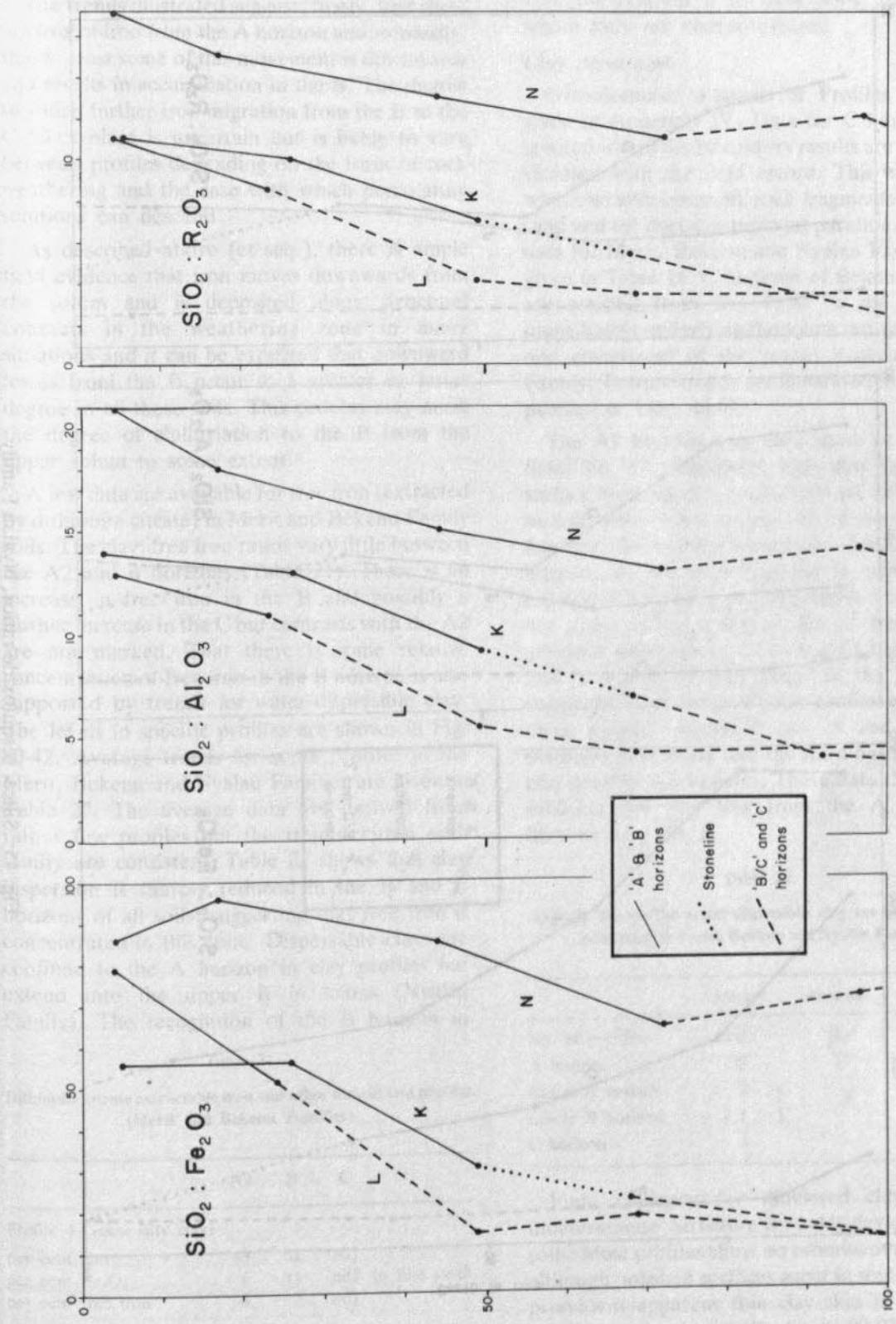


Fig. 44: Silica: sesquioxide ratios, Bekenu Family

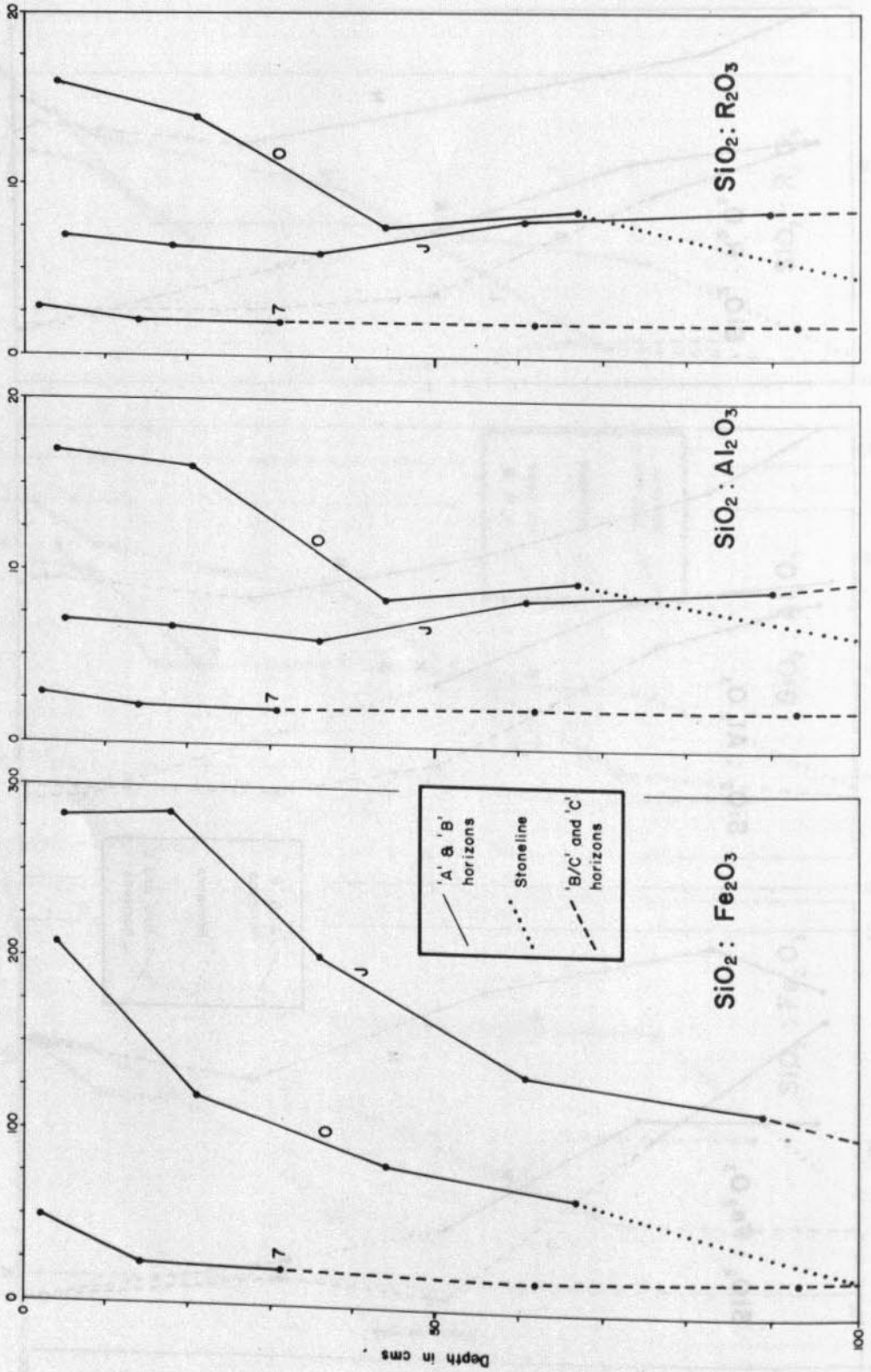


Fig. 45: Silica: sesquioxide ratios, Nyalau Family

cases). It may also be noted that the iron peak does not coincide with the limits of the textural B in this profile.

The trends illustrated suggest, firstly, that there is a loss of iron from the A horizon and, secondly, that at least some of this movement is downwards and results in accumulation in the B. The degree to which further iron migration from the B to the C takes place is uncertain but is likely to vary between profiles depending on the form of rock weathering and the ease with which percolating solutions can descend.

As described above (et seq.), there is ample field evidence that iron moves downwards from the solum and is deposited along structural contacts in the weathering zone in many situations and it can be expected that downward losses from the B occur to a greater or lesser degree in all these soils. This process may mask the degree of chilluviation to the B from the upper solum to some extent.

A few data are available for free iron (extracted by dithionite citrate) in Merit and Bekenu Family soils. The clay: free iron ratios vary little between the A2 and B horizons (Table 21). There is an increase in free iron in the B and possibly a further increase in the C but contrasts with the A2 are not marked. That there is some relative concentration of free iron in the B horizon is also supported by trends for water-dispersible clay. The levels in specific profiles are shown in Fig. 40-42. Average trends for some profiles in the Merit, Bekenu and Nyalau Families are given in Table 22. The average data are derived from rather few profiles but the trends within each family are consistent. Table 22 shows that clay dispersion is sharply reduced in the B and C horizons of all soils, suggesting that free iron is concentrated in this zone. Dispersable clays are confined to the A horizon in clay profiles but extend into the upper B in loams (Nyalau Family). The recognition of the B horizon in these profiles was made on field features (texture, structure, colour), not on laboratory parameters. The 'chemical B' does not necessarily coincide with the textural B in these soils, particularly where they are coarse-textured.

Table 21

Dithionite citrate extractable iron and other data in two profiles (Merit and Bekenu Families)

	A2	B	C	
Profile 4 (Jakar silty clay)				
per cent clay	43	51	nd)	
per cent Fe_2O_3	6	11	nd)	in fine earth
per cent free iron	4	7	nd)	
Profile 7 (Sarikei clay loam)				
per cent clay	31	35	38)	
per cent free iron	3	4	nd)	in fine earth
per cent free iron	7	8	8	in clay

Clay movement

Granulometric analyses of Profiles 2-10 are given in Appendix IV. Data for C horizons are ignored where the laboratory results are greatly at variance with the field record. This may occur where weakly-coherent rock fragments break to sand and silt during sample preparation. Average data for Merit, Bekenu and Nyalau Families are given in Table 14. C horizons of Bekenu profiles are omitted from this Table as the lithology immediately underlying the solum represents only one component of the parent material in this Family. Texture trends are illustrated for selected profiles in Figs. 40-42.

The A1 horizon may have more or less clay than the A2. Relatively high clay figures for surface horizons may result from additions due to surface wash from upslope or by movement of fine particles to the surface by soil fauna. The A2 horizon has less clay than the B, although the amount of clay increase with depth is commonly not great. Clay levels in the C horizon are generally comparable to, or slightly higher than, that in the B. A 'clay bulge' in the B is only suggested by data fron Nyalau profiles and of the three profiles described two (8 and 9) show evidence of layering and the third has a minimal clay peak in this horizon. These data show more evidence for clay loss from the A than for illuviation in the B.

Table 22

Average trends for water-dispersible clay (as percentage of total clay) in Merit, Bekenu and Nyalau Families

	Merit	*Bekenu*	*Nyalau*
No. of profiles	(4)	(2)	(3)
A horizon	35	37	41
Upper B horizon	2	6	38
Lower B horizon	1		4
C horizon	t	t	t

Field evidence for illuviated clay is also indeterminate. Structure is weakly devloped in all soils. Most profiles show no prominent clay skins, although polished surfaces occur in some cases. A prominent apparent thin clay skin in a Nyalau subsoil was sectioned (Profile 8, 89-92 cms) but no coatings were found on channel walls. The majority of thin clay skins apparent in the field appear to be mainly pressure coatings. Thin

sections suggest that the subangular blocks developing in subsoil horizons are incompletely separated and the channels bounding them are discontinuous, thus limiting clay migration in these horizons to travel over short distances. It is difficult to confirm this in two-dimensional sections but the continuously moist state of these soils supports this probability.

Sections have been studied from selected horizons of profiles in Merit (3,4) Bekenu (6) and Nyalau (8-10) Families and are described in Appendix IV. The evidence for clay illuviation from these studies can be summarised as follows: (a) cutans (using Brewer's terminology) are present in the A1 and A2 horizons of some profiles (3,4,9) on both channel and pore walls, but are invariably thin and diffuse. They are diffusion rather than illuviation cutans. Where the texture is loam (6) no cutans may be apparent in the A horizon. (b) some cutans are present in the B horizons of all profiles on walls of channels and pores but the majority are also thin diffusion cutans. In some profiles (4,6,10) well-defined illuviation cutans are found on the same sites but are almost invariably thin and those on channel walls are discontinuous. This limited cutan distribution extends to the C horizon if it comprises well-weathered material without hard rock fragments but where such fragments are dominant the cleavage channels within them commonly have well-defined illuviation cutans which may partially block the channel. (c) illuviation cutans in all profiles examined are pale yellow to yellowish brown in plain transmitted light, anisotropic and strongly-oriented. Most can be classed as argillans or ferri-argillans in Brewer's terminology. Poorly-oriented sesquans fill some rock fragment cleavage cracks. Unoriented material partially filling some voids in the A and B horizons are considered to be isotubules. (d) most A and B horizons show evidence of faunal disturbance (striotubules, fecal pellets) although no marked evidence was seen in Nyalau sections (possibly because reorganisation of matrix material is less obvious where there is a high sand fraction). In all profiles where striotubules are present the illuvial cutans are mainly associated with striotubule voids.

The thin section evidence from these soils suggests that some clay is illuviated from the A to the B and from the B to the C horizon, but that the amount of clay moved by this process is limited. In fine-textured soils a constraint is the general sparsity of conducting channels resulting from the lack of soil structural development. Channels extending over a long distance are generally confined to cavities left by roots or formed by the passage of fauna and the common development of illuvial cutans in association with striotublue voids is noteworthy. The lack of thin-section evidence for cutans in the solum may itself, however, be partly due to destruction by faunal disturbance, as the sparse illuvial cutans which are present are commonly disrupted.

Estimates of illuvial cutan distribution are difficult in these soils as a large proportion of observed cutans are both thin and somewhat diffuse. Cutans which are convincingly of illuvial origin are consistently few (less than 1 per cent of the soil mass) but a proportion of the remainder may also comprise translocated material. Accepting this, and that some deposits of illuviated clay in the B are destroyed by faunal disturbance, the evidence for clay illuviation does not appear to be adequate for the clay trends in these profiles to be solely a result of this process.

It has been suggested that A2/B clay contrasts in such soils may reflect clay formation in the B and clay destruction in the A (Simonson, 1950; cf McCaleb, 1959). Increasing intensity of clay destruction towards the surface has also been proposed as the main reason for clay trends in some 'Podzolised Latosolic' and 'Red-Yellow Podzolic' soils in west Java (van Schuylenborgh, 1957). Mohr et al (1972: 282), reviewing data from a number of sources, find the evidence for clay destruction doubtful and concludes that this cannot be considered an important process in the formation of Red-Yellow Podzolic Soils, ascribing the clay trends of these soils mainly to illuviation and lateral clay losses from the A. Buol et al. (1973: 276) emphasise illuviation but consider, with Simonson, that clay formation in the B is probably significant. The relevance of conclusions from these sources to the present soils is uncertain, as the profiles considered are not necessarily comparable.

Data on clays of fine-textured profiles (Merit and Jakar Series; Tables 17 – 19) show that Si:A1 ratios decrease with depth but the trend is slight and there is little contrast between the A and the B horizons. Clay mineralogy, on available data, generally also shows little contrast between horizons, (2, 4, 6, 7 and 10) although there is some increase in kaolinite and gibbsite with depth in one Merit profile (2) and somewhat more gibbsite in upper horizons of one Nyalau profile (10). There appears to be no conclusive evidence that clay destruction is a major process giving lower clay levels in the A2 horizons of these soils and further data are needed on this point.

Other processes which may lead to clay depletion in the A horizon are lateral eluviation of clay in suspension and downslope creep of

surface horizon material, affecting all materials but involving preferential movement of finer particles. Fauna may also transport clay to the surface which is then removed by surficial erosion. Although this is as likely to lead to higher clay levels in the A1 as to lower levels in the A2, the process can be expected to affect the upper part of the profile more than lower horizons and result in an A/B texture contrast. The evidence for slope creep and faunal disturbance (et seq.) together with the small amounts of illuviated clay seen in thin sections of B horizons and the disproportionate thickness of the B in comparison with the A in some profiles suggests that lateral removal of clay from the A is an important process and is a major factor responsible for the clay trend in the subsoil.

The expression of processes which affect surface horizons to a greater degree than the subsoil are reduced where truncation of the profile by erosion is rapid. That this is an important process in upland soils is shown by surface wash features, the many profiles with minimal development of the A horizon, and indications in some profiles that the A is developing in a prior B. This is, for example, suggested in Profile 3 (Merit) on a 3° slope where the level of iron in the surface horizon is higher than that in the C (Table 17). The effect of wastage on steeper slopes in minimising the development of textural horizonation is indicated in Table 23, where data from 51 profiles (from the Area and also from west and north Sarawak), are averaged. Regardless of the textural class of the profile the steepest clay gradient tends to occur in soils on shallow slopes with least surface wastage. In clay profiles the average gradient smooths out progressively on steeper slopes. This may be related to accelerated truncation through surface erosion. Silt and loam profiles appear to have a more erratic but broadly similar trend.

Table 23

Merit, Bekenu and Nyalau Families: Maximum A2/B clay increase within 30 cms depth on a range of slope categories; averaged from 51 profiles including 24 from the Area (number of profiles given in brackets)

Slope (°)	*4*	*4–10*	*10–20*	*20–40*
Clay profiles (Merit)	1.48 (7)	1.26 (7)	1.23 (8)	1.13 (7)
Loam and silt Profiles (Bekenu, Nyalau)	1.40 (6)	1.17 (7)	1.25 (6)	1.17 (3)

Minor soils developed over acid igneous and related rocks

Soils developed over granodiorite, rhyolite and related igneous rocks are confined to a small areas in the northeast. Details have been studied from four profiles (23 – 26 in Appendix IV) to indicate the range of soils associated with the Piring and Arip igneous complexes.

Profile 25 (Piring Series) represents a deep soil partially mantling the Piring ridge and extending onto the steep upper slopes. It is believed to be derived from quartz-biotite hornfels. The clay content is high and increases slowly with depth (Table 60). Water-dispersable clay is low in the subsoil. There is little differentiation in clay mineralogy, which is dominantly kaolinite throughout. A stoneline occurs at about 90 cms. and, as the site has a 20° slope, the solum above this level (and possibly below) is probably subject to significant lateral creep. The heavy mineral separates of the fine sand (Table 61) shows erratic

Table 24

Silica, sesquioxides and clay in the fine earth of a Nyaroh clay (Profile 26)

Horizon	*Depth (cms)*	*Clay (%)*	*SiO_2 (%)*	*Al_2O_3 (%)*	*Fe_2O_3 (%)*
A1	0–8	50	36	30	11
A2	8–28	56	36	31	12
B2	28–43	57	37	31	14
B31	43–66	63	36	32	13
B32	66–91	65	36	31	13
C1	91–124	65	37	32	12
C2	124–157		36	32	12

Table 25

Silica: sesquioxide ratios in the fine earth of a Nyaroh clay (Profile 26)

Horizon	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A1	1.6	2.0	9.0	4.5
A2	1.6	2.0	7.9	4.1
B2	1.6	2.0	7.0	3.4
B31	1.5	1.9	7.6	4.0
B32	1.6	2.0	7.6	3.8
C1	1.6	1.9	8.4	4.4
C2	1.5	1.9	8.2	4.3

Table 26

Silica, sesquioxides and clay in the fine earth of an Arip sandy clay loam (Profile 24)

Horizon	*Depth (cms)*	*Clay (%)*	*SiO_2 (%)*	*Al_2O_3 (%)*	*Fe_2O_3 (%)*
A	0–5	21	40	28	7
B1	5–43	32	43	30	9
B2	43–69/84	33	40	30	9
C	69/84–140		39	30	11

Table 27

Silica: sesquioxide ratios in the fine earth of an Arip sandy loam (Profile 24)

Horizon	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A	2.1	2.5	15	6.0
B1	2.0	2.4	13	5.2
B2	1.9	2.3	11	5.0
C	1.8	2.2	10	4.4

Table 28

Silica, sesquioxides and clay in the fine earth of Changgan sandy clay loam (Profile 23)

Horizon	*Depth (cms)*	*Clay (%)*	*SiO_2 (%)*	*Al_2O_3 (%)*	*Fe_2O_3 (%)*
A11	0–4	23	26	32	16
A21	4–13	28	27	33	18
A22	13–36	27	26	32	18
B	36–56	32	26	32	20
C1	56–81	38	27	32	20
C2	81–100		25	31	21

Table 29

Silica: sesquioxide ratios in the fine earth of Changgan sandy clay loam (Profile 23)

Horizon	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A11	1.05	1.4	4.3	3.1
A21	1.03	1.4	4.0	2.9
A22	1.02	1.4	3.8	2.8
B	0.99	1.4	3.5	2.5
C1	0.99	1.4	3.5	2.5
C2	0.95	1.4	3.2	2.3

trends but suggests that at least the surface horizons have a different parentage from the material at depth. Silicate analyses are not available and thin sections were not prepared. The generally weak structure, strengthening slightly in the B horizon, together with the lack of shiny ped surfaces observed in the field, suggest that the processes operating in this profile, are mainly silication, some vertical movement of iron, a minor amount of clay translocation to the B and a more significant loss of clay by mechanical eluviation from the A; trends resulting from these processes are modified by layering through downslope creep and surficial erosion, possibly coupled with a degree of faunal sorting within the solum, although the stoneline at this site could be the result of creep alone.

Profile 26 (Nyaroh) is also deep and has a high clay fraction. It is found on a shallow slope in rolling terrain between rhyolite hills. The parent material is uncertain but although carbonaceous shale outcrops nearby the uniform colour and structure of the profile, the clay and iron percentages and the soil depth all suggest that this soil is derived either from acid igneous or metamorphic rocks. As in Piring Series, there is a slight silication trend (Table 25) and although a minor iron accumulation in the B is indicated by the SiO_2:Fe_2O_3 ratio it is too small to be convincing. It does, however, occur in the horizon immediately above that in which faint mottling appears in the profile and, as in Profile 13 on very different parent material, this may indicate that vertical leaching of iron takes place to some extent in this profile but is interrupted by periodically poor drainage in the lower subsoil. The horizon in which the iron peak occurs is that with the strongest structural development and some apparent clay skins in the field sample. Thin sections confirm, however, that these are pressure coatings. Only diffuse cutans are present and structural peds appear to be incomplete. There is evidence of faunal activity to a depth of over 1 metre. No differentiation in clay mineralogy between horizons was found. Kaolinite and vermiculite are dominant in all samples analysed between 8 and 124 cms. Water-dispersible clay is very low in the B and moderately low in the A also. Truncation through surficial erosion is likely to be less at this site than in Profile 10 and there is no evidence of lateral creep. The silicate trends are, however, more erratic than in Profiles 23 and 24 and there remains a possibility that this soil is, despite its apparent uniformity, developed in clay wash material from surrounding massifs. No assistance regarding parent material is given by the sand

mineralogy in this very clayey profile: the heavy crop from all horizons was too small to allow comparison and mainly comprised opaques.

Profile 24 (Arip Series) is found in a footslope position, on the flanks of the igneous Arip ridge. The geology is mixed but the profile is believed to be largely derived from rhyolite. A stoneline of iron-enriched rock fragments is present at 43 cms, which may indicate a discontinuity at this point. Little evidence of faunal activity was seen in thin section and, as the forest cover is poor and there is a negligible litter layer, faunal action may be less in this soil than in the majority of others discussed. The landform and slope suggest that the stoneline in this instance has developed as a result of slope creep. No marked bisequency is indicated by the fine sand mineralogy (Table 64), except perhaps in tourmaline distribution, and it is considered that the parent material of the solum above 43 cms, is not significantly different from the C horizon now present below the profile.

Iron is highest in the C horizon (Table 26) and decreases towards the surface, aluminium is constant throughout (the lower figure for the A probably resulting from the figures being uncorrected) and there is a silication trend, all ratios declining slightly with depth. Water-dispersible clay is low in the B. There is some evidence of clay illuviation in this profile. The subsoil is massive and channels are discontinuous in thin section, but there are many voids and some of these have well-ordered argillans, although the majority of cutans are diffuse and those which appear to be definitely due to illuviation are invariably thin. The clay trend and the thinness of identified argillans in the profile suggests that, while some vertical clay translocation takes place, the losses from the A are likely to be mainly by mechanical removal through surface sheet wash and lateral removal from the A in suspension.

Profile 23 from the Piring foothill zone (Changgan Series) is developed over granite or granodiorite, although hornfels fragments in the subsoil suggest that colluvial drift material may also be involved in the profile. There is an increase in clay with depth (Table 65) and this extends into the C horizon. Iron increases from the A to the C, while aluminium remains almost constant (Table 28). The Si:Fe ratio declines slightly with depth but the Si:Al remains constant into the C horizon (Table 29). Although total iron levels are high much of the clay is water-dispersible in all horizons above the C (Table 65). Much of the iron is probably combined in ilmenite. Heavy mineral separates of the fine sand (Table 66) proved to be mainly ilmenite and this fraction is exceptionally high throughout the profile. Crystalline clay minerals are dominantly kaolinite but the clay matrix is rather isotropic and probably contains a high proportion of amorphous iron. No cutans were seen in thin section. Their development may be masked by iron but, as the structure is weak and blocks incomplete, it is believed that cutans are largely absent and clay illuviation small. There is little chemical horizonation although iron mobility is expressed to some extent. There are only slight indications of clay and sesquioxide accumulation in the B and textural trends in the profile are probably largely the result of lateral losses of clay from the A.

From the view point of soil-forming processes, the profiles from the Piring and Arip igneous areas appear to be closely similar to those developed over sedimentary rocks in the same weathering environment, although Piring and Nyaroh Series have more 'oxic' characteristics than equivalent clay profiles over shale.

Dominant processes

Andriesse (1975) studied seven profiles from west Sarawak including Serin, Gumbang, Semongok and Nyalau profiles, plus a profile then classed as Gading Series which on the present proposed criteria would correlate with Changgan. The Nyalau profile is comparable to Nyalau Series soils recorded in the Area. The Semongok profile is less relevant, as this Series is not found in the Area and is in some ways a typical of the Merit Family. There is also a little doubt regarding the degree of correlation between west Sarawak soils over igneous rocks and those found elsewhere. Andriesse concluded that the soils studied show removal of iron and residual silication, that there is no evidence for sesquioxide accumulation in the solum, although 'low magnitude' accumulation may occur. Any accumulation is more likely to be of aluminium than of iron. 'The podzolisation process in the upland soils amounts under well-drained conditions to only a deferritization process as defined by Mohr et al (1972) without being accompanied or succeeded by an argeluviation, argilluviation and/or an organic precipitation process' (Andriesse, 1975: 143). Andriesse stresses that a 'chemical B' commonly exists at depth in the weathering zone (indicated particularly by iron accumulation — 'ferritization').

Data from soils in the Area also indicate the importance of residual silication but suggest a limited amount of iron accumulation in the B in

addition to iron migration from the solum to the C horizon, Aluminium, on the other hand, appears to be relatively immobile. There is evidence for some illuviation of clay to the B and C horizons, but much of the clay contrast in subsoil horizons is considered to result from lateral removal of clay from the A. There is little convincing evidence for clay formation in the B and its destruction in the A although these processes probably occur to some degree. An important process is the homogenisation of the solum material (and the reduction of contrasts between horizons) due to faunal disturbance. Migration of iron and illuviation of clay may be more important processes in Bekenu and Nyalau profiles than in Merit. Faunal action may be more intense in Bekenu and Merit soils than in loamy Nyalau profiles.

Grey-White Podzolic Soils

Averaged data for important soils in this Group are compared with those of the main Red-Yellow Podzolic Soils in Tables 14 – 16. Soils in the Bandang and Saratok Families (Profiles 16 – 18) show strong leaching and removal of clay and iron from the A horizon. There are slight indications of iron accumulation in the B of some profiles but not in others. Total iron levels are very low, however, and minor variations in reported iron levels between subsoil horizons may not be significant. The clay increase with depth may be either abrupt or diffuse. There are no field indications of illuviated clay in profiles examined and no thin sections are available for these soils.

More data are available for Kerait Family soils and silicate analysis was completed for the clay fractions of two profiles (14, P). These data (Tables 30 – 33) show that Si:Al ratios decrease slightly with depth but do not suggest great aluminium mobility, although a slight aluminium accumulation in the B is indicated in one profile (P). Iron is more mobile and in one profile (14) there is a pronounced iron peak coinciding with the upper part of the textural B horizon. In the other (P) the trend is more erratic but Fe accumulation is also indicated. Field evidence from road cutting exposures suggests that there is little or no iron deposition in the weathering zone of these soils. In addition to the low levels of iron available for redistribution the massive pallid clays to which carbonaceous shales commonly weather generally lack structural channels which would allow iron migration and offer sites for iron accumulation. The iron peak in the B of profile 14 thus probably reflects accumulation above a relatively impervious (and less well-drained) substratum.

The clay increase in the B is marked and may be abrupt, contrasting with the trend of most Red-Yellow Podzolic Soils. This contrast need not be overstressed, as few profiles of Kerait Family have been analysed, but an abrupt clay increase is also reported for two Kerait profiles from west Sarawak (Andriesse, 1972: 300 – 302). Thin sections of Profile 14 show few, thin well-ordered (and probably illuvial) cutans on some channel walls in the B horizon but only diffuse cutans elsewhere (no cutans being seen in the A). The clay deficiency in the A horizon is considered to be due mainly to lateral removal, together with some clay destruction. Clay illuviation is a minor process.

Striotubules are present in sections examined of both B and C horizon material of Profile 14, termite chambers are seen in road-cutting exposures of these soils at some depth, and the Grey-White Podzolic Soils therefore appear to be affected by faunal action to a significant degree.

In general, the processes involved in the formation of these soils appear to be those responsible for the development of their Red-Yellow associates, modified firstly by the low levels of iron in the parent materials and, secondly, by the limited opportunities for downward translocation of sesquioxides and clays to the C horizon offered by the massive pallid clays to which these materials weather.

General Comments Regarding Well-Drained Upland Soils

There is rapid leaching of soluble salts but this is limited by the low reserves of easily weatherable minerals in these parent materials. There is surface accummulation of organic matter but this is partly offset by rapid oxidation and breakdown. Some clay destruction takes place but silicate trends and base saturation levels suggest that this is not a major process, although it may be the case that continuous truncation by

Table 30

Silica, sesquioxides and titanium in the clay fraction of a Kerait loam (Profile 14)

Horizon	*Depth (cms)*	*Clay (%)*	*SiO_2 (%)*	*Al_2O_3 (%)*	*Fe_2O_3 (%)*	*TiO_2 (%)*
A1	0–8	23	46	31	1.9	1.1
A2	8–23	25	45	33	2.0	1.1
Bt	23–58	32	44	33	2.5	1.0
C1	58–97	46	45	33	2.1	1.0
C2	97–120	54	46	33	1.8	0.9

Table 31

Selected molar ratios for the clay fraction of a Kerait loam (Profile 14)

Horizon	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$	$\frac{Fe_2O_3}{TiO_2}$
A1	2.5	2.6	65	25	0.9
A2	2.3	2.4	60	25	0.9
Bt	2.2	2.3	47	21	1.2
C1	2.2	2.3	57	24	1.0
C2	2.2	2.3	65	28	1.0

Table 32

Silica, sesquioxides and titanium in the clay fraction of a Kerait very fine sandy loam (Profile P)

Horizon	Depth (cms)	Clay (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	TiO_2 (%)
A11	0–8	13	46	28	1.1	0.013
A12	8–20	14	46	32	1.4	0.015
A21	20–33	17	43	33	2.3	0.012
A22	33–58	17	41	33	2.0	0.011
Bt	58–94	32	42	33	2.4	0.008
C	94–122	50	46	33	2.1	0.006

Table 33

Selected molar ratios for the clay fraction of a Kerait very fine sandy loam (Profile P)

Horizon	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$	$\frac{Fe_2O_3}{TiO_2}$
A11	2.7	2.7	116	42.5	42
A12	2.4	2.5	88	35.2	47
A21	2.2	2.3	51	22.7	96
A22	2.1	2.2	55	25.6	91
Bt	2.1	2.2	46	21.3	150
C	2.3	2.4	59	24.4	175

surface erosion obscures clay breakdown effects in the A horizon.

Silication trends are common to all profiles examined and are mainly the result of iron leaching, aluminium being less mobile. While iron is lost from the A horizon and some is translocated to the B, the main trend is towards a net loss from the solum as a whole, coupled with some accumulation in structural channels in the weathering mantle.

Some clay is moved from the A to the B but the amount translocated is limited. This may be partly due to the weak subsoil structure developed in a moist soil environment and the reduced development of continuous conducting channels which would facilitate clay movement, and partly to the increasing free iron oxide percentage with depth which tends to immobilise clay in the B and C horizons.

There are, however, commonly marked clay losses from the A and a definite contrast in clay levels between the A and the B. The relatively uniform clay chemistry throughout the solum, the minimal field and microscopic evidence for clay illuviation in the B, and the disproportionate thickness of the B in many profiles when compared to the A all suggest that the clay deficiency in the A is mainly the result of mechanical removal of clay from the upper horizons by lateral eluviation in suspension and, in some soils, through transport to the surface by soil fauna, where some clay is removed through surface sheet wash.

Many profiles show evidence for faunal activity throughout the solum and indications that there is much faunal disturbance. Stoneline concentrations at the base of many profiles are believed to be largely one result of this. The diffuse manner in which most subsoil horizons grade into one another is a further consequence. Stonelines are also developed, particularly on steep slopes, by lateral soil creep and this, together with the layering of material in which many profiles subject to slope movement have developed, tends to obscure trends towards horizon segragation resulting from other processes. Vertical slumping of material into cavities left by roots in an environment with a rapid biocycle is also important in tending to even-out horizon contrasts. Continuous truncation of the profile by surface erosion, particularly on steep slopes, acts against the development of mature profiles with pronounced horizonation. Under many forms of cover soil erosion is less extreme than might be expected from the rainfall regime but truncation remains rapid in comparison to some other processes and may be a major cause of the lack of secondary weathering and transformations noted in the mineralogy of the clay fraction.

The processes summarised above appear to operate throughout the range of upland soils developed over acid parent materials, but some contrasts between soil families are found. There is

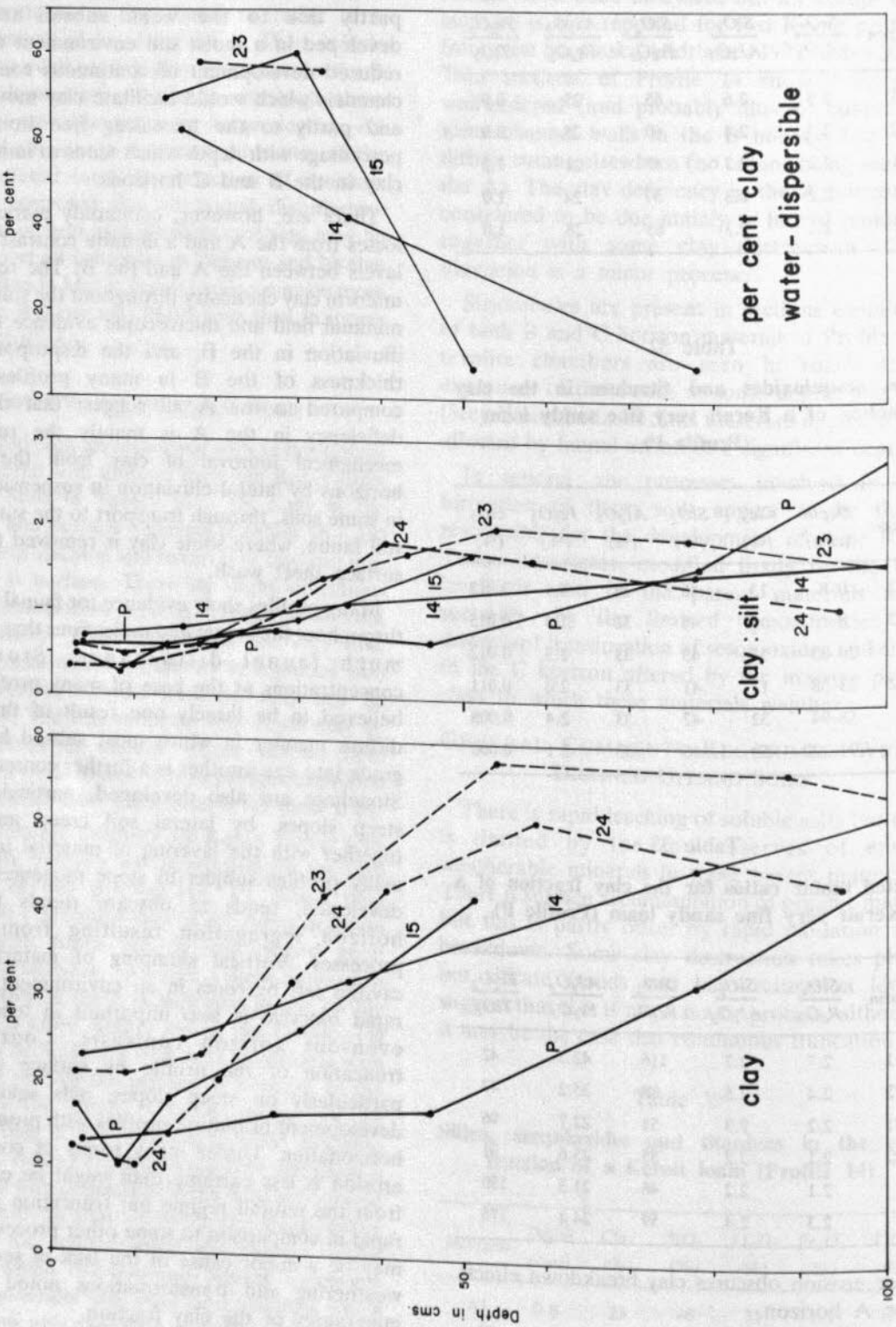


Fig. 46: Clay trends, Kerait (14, P), Bandang (15) and Ajoh (23, 24) Families

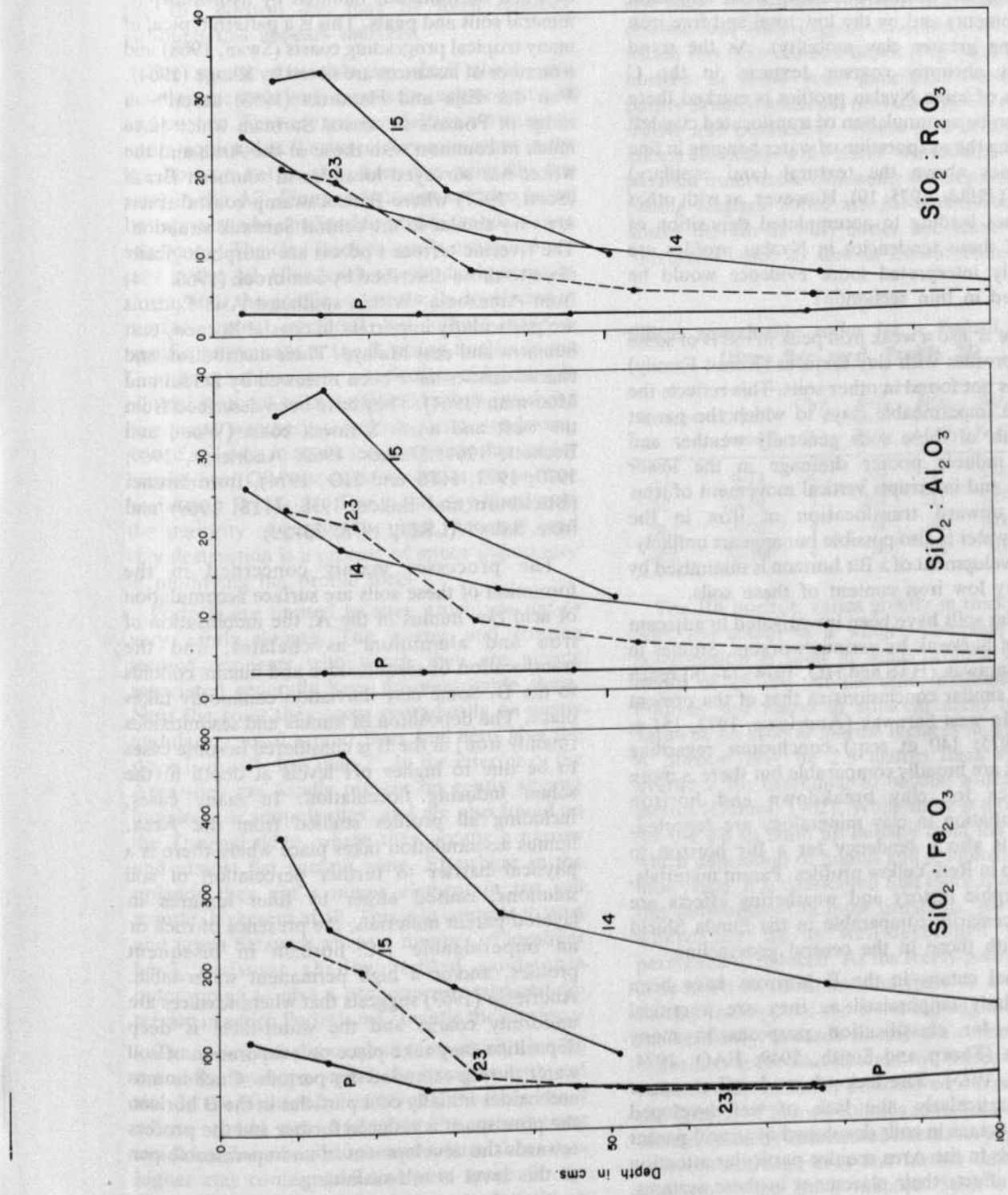


Fig. 47: Silica: sesquioxide ratios, Kerait (14, P), Bandang (15) and Ajoh (23) Families

a tendency for a weak clay bulge to be developed in the B horizon of some loam profiles (Nyalau and Saratok Families) in contrast to the silt and clay families. Vertical translocation of clay is facilitated in these profiles by the coarse texture (high porosity counterbalancing weak structural development) and by the low total and free iron (allowing greater clay mobility). As the trend towards abruptly coarser textures in the C horizon of some Nyalau profiles is marked there may also be accumulation of translocated clay left following the evaporation of water hanging in fine capillaries above the textural (and capillary) break (USDA, 1975: 19). However, as with other processes leading to accumulated deposition of clay, if these tendencies in Nyalau profiles are correctly interpreted more evidence would be expected in thin section.

There is also a weak iron peak in the B of some pallid profiles with clay textures (Kerait Family) which is not found in other soils. This reflects the massive impermeable clays to which the parent materials of these soils generally weather and which induces poorer drainage in the lower subsoil and interrupts vertical movement of iron Some upward translocation of iron in the groundwater is also possible but appears unlikely. The development of a Bir horizon is minimised by the very low iron content of these soils.

Similar soils have been investigated in adjacent areas of Sarawak by various workers. Studies in north Sarawak (HTS and HO, 1974: 74–78) reach closely similar conclusions to that of the present study. In west Sarawak (Andriesse, 1972, 151 et seq. 1975: 140 et seq;) conclusions regarding process are broadly comparable but there is more evidence for clay breakdown and horizon differentiation in clay mineralogy are reported. There is also a tendency for a Bir horizon to develop in Red-Yellow profiles. Parent materials, geomorphic history and weathering effects are not necessarily comparable in the Sunda Shield area with those in the central geosyncline.

Illuvial cutans in the B horizons have been particularly emphasised as they are a critical feature for classification purposes in many systems (Thorp and Smith, 1949; FAO, 1974; USDA, 1975). The lack of good soil structure and, particularly, the lack of well-developed illuvial cutans in soils developed over acid parent materials in the Area require particular attention as this affects their placement in these systems.

Podzols

Podzols are found developed in sands mantling marine terrace tracts in the hill-swamp fringe zone of the Area, in some of the subrecent and older sands near the coast itself, more locally on riverine terraces in the interior of the Area and occasionally as residual soils on uplands. The marine terrace Podzols, which are particularly widespread, commonly occupy fragmented tracts between bottomlands mantled by hydromorphic mineral soils and peats. This is a pattern typical of many tropical prograding coasts (Swan, 1968) and a number of instances are noted by Klinge (1964). Van der Eijk and Hendriks (1953) describe a range of Podzols in coastal Surinam which have much in common with those of the Area and the writer has surveyed localities in southern Brazil (Scott, 1977) where Podzol/swamp coastal tracts are very similar to the central Sarawak situation. The riverine terrace Podzols are morphologically close to those described by Sombroek (1966: 154) from Amazonia. Within southeast Asia Podzols are particularly important in coastal Borneo, east Sumatra and east Malaya. Their distribution and characteristics have been reviewed by Dudal and Moorman (1964). They have been described from the west and north Sarawak coast (Wood and Beckett, 1961; Dames, 1962; Andriesse, 1969; 1970; 1972; HTS and HO, 1974), from Brunei (Blackburn and Baker, 1958; HTS, 1969) and from Sabah (LRD, 1975; 53–59).

The processes mainly concerned in the formation of these soils are surface accumulation of acid raw humus in the A, the mobilisation of iron and aluminium as chelates, and the translocation of sesquioxides and humus colloids to the B. Some clay illuviation commonly takes place. The deposition of humus and sesquioxides (mainly iron) in the B is considered in some cases to be due to higher pH levels at depth in the solum inducing flocculation. In many cases, including all profiles studied from the Area, humus accumulation takes place where there is a physical barrier to further percolation of soil solutions, caused either by finer textures in layered parent materials, the presence of rock or an impermeable IIC horizon in bisequent profiles, and/or a high permanent water-table. Andriesse (1969) suggests that where textures are uniformly coarse and the water-table is deep deposition may take place on evaporation of soil water during extended dry periods. Once humus and oxides initially coat particles in the B horizon the pore space is reduced further and the process towards the development of an impermeable pan at this level is self-sustaining.

Partial silicate data are available for Profile 28 (Table 78) and molar ratios are given in Table 34. Both iron and aluminium are strongly leached from the A and increase with depth in the Bh. The mobility of iron is greater than aluminium.

Thin sections of Profiles 20 and 21 show that clay illuviation takes place. In Profile 30 cutans are present in the Bh and are well-ordered. Poorly-sorted clay infill material is also found in some channels. In Profile 31 cutans are only present in the IIC horizon and may be fossil features, although this appears unlikely.

The parent materials in which these soils develop are invariably quartzose, coarse-textured and porous. They are low in weatherable minerals and sesquioxides. Textures vary somewhat in the A1 horizon but in this Area are normally fine sand in the A2. Fine sandy loams are also found but appear to be confined to profiles residual over sandstone. The clay fraction rarely exceeds 5 per cent in the A2. Clay levels remain fairly constant throughout the profile in some soils developed in marine parent material but others have a significant increase in the B, rising further in the C, although this may be a reflection of layering in alluvial material or of an alluvial solum overlying bisequent weathering residue from sandstone. Low clay levels in the A may be partly due to clay breakdown. Gibbsite is dominant in the surface horizon of Profile 31. The initial clay fraction in the majority of profiles is small, however, and clay destruction is a process of minor importance in modifying the profile form.

Podzols are limited to sites which are flat or very gently sloping. The marine and riverine terrace remnants with which they are mainly associated generally have no measurable slope. Near the coast they occur sporadically on gently undulating fossil strand lines but here also the slope is usually less than 2°. In the interior of the Area they are locally present on gently sloping footslope or summit sites, and are also found on the Tunggal ridge, where they occupy a narrow and almost flat summit zone. Elsewhere in the uplands they are a minor element in the soil mantle, if present at all. This is in contrast to west and north Sarawak where a number of localities have resistant shallow-bedded sandstones outcropping to give a pronounced scarp-and-dip terrain in which Podzols may mantle the dipslope.

The point of discontinuity at which the Bh normally develops varies in character with the site. In the Silantek Series (29, 31) the Bh is found where sands are underlain by weathering residuum from sandstone and where there is a higher clay content and less pore space. In the Tunggal Series (30) the solum rests directly on almost unaltered conglomerate and the Bh horizon is extended into the C horizon as infilling in structural cracks in the rock. At lower terrace sites the position of the water-table appears to be critical and Podzols develop at sites where it normally remains below the surface but is within a shallow depth (1–2 metres). Thus in gently undulating strand-line complexes near the coast gleyed sands and other hydromorphic soils occupy the swales and Podzols are confined to the low rises; the surface horizons are here freely-drained but waterlogged conditions are found within less than 1 metre depth (Fig. 39). The Bh horizon in these soils generally overlies the poorly-drained material, provided the Bh remains friable and permeable. Where it is cemented it affects internal soil water movement and a perched water-table commonly develops above it. Strong seepage zones are particularly common above the Bh in Miri Series and leave humus 'tidemarks' such as that in Colour Plate 12.

Table 34

Silica: sesquioxide ratios for a Podzol profile (Buso fine sand, Profile 28)

Horizon	*Depth (cms)*	*Clay %*	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A1	0–23	4	299	317	5300	17
A2	23–50	3	203	211	5200	25
Bh1	50–76	4	81	88	1000	11
Bh2	76–100	4	66	79	400	5

The Bh horizon varies greatly in thickness, as does the solum as a whole. Complete Podzol horizonation is seen in some profiles within a depth of 25 cm. At the other extreme, 'giant Podzols' are found in adjacent areas of north Sarawak on coastal marine terraces in which the A horizon may be 2.5 metres thick and may overlie a Bh extending to beyond a depth of 4 metres (Dames, 1962). While there is a tendency for the Bh to build up initially from the level at which deposition of humus and sesquioxides first took place, it is considered that there is a limit to this development in most situations, particularly where the Bh is well-developed and its permeability reduced. As the freely-permeable A is reduced in thickness and there is a constant rainfall-fed input of soil water moving through it, the tendency towards lateral deflection of soil water above the illuvial zone will increase, and a balance will eventually be achieved where most of the burden of humus colloids mobilised in the A are deflected by accelerated lateral seepage out to adjacent drainage lines and further depositional build-up of the Bh is reduced. Such a trend is particularly likely in profiles where the Bh is fully cemented. These are not necessarily older than those with friable illuvial horizons. Miri Series (which has a cemented Bh) is generally confined to relatively old terrace deposits on the landward

margins of the coastal plain, but soils with friable Bh horizons (Buso Series) are found in terrace deposits of all ages and are the dominant Podzol form in most localities. While Miri Series has no doubt developed through a Buso stage, the speed with which this occurs may depend on a number of factors, in which the ground-water regime may be important. Andriesse (1969) considers that there is a correlation between thick, hard Bh horizons and sites which are excessively dry outside the rainy season and that the evaporation of soil water in such dessication periods may affect the degree of cementation. Deep Podzols in excessively drained material in west and north Sarawak suggest this but, within the Area, Podzols with cemented Bh horizons are not confined to such sites.

Podzols are occasionally encountered in the coastal plain at continuously wet sites, occupying a position on the terrace/swamp fringe as a transition between Buso and Igan Series. A thin surface peat has formed and the water-table is at or near the surface. These profiles (Grang Series) are considered to be fossil and to have been formed when lower water-tables prevailed in the locality. No relative rise in sea-level need be introduced to explain this. The amplitude of relief is minimal and the deteriorating drainage and rise in general water-table level to be expected behind a prograding coast is sufficient to drown Podzol profiles on low sites and to initiate a cycle where paludisation is the dominant process.

Table 35

Silica: sesquioxide and titanium in the clay fraction of an Ajoh-Merit loam (Profile 13)

Horizon	*Depth (cms)*	*Clay (%)*	*SiO_2 (%)*	*Al_2O_3 (%)*	*Fe_2O_3 (%)*	*TiO_2 (%)*
A11	0–5	13	41	25	8.2	0.44
A12	5–15	12	38	26	8.3	0.94
A2	15–30	20	40	28	12.0	1.30
B1t	30–46	34	39	28	12.7	0.72
B2t	46–63	45	40	30	11.6	0.70
C1	63–91	49	41	30	8.4	0.58
C2	91–120	49	42	31	8.9	0.90

Table 36

Selected molar rations for the clay fraction of an Ajoh-Merit loam (Profile 13)

Horizon	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A11	2.3	2.8	13.3	4.7
A12	2.0	2.4	12.1	5.0
A2	1.9	2.4	8.9	3.7
B1t	1.8	2.4	8.2	3.5
B2t	1.8	2.3	9.1	4.0
C1	2.0	2.3	13.0	5.6
C2	2.0	2.3	12.6	5.5

Hydromorphic Upland Soils

Profiles of Ajoh and Penipah Series are described in Appendix IV, together with an intergrade Ajoh-Merit soil (13, 15, 19, 22). These soils cover very restricted areas. They are developed from similar materials to the Red-Yellow and Grey-White Podzolic Soils and, with the exception of the strong mottling due to poorer drainage, are comparable to them in field morphology.

There is a marked clay increase with depth in all profiles and this is generally abrupt. Sand fraction variability suggests layering of the material in some profiles and bisequent soils are, on comparable data from west Sarawak, likely to occur on the upland flat sites associated with this Group. Cutans of possibly illuvial origin are sparse in the B (or IIB) horizons of two profiles (13, 22) examined. The low clay in the A, if not representing a coarser overburden, is therefore considered to result from lateral eluviation and clay destruction. Thin sections show faunal disturbance to be important throughout the solum and may also lead to some clay removal from upper horizons.

Silicate data are available for the clay fraction of the Ajoh-Merit intergrade profile (13). They show (Tables 35–36) that residual silication is important, and that iron is particularly mobile. Aluminium is less mobile but shows stronger contrasts than in the well-drained profiles examined. There is probably some loss of aluminium from the A but no apparent accumulation in the B. Leaching of iron from the A, on the other hand, is accompanied by a marked iron peak in the B above the poorly-drained impermeable C material (compare Kerait, Profile 14). Interpretation is uncertain as apparent iron losses are confined to the A1 and the iron peak begins in the A2. This, coupled with the erratic Ti trend (Table 35) suggests that some of the horizon contrasts my be the result of bisequent material. Nevertheless, available data on these soils suggests that present soil-forming processes relate them to the Red-Yellow and Grey-White Podzolic Soils.

Mineral Soils on Riverine Bottomlands and the Coastal Plain

The mineral soils found in bottomland sites are largely classed under the Groups of Alluvial and

Gley Soils. In riverine floodplains well-drained levee soils near the river bank commonly grade back through a zone of progressively poorer drainage to permanently waterlogged areas mantled by Organic Soils. Profiles 32–35 in Appendix II illustrate well-drained soils in such sites, Profiles 38, 39 and 40 soils with poorer drainage characteristics. Colour Plates 13–15 also refer.

Although these soils are developed in young deposits and other processes are limited by intermittent or continuous saturation, profile trends suggest that the processes important in upland soils developed in similar parent materials are operating here also. Many well-drained profiles show a tendency towards silication and a concentration of iron in the middle of lower subsoil, expressed as a 'colour B' or, at less well-drained sites, by a prominently mottled zone. There is also an iron peak in some profile subsoils which is not reflected in colour (e.g. 34; Table 90) although in others iron is high in all horizons with at least moderately good drainage. Some horizon contrasts may only reflect layering but there is a general tendency for SiO_2:R_2O_3 ratios to decrease with depth, and for there to be an iron peak in the subsoil immediately above the level at which internal drainage deteriorates abruptly. Data from one poorly-drained profile (40; Tables 37 and 83) suggest that (above the discontinuity at 117 cm) some leaching of sesquioxides and possibly some loss of clay from the A horizon may occur in these soils also. The marked Si:Al trend is noteworthy; in upland soils this is also only prominent in profiles with poor drainage.

Where clay mineralogy data are available kaolinite and illite are dominant and no differentiation is reported between horizons. There is a general tendency for clay to increase with depth in most profiles which are not obviously layered. There is no evidence to indicate whether clay formation and destruction play a major part in this trend but thin sections of a moderately well-drained soil (39) show some illuviated clay and traces of considerable faunal activity.

While genetic trends are commonly not marked in these relatively young soils some profile development is apparent and shows the rapidity with which processes leading to sesquioxide mobility, residual silication and clay translocation affect the profile in this climate.

The drainage state of bottomland soils deteriorates towards the coast. In coastal and estuarine sites no well-drained fine-textured soils are found unless drainage improvement has been applied. Limited oxidation of marine sediments occurs due to the high tidal range and the build-up of material in surface mounds by mud-lobsters *(Thallasina anomala)*. The main processes evident are the reduction of accumulated sulphates by bacteria under the pioneer mangrove cover and the reaction of hydrogen sulphide with soil iron compounds to form iron sulphides. On oxidation ferric sulphates, sulphuric acid and aluminium sulphates (from clay minerals) are formed, the soil develops very high acidity and, among other limitations, is generally characterised by aluminium toxicity, phosphorus deficiency and poor subsoil structure. The processes involved have been review by Moormann (1963). Studies in west Sarawak (Andriesse and Sim, 1968; van der Kevie, 1969; Andriesse et al, 1972), on areas comparable to the deltaic zone in which Rajang and Pendam Families are dominant in the Area, stress the importance of the mud-lobster in both developing mounded microrelief which accelerates surface oxidation of material, and in bringing homogenised material from depth in the profile (where sulphide levels may be highest in undisturbed deposits) leading to acidification and the development of jarosite crusts. The

Table 37

Silica: sesquioxide ratios in a poorly-drained profile developed in riverine alluvium (Pakan sandy clay loam) (Profile 40)

Horizon	*Depth (cms)*	*Clay %*	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A1	0–23	14	43	50	293	6
A2g	23–46	20	15	17	127	7
B1g	46–94	31	11	14	66	5
B2g	94–117	47	6	7	41	6
IIC1g	117–168	46	5	6	39	6
IIC2g	168–193		5	6	58	10
IIC3g	193–218		5	6	57	10

development of some subsoil structure, segregation of iron mottles and homogenisation of the soil matrix are, however, processes which begin in advance of the marked disturbance due to mud-lobsters. Thin sections of Profile 45 show these processes at a site on the edge of the mangrove cover, seaward of the zone in which mud-lobster mounds occur. Sections of subsoil material some 2 metres beyond the vegetation edge at this site show only thin undisturbed depositional layering. Root-probing and mining

by small shoreline crabs are likely to be responsible for initial reorganisation of the soil material.

Further soil development beyond acidification and faunal disturbance is generally associated with drainage improvement, commonly in conjuction with agricultural use (or behind a prograding coastline beyond the limits of tidal inundation), but initial changes are largely confined to progressive ripening (Pons and Zonneveld, 1965) and the development of an A1 horizon, as in Profile 41.

Well-drained soils in coastal situations are confined to beach sands (Kabong Family). A weak colour B horizon is expressed in some profiles, suggesting some leaching in the upper horizons, but the majority of these profiles show no development above the gleyed substratum other than a thin A1 horizon. They are generally moderately rich in weatherable minerals, particularly amphiboles and pyroxenes (et seq.). In somewhat older materials behind the present coast soil processes in sands are to a large degree a function of drainage, Podzols occupying some higher flats and gleyed soils (Tatau Family) or Organic Soils the intervening swales (Fig. 39).

Organic Soils

The origin and development of peat swamp deposits in the Area has been briefly discussed above (et seq.). A broader review for the region is given by Andriesse (1974). Present processes operating in these areas are a continued slow accumulation of (largely fibric) plant residues under waterlogged conditions. Anderson and Ahmed (unpublished data) have analysed peat samples under a variety of forest communities. Their results suggest that there is a relationship between lower nutrient reserves and poorer forest successions towards the interior of the main swamps. The swamp surface topography and drainage, the depth to underlying mineral layers, and the rate of peat accumulation are probably connected with these trends, but, in the context of an accumulating organic mantle, it is difficult to isolate causes and effects. The difficulties of adequately characterising chemical levels in this highly varied material also limits the conclusions which can be drawn. The deep peats have very low development potential and have not been studied in any detail within the Area. Aspects of their formation which deserve study include the effects of logging in the basin swamp interior areas and that of drainage schemes implemented in recent years in some swamp-margin tracts.

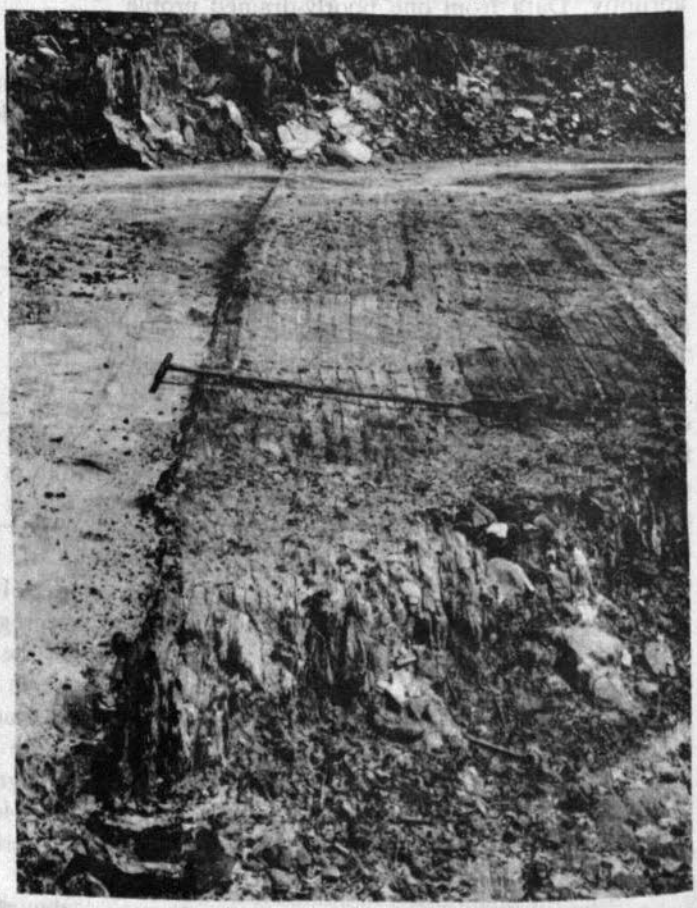


PLATE 19. Belaga II Formation sedimentary rocks exposed by excavation near Meradong, which comprise thinly bedded sandstones (at the head of the 4-foot auger), silty shales, and clay shales (at the bit). A prominent zone of iron-enrichment has developed at the sandstone/shale interface. Minor iron enrichment is present at structure lines within the shales but this is very weakly expressed. The soil mantle previously on the site comprised sandy clay loams of the Bekenu Series.

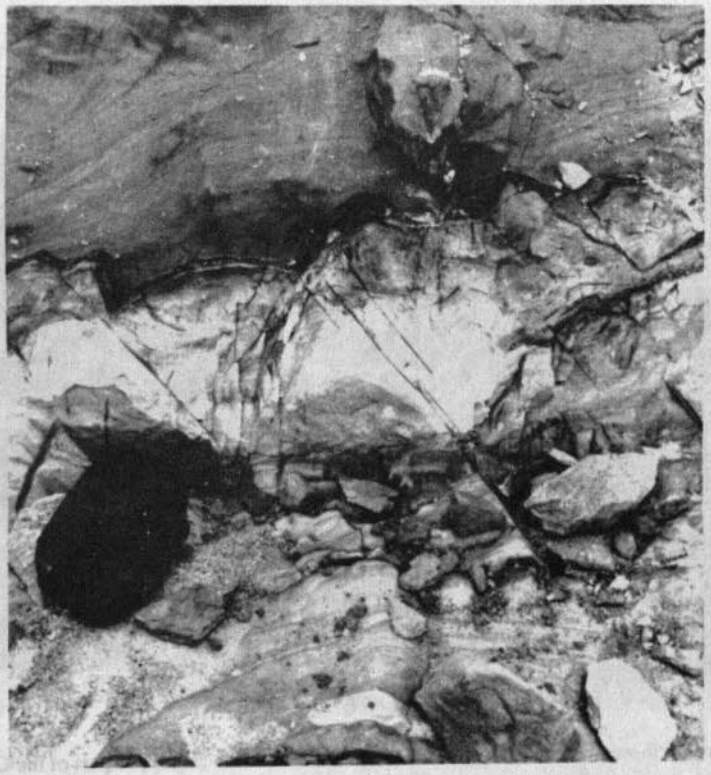


PLATE 20

Iron-enrichment in weathered sandstone. The zone at the top of the picture has formed in a structural plane within the sandstone, that in the centre at an interface between the sandstone and the sandy shale in the foreground. This material will fracture to fragments which concentrate as a stoneline at the base of the solum.



PLATE 21

Prominent stoneline development at the base of a Bekenu Series solum. The thickness of the stoneline is related to the frequency of iron-enrichment zones in the varied sedimentary parent materials. The irregularity in depth may result from different weathering rates in the parent materials but is difficult to explain. It does, however, suggest that vertical sorting processes are more important than lateral creep in stoneline concentration at this site.

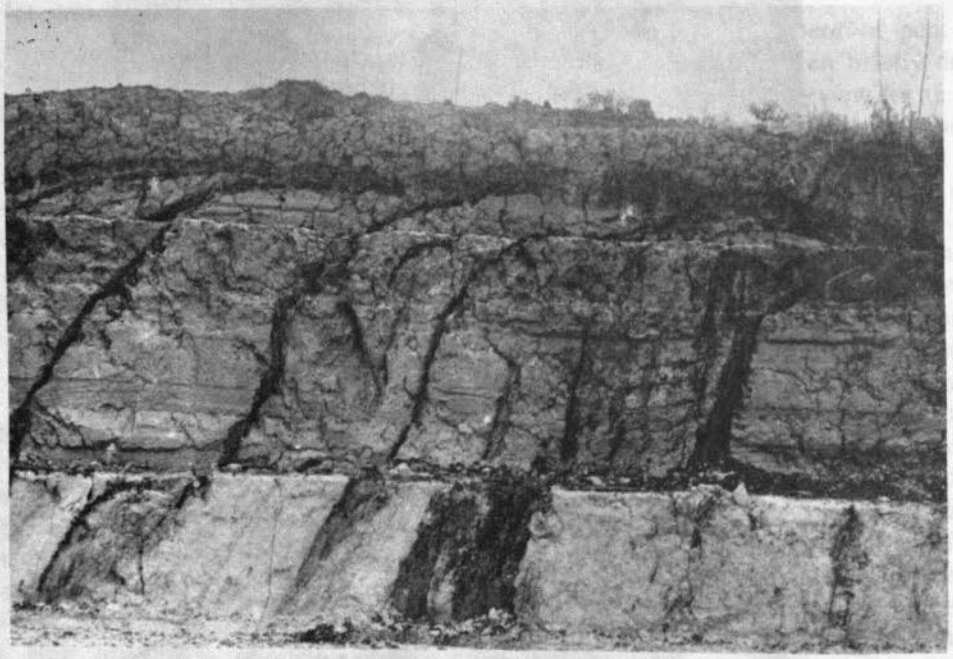


PLATE 22

Iron-enrichment zones in weathered shales with subordinate sandstones. The upper part of the C horizon is subject to downslope creep and these zones bend to the direction of creep before merging as a stoneline at the base of the solum. The original soil has been truncated during roadbuilding but was either Bekenu or Merit Family.



PLATE 23

Steeply-bedded Belaga II Formation carbonaceous shales. The weathering zone changes abruptly from soft dark grey or black material with relict rock structure to light grey or white clay from which traces of rock structure fade out towards the surface. The soil mantle comprises yellow and pale yellow clay loams and clays of the Merit and Merit-Kerait intergrade series.



PLATE 24

Soil disturbance by wind-throw of trees. In falling the root mat near the base of the trunk has remained almost intact and has bodily lifted large portions of soil mantle (Bekenu Series), leaving a cavity into which disturbed fill will wash. Disturbance by tree-fall will effect the A horizon and may extend to the B.



PLATE 25

A chamber widened from a prior root channel to accommodate a free-hanging terminaria.

CHAPTER 11

SOIL CORRELATION

A number of soil classifications have been used in Southeast Asia which broadly stem from the classification scheme of the United States Department of Agriculture (Baldwin et al., 1938; Thorp and Smith, 1949). These include the preliminary classification of Sarawak soils (Dames, 1962), the national classification of Indonesia (Dudal and Soepraptohardjo, 1957; Soepraptohardjo, 1976) and the regional scheme of Dudal and Moormann (1964). It is convenient to consider these together in relation to the Area's soils.

The Thorp And Smith Classification And Derivatives

Red-Yellow Podzolic Soils and Latosols (Lateritic Soils)

The early USDA classification system (Baldwin et al., 1938) stressed the uniform friable profile of Yellowish-Brown Lateritic Soils and, in addition, extended the colour parameters of Red-Yellow Podzolic Soils to include yellowish brown over red profiles. On that basis most local Red-Yellow Podsolic Soils are closer to their USDA equivalents than to the USDA Lateritic Soils. Only Nyalau might be considered 'Lateritic' as it is generally uniform and friable. This, however, is largely a reflection of course texture and deep weathering. Thorp and Smith (1949) narrowed the definition of Red-Yellow Podzolic Soils to profiles with a light-coloured bleached A2 horizon over a yellow or redder more clayey B. This excludes the majority of the Area's upland soils if taken literally. Concurrently, however, Lateritic Soils were reconsidered and replaced by a Latosol Group (Kellogg, 1948; 1950) which emphasised, among other parameters, low Si:R ratios of the clay fraction, low CEC, few primary minerals and low silt content. The Latosol Group was identified with old soils on stable land surfaces and with a desilication process. Upland soils in the Area differ from this concept in age, environmental situation and, in most cases, in one or more of the above profile characteristics. The minority of soils with latosolic features are believed to have inherited them from the parent materials. It is thus difficult to correlate the Merit-Bekenu-Nyalau sequence with either Group of the Thorp and Smith system, but a classification as weakly expressed Red-Yellow Podzolic Soils seems more appropriate than other alternatives.

The definition of Red-Yellow Podzolic Soils was further complexed by genetic studies emphasising progressive clay formation and breakdown and an increasing clay content from the A to the C (Simonson, 1950) and conflicting studies (McCaleb, 1959) which emphasised the importance of clay translocation and the presence of a textural B horizon in these soils. These features led to correlation of well-developed Red-Yellow Podzolic Soils with Ultisols in the later USDA taxonomy and to a converse assumptions that local Red-Yellow Podzolic Soils possessed an argillic horizon as defined in that taxonomy. This assumption was made in the earlier classification applied in Sarawak (Soil Survey Staff, 1966). Inconsistencies in applying the Red-Yellow Podzolic and Latosol labels are particularly great where weakly differentiated profiles are concerned which may be considered to have some properties of both Groups, and this is partly true of upland soils in the Area.

Dames (Table 38; 1962: 31 et seq.) noted the general lack of illuviation clay coatings in Sarawak upland soils over sedimentary rocks and also stressed that a well-defined A2 was absent in most cases. He considered most profiles to be Yellow Latosols and that many of those with sufficiently bleached A2 horizons to be called Red-Yellow Podzolic Soils were more properly intergrades to Latosols. Haantjens et al. (1967) classified soils in New Guinea similar to those of the Merit Family as Red and Yellow Latosols although stating that some have a clay increase with depth and a colour B horizon, and that such forms have also been classed as Red-Yellow Podzolic Soils (among other labels). Haantjens et al. appear to emphasise a distinction between a clay trend due to illuviation (the Red-Yellow Podzolic Soils) and one due to lateral removal of clay from upper horizons (included in the Latosols). The present study would indicate a Latosol label for the Area's upland soils on that arguments, or a placement as Latosol-Red Yellow Podzolic intergrades. Van Schuylenborgh (1957) studied four acid clayey soils in west Java which were similar to Merit Family although all had a clay peak in the B. He classed those with a decreasing Si:R ratio as Red or Yellow Podzolic Soils and those where the clay increase with depth was combined with an increasing Si:R ratio as 'Podzolised Reddish-brown Latosolic Soils'. The latter term was used by Dames (1955) in east Java and was correlated by him with USDA Red-Yellow Podzolic Soils. All soils in the Merit-Bekenu-Nyalau sequence, together with profiles studied in the Area from igneous rocks, would be Red-Yellow Podzolic Soils by van Schuylenborgh's approach.

The national classification of Indonesia (Dudal and Soepraptohardjo, 1957) defines Red-Yellow Podzolic Soils, inter alia, as having a relatively heavy blocky accumulation horizon but while the leached overlying horizon is 'light grey to yellowish' it is stated that this horizon may not be well-expressed. In Latosols, on the other hand, the system emphasises the uniform friable profile, accumulation of sesquioxides and concurrent leaching of silica. While there is some doubt about the degree of accumulation in the B of the Area's Soils, there is little difficulty in equating them with Indonesian Red-Yellow Podzolic Soils rather than Latosols by these definitions. In a later review of the system, however, Soeprptohardjo (1976) implies that all Red-Yellow Podzolic Soils have an argillic horizon. This requirement causes difficulties in correlation with the current Indonesian system (Table 39).

There is no close correlation with Red-Yellow Podzolic Soils in the Dudal and Moormann (1964) scheme where this Group is mainly equated with the Ultisols of the current USDA taxonomy, and, although the degree of leaching in the A2 horizon is not stressed, there is pronounced clay increase in the B and higher clay in B than the C horizons. Except for some deep sandy profiles (Nyalau Family) there is also little correlation between the upland soils of the Area and the Red-Yellow Latosols of this system

The difficulties in correlating the Area's upland soils with variants of the Thorp and Smith system may stem partly from the fact that they are commonly shallow soils on sloping sites and do not show extreme expression of the processes concerned in their development. Difficulties also arise, however, from the varying emphasis placed on texture, structure, colour and chemical trends in reflecting the relative importance of processes involved. Nevertheless it is thought that difficulties in correlation with, for example, the Indonesian system are probably more theoretical than real, and that in practise profiles with the form of the Merit-Bekenu-Nyalau soils are included in the Indonesian concept of Red-Yellow Podzolic soils regardless of the official definition of that Group. The Group is, for example, reported to be dominant in much of the dissected interior of Kalimantan where soils very similar to those of the Area can be expected (Driessen and Soepraptohardjo, 1974: 4).

Grey-White Podzolic Soils and Hydromorphic Upland Soils

Pallid or gleyed upland soils have been recognised as Grey Podzolic Soils (Dudal and Moormann

Table 38

Approximate correlation at Great Soil Group level between the proposed classification and that of Dames (1962)

Dames (1962)		Proposed classification
Yellow Latosols and Red-Yellow Podzolic Soils		Red-Yellow Podzolic Soils; some Regosols
Grey Hydromorphic Soils		Hydromorphic Upland Soils; some Grey-White Podzolic Soils
Humus Podzols	shallow, normal	Podzols
	giant	Kilong Series (Regosols)
Low Humic Gley Soils		Gley soils developed in riverine alluvium
Alluvial Soils	River alluvial soils	Most Alluvial Soils and Alluvial-Gley intergrades
	Soil of mangrove and nipah swamps	Gley Soils developed in marine alluvium
	Recent coastal sands	Alluvial Soils developed in marine sands
Lithosols		Lithosols
Bog Soils	shallow	Shallow and some deep Organic soils
	deep	Most deep Organic Soils

Table 39

Approximate correlation at Great Soil Group level between the proposed classification and those of Dudal and Moormann (for Southeast Asia) and Soepraptohardjo (for Indonesia)

Dudal and Moormann (1964)	Soepraptchardjo[1] (1976)	Proposed classification
Red-Yellow Latosols	Latosols	Few Red-Yellow Podzolic Soils
Red-Yellow Podzolic Soils	Red-Yellow Podzolic Soils	Most Red-Yellow Podzolic Soils if textural B requirement is waived; otherwise few.
Grey Podzolic Soils	—	If textural B requirement is waived, most Hydromorphic Upland Soils and possibly some Grey-White Podzolic Soils; otherwise few
Low Humic Gley and Grey Hydromorphic Soils	Low Humic Gley Soils	
	Grey Hydromorphic Soils	
Podzols	Podzols	Podzols; some Regosols
Regosols	Regosols	Most Regosols
Alluvial Soils	Alluvial Soils	Alluvial Soils; Gley Soils; few shallow Organic Soils
(Lithosols not discussed)	Lithosols	Lithosols; shallow Red-Yellow Podzolic Soils (>50 cms)
Organic Soils		Organic Soils with >30 cm organic mantle
	Organic Soils	Organic Soils with >50 cm organic mantle

(1) together with Dudal and Soepraptohardjo (1957) for some details.

only), Low Humic Gley Soils and Grey Hydromorphic Soils (Dudal and Moormann, Soepraptohardjo, and Dames). There is difficulty in equating the Grey-White Podzolic Soils of the proposed system with the Grey Podzolic Soils of Dudal and Moormann as the latter are mainly associated with old alluvium on terrace sites with shallow slopes and slow surface drainage, have some illuvial clay coatings evident at depth and, except in coarse-textured profiles, require a textural B horizon. Local Grey-White Podzolic Soils on upland sites do not meet these requirements. The Low Humic Gley and Grey Hydromorphic Soils of the other systems quoted have too poor a drainage status to be considered here. There is some doubt regarding the degree to which the drainage class of pallid soils studied by Dames (1962) was inferred from colour and mottling. Upland Grey-White Podzolic Soils possibly overlap with Dames' Grey Hydomorphic Soils.

The Grey Hydromorphic and Low Humic Gley Soils of Dudal and Moormann (1964) and Soepraptohardjo (1976) are both associated with terrace alluvium and slow drainage, and are probably better correlated with Hydromorphic Upland Soils. Dudal and Moormann consider them as one Group and require a textural B and a marked contrast between the clay content of the A and the B. Hydromorphic Upland Soils in the Area generally meet the latter requirement but not the former. A clay peak is characteristic of the Grey Low Humic Gleys; they are correlated with Tropaquults and Tropaquepts respectively in the USDA taxonomy. In a previous presentation of the Indonesian system (Dudal and Soepraptohardjo, 1957) a distinction was made between soils with no pronounced textural differentiation (Low Humic Gley) and those with a sharp contrast between the coarser-textured leached layer and underlying clay (Planosols). Planosols appear to

have been dropped in the current Indonesian system.

Other soils

There is little difficulty in correlating other Groups within the classifications discussed, although the limits between Groups are commonly only broadly defined. The Dudal and Moormann (1964) and Soepraptohardjo (1976) classification are very similar to that of the Area in their approach to bottomland soils (Table 39) although different depth limits to Organic Soils are adopted. The arrangement used by Dames (1962) is in marked contrast, however, as the Low Humic Gley and Alluvial units are applied in rather different senses (Table 38). Local Podzols (except where excessively deep) correlate well with the Podzol Group of all three systems, in each of which they are designated as Humus Podzols. Dames makes a subdivision on depth in this Group.

Other Malaysian classifications on this model

The soil classification used in West Malaysia (Leamy and Panton, 1966) is based on the Thorp and Smith model and classes soils similar to the Merit-Bekenu-Nyalau sequence in Red and Yellow Latosols or Red and Yellow Podzolic Soils. The distinction is mainly based on the absence or presence of a textural B horizon. The system has not been fully developed: many riverine and swamp soils are combined in 'miscellaneous land units'. Classification in West Malaysia is now actively under review, but largely within the terms of the USDA taxonomy.

Soils in Sabah were initially classified within the terms of the Thorp and Smith system (Thomas and Allen, 1966) and Groups of Red-Yellow Podzolic and Red Podzolic Soils, were recognised, among others. A clay increase at depth was diagnostic in the Podzolic Soils but no textural B was specified, nor were illuvial clay skins mentioned. The Sabah definition of Red-Yellow Podzolic Soils would apply to the majority of soils in this Group in the Area. The 1966 system has now, however, been replaced by one based on the FAO (1970) scheme and these soils have been largely classed as Acrisols (LRD, 1975).

Classification in Malaysia is in a very fluid state and correlations can more usefully be made at Family and Series level. This is attempted for the Area's soils in Appendix VIII.

Other Regional Classification Systems

Extrapolation of systems used in other tropical regions to the Area's soils is dangerous but possible correlations of the Red-Yellow Podzolic Soils are briefly noted, these being of particular interest. Considering the main classifications used in Africa these soils may be related to the Tropical Fersiallitic Soils of the Portuguese system (Botelho da Costa et al., 1964) but generally have too high an Si:R ratio and too low saturation. Both Si:Al and Si:R are too high for Ferrallitic Soils. In the INEAC classification applied in the Congo (Tavernier and Sys, 1965) these soils may possibly be related to either the Non-Hydromorphic Brown Tropical Soils or to the Hygroferrisol – Recent Tropical Soils intergrades, although the CEC is too high for the former and most Red-Yellow Podzolic Soils in the Area do not have the dominantly kaolinitic clays required by the latter. In the French system (CPCS, 1967) they may be considered 'strongly desaturated' Ferrallitic Soils as they are too unsaturated for Tropical Ferruginous Soils. A difficulty in equating Sarawak Red-Yellow Podzolic Soils with categories in African system is that a provision for 'podzolic' soils also generally includes a requirement for a textural or structural B with illuvial clay coatings, while possible alternative categories without such requirements largely concern old soils with low-activity clays.

The most extensively-used classification system adopted in tropical South America, is that of Brazil (Lemos, 1968) which is patterned on the system of Thorp and Smith with modifications derived from USDA (1975) and FAO (1974). Most Red-Yellow Podzolic Soils from the Area would be considered Cambisols in that system, as texture and structure requirements of a podzolic B horizon are not met. There are no close parallels in the Australian classification (Stace et al., 1968) where Podzolic Soils have well-developed structure and strong A2/B contrasts (duplex profiles). Red-Brown Earths also have greater horizon differentiation than the Area's Red-Yellow Podzolic Soils, together with a strongly-structured textural B horizon with well-developed clay skins. Strong B structures also distinguish Australian Xanthozems from most Red-Yellow Podzolic Soils in the Area.

The USDA Taxonomy (1975)

Broad correlations with the current USDA taxonomy are given in Table 40. Reference profiles described in Appendix IV are classified in this system in Appendix V.

There are a number of difficulties in applying the USDA system locally. Many concern the recognition of diagnostic horizons required for Order placement, particularly in upland Red-Yellow Podzolic Soils. Soils in this Group may show indications of illuviated clay in thin section but the evidence is commonly indeterminate and

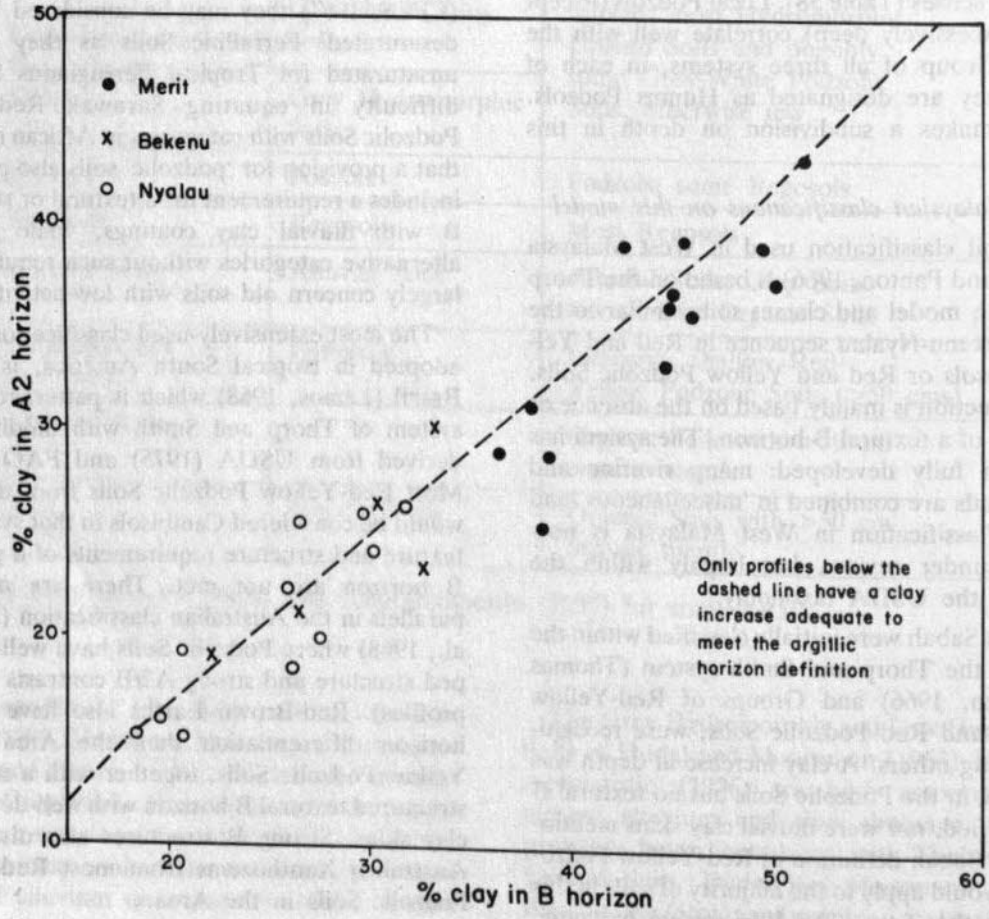


Fig. 48 A2: B clay contrasts in Merit, Bekenu and Nyalau Family profiles (maximum contrast within 30 cm depth)

may be confined to the C horizon rather than the B. Clay cutans recognisable in section as definite illuviation cutans are commonly negligible in extent, although other more diffuse cutans may also be of this class. The few clay coatings seen in the field which have been investigated in thin section have proved to be pressure coatings, if traceable at all. The evidence suggests that, on the clay coating parameter alone, most soils in this Group do not have an argillic horizon and cannot be Ultisols. Furthermore, while the clay increase with depth is adequate for an argillic horizon in some profiles it is not so in others (Fig. 48), this requirement disqualifying many Bekenu and Nyalau profiles and some Merit soils. A few profiles within the Group may, therefore, be considered to marginally meet the parameters of Ultisols but this is doubtful, and the majority do not. Those which may qualify would be Aquic or Typic Paleudults, a placement which is unsatisfactory as that Great Group is conceived to cover old soils on stable land surfaces.

Most Red-Yellow Podzolic Soils on sedimentary rocks are considered to be Dystropepts, generally Oxic with some Typic. Some shallow profiles are Troporthents (Typic or Lithic). Some Nyalau profiles are Haplorthox, Profile 8 being Quartzipsammentic. Two others (O, J), not described in Appendix IV, are Tropeptic and Tropeptic Quartzipsammentic Eutrorthox respectively. Whether more oxic characteristics are developed because the sandstones weather rapidly or whether they are inherited more or less directly from these rocks is questionable.

Of the profiles studied from soils over acid igneous rocks, Piring and Nyaroh Series are Typic Haplorthox and Arip a Typic Dystropept. The Changgan profile described (23) is classed as an Oxic Dystropept.

The Grey-White Podzolic and Hydromorphic Upland Soils present the same problems regarding the recognition of an argillic horizon as is found in the Red-Yellow Podzolic Soils. Like the latter they are considered to be mainly Dystropepts, the Grey-White Podzolic Soils being largely Oxic, the Hydromorphic Upland Soils mainly Aquic or Aquic Oxic. Some Hydromorphic Upland Soils marginally qualify as Typic Tropaquepts. If the presence of an argillic horizon is accepted, these soils would largely be Aquic Paleudults. One Ajoh profile (22) would appear to qualify as an Aeric Albaquult. Correlation of the Grey-White Podzolic and related soils in this taxonomy is complicated by the lack of clear provision for soils which are pallid but not markedly wet.

Podzols from the Area qualify for a number of Subgroups in the Tropaquods and Tropohumods. The Aqoud/Humod distinction is difficult in these soils as the albic horizon is commonly almost devoid of iron and profiles which are sufficiently wet for an Aquod may lack mottling. Assumptions from site characteristics must then be used to indicate drainage class, which is unsatisfactory. Inadequate data on the spodic horizon of profiles in the Area also leads to some uncertainty in correlating the well-drained Podzols with Humods.

Most Organic Soils are believed to have an organic mantle which is dominantly fibric, although the volume determinations and sodium pyrophosphate extraction necessary to confirm this are lacking. Some shallow Organic Soils are probably hemic or sapric.

Soils in other Groups can be correlated with the USDA taxonomy with little difficulty but, as Table 40 and Appendix V show, there is little in common between the taxonomy divisions and those of the proposed system. Most local Groups include soils in at least two USDA Orders and involve a variety of USDA Suborders and Great Groups.

Table 40

Broad correlations between the proposed classification and the USDA taxonomy (USDA, 1975)

USDA Great Group	*Main local correlations*
Haplorthox	Few Red-Yellow Podzolic Soils (Piring, Nyaroh, Some Nyalau).
Eutrorthox	Few Red-Yellow Podzolic Soils (some Nyalau).
Trophumod	Some Podzols (on upland sites).
Tropaquod	Most Podzols (mainly on lowland sites).
Dystropept	Most Red-Yellow and Grey-White Podzolic Soils; some Alluvial Soils (Other than sands).
Tropaquept	Few Gley Soils.
Troporthent	All Skeletal Soils; many Regosols; some Alluvial Soils; some shallow and steepland Red-Yellow Podzolic Soils.
Quartzipsamment	Some Alluvial Soils; most Regosols.
Tropofluvent	Some Alluvial Soils.
Tropaquent	Some Gley Soils.
Fluvaquent	Some Gley Soils; some shallow Organic Soils.
Hydraquent	Some marine Gley Soils.
Sulfaquent	Some marine Gley Soils.
Tropofibrist or Tropohemist	Most Organic Soils

Table 41

Broad correlations between the proposed classification and the World Soil Map legend (FAO, 1974)

FAO Subunits	*Main local correlations*
Xanthic Ferralsol	Few Red-Yellow Podzolic Soils (Piring, Nyaroh, Some Nyalau).
Humic Podzol	Some Podzols (mainly on upland sites).
Gleyic Podzol	Most Podzols (mainly on lowland sites).
Dystric Cambisol	Some Red-Yellow Podzolic Soils (Arip, some Jakar); some Skeletal Soils.
Chromic Cambisol	Few Red-Yellow Podzolic Soils (some Jakar).
Ferralic Cambisol	Most well-drained Red-Yellow and Grey-White Podzolic Soils.
Gleyic Cambisol	Some Alluvial Soils; most Hydromorphic Upland Soils.
Eutric Cambisol	Possibly some Red-Yellow Podzolic Soils.
Eutric Gleysol	Some marine Gley Soils.
Dystric Gleysol	Some riverine Gley Soils.
Humic Gleysol	Some riverine and marine Gley Soils.
Eutric Fluvisol	Some marine Gley Soils.
Dystric Fluvisol	Many riverine and some marine Gley Soils; some Alluvial Soils.
Thionic Fluvisol	Some marine Gley Soils.
Albic Arenosol	Some Regosols
Dystric Planosol	Possibly some Hydromorphic Upland Soils.
Eutric Regosol	Few Alluvial Soils.
Dystric Regosol	Most Skeletal Soils; some Regosols and sandy Alluvial Soils; few Red-Yellow and Grey-White Podzolic Soils.
Lithosols	Some Skeletal Soils.
Eutric Histosol	Few Organic Soils.
Dystric Histosol	Most Organic Bog Soils.

The World Soil Map Legend (FAO, 1974)

Broad correlations between the proposed system and the World Soil Map legend are given in Table 41. Correlation of reference profiles are given in Appendix V. The FAO system stems to a great extent from the USDA taxonomy and involves the same diagnostic subsurface horizons. The problems of placing upland soils in this system are therefore those discussed above (et seq.) in connection with the USDA taxonomy. The arguments already stated support correlation of the main-Red-Yellow Podzolic Soils with FAO Cambisols.

Aside from the problems connected with identification of argillic horizons, there is little difficulty in correlating local Groups with this system. This is partly due to the system not being developed beyond two categories: it has been stressed that this is a Key to a world mapping legend and not in itself a soil classification (Dudal, 1972). Far fewer diagnostic criteria are involved than are employed in the USDA taxonomy and fewer correlation problem therefore arise.

In contrast to the USDA taxonomy, units of Gleysols, Fluvisols and Lithosols are separated in the FAO system. While these do not coincide with Groups in the proposed classification for the Area (Table 41) they reflect a similar bias. The proposed local classification is more closely comparable to the FAO system than to that of USDA, although the same basic difficulties are found in placing many soils at the highest level in both systems

Soil Groupings By Numerical Ordination Methods

A somewhat independent commentary on the classification adopted for the soils of the Area is

offered by numerical ordination techniques and, in order both to compare the resultant groupings with those of the classification and to explore the usefulness of such methods in the context of these soils, an analysis of 38 profiles of mineral soils (together with four contrasting profiles from west Sarawak) was undertaken. The profiles were defined by 56 physical and chemical variables of the A2 and B horizons and were compared by three similarity indices (Canberra Metric, Euclidean Distance and Mean Character Distance). Details of the methods are given in Appendix VII and the similarity phenograms derived from the study in Fig. 49.

Euclidean and Mean Character Distance indices give similar groups. Marine Gley Soils, Podzols, Regosols, marine Alluvial Soils (sands) and Red-Yellow Podzolic Soils from igneous rocks all form well-defined sets. This is generally reflected by the Canberra Metric method also but here there is less distinction between Podzols and marine sandy Alluvial Soils or between iron-rich Red-Yellow Podzolic Soils and other profiles. All three methods fail to isolate the Merit-Bekenu-Nyalau sequence from other soils in a clear manner and underline both the variability in chemical characteristics among these soils and, conversely, the narrowness of the overall range in profile characteristics found in the Area's soils once extreme profile forms such as Podzols, Regosols, etc. are isolated.

It is difficult to guage the significance which should be attached to ordinations of this type. The appropriateness of the methods used when applied to the ordering of soil materials remains in some doubt. The assumption that a soil is best characterised by the greatest available number of independent, measurable, unweighted features remains an assumption, particularly if it is intended to compare the ordination with a previously-established classification, as the latter is intentionally biased (in favour of, among other things, genetic theory, mappability, agricultural relevance, facility in correlation, and ease of application in normal survey conditions). While numerical ordination can be a useful control on such a classification it can also be, at least in part, quite irrelevant to it. There are further limitation which apply at least to the present study. The choice of characters was dictated by availability of data and was not necessarily the best for the purpose. The basic data used are also somewhat suspect as, on the one hand, laboratory determination errors which are discounted or ignored in most normal classification approaches may significantly affect ordinations of this type while, on the other, the majority of field characteristics are translated to numerical scales which are acknowledged to be coarse and inadequate. The ordination provides a factual statement within the terms of the data and techniques employed but its significance must be judged with caution. A lack of correlation with the proposed classification may only reflect the fact that the numerical study is weighted towards chemical characteristics while the classification rests heavily on field parameters. Close agreements between the groupings, on the other hand, may only indicate that some soil communities among these studied are sufficiently distinct that they would isolate themselves by any grouping method.

In the present study the primary separation of profiles developed in marine and estuarine clays and silts can be explained by the many chemical criteria on which they contrasts with all other soils. The chemical bias is also shown in the clustering of beach sand soils with Podzols by one method, emphasising the low fertility of both. The general distinctions between pallid and yellow-red soils and between loams and clays tends to confirm the emphasis on texture and colour in the classification but the distinctions are not clear-cut and are apparently affected by the great variability in the levels of the chemical characteristics employed. Inclusion of a broader range of physical variables would no doubt give a different pattern. The phenograms suggest, however, both that the soils developed over sedimentary and acid igneous rocks form a rather heterogeneous but not dissimilar group, and that many family divisions within these soils (such as those between Nyalau, Bekenu and Merit) are based on rather few features. These indications are probably valid. The close relationship between riverine alluvial soils and their upland equivalents may also be noted.

Of interest are cases where the numerical clustering is consistently at variance with the soil classification. A case in point is a Nyalau Series profile (8) which by all three methods forms a primary cluster with the Arip profile (24) developed over rhyolite, and is well-separated from two other Nyalau Series profiles (9 and 10). Reference to the profile data shows that the atypical Nyalau Series profile is developed over highly feldspathic sandstone in comparistion to the quartzose sandstones of profiles 9 and 10, and that CEC, "total" P and HCl-extractable K are noticeably higher than in those profiles and the base saturation much lower. These contrasts were not appreciated prior to the study, and may be sufficiently important to justify separation of such soils at a Series level.

It is concluded that numerical taxonomy exercises of this type are a useful adjunct to the development of a soil classification, particularly where the majority of important soils considered have a rather narrow spectrum of variables. Within a context such as the soil survey of Sarawak their greatest value probably lies in the ability to bring out relationships not previously noted and, as in the example of the Nyalau profile quoted above, to isolate apparent inadequacies in the established classification structure which may deserve further study. The execution of the present ordination exercise emphasised, however, that full benefits from the technique cannot be gained if reliance must be placed on routine profile description records for the basic data. If the profile is to be included in a numerical ordination study field characteristics must be recorded with greater precision than is normally necessary and in terms more suited to numerical scaling; to counterbalance the many 'laboratory' parameters available a wider range of 'field' variables should be recorded and, for this and other studies, records of bulk density, moisture-retaining capacity, penetrability, shear strength and root volume would be most useful. More adequate computing facilities than were available for this study are also essential.

Discussion And Conclusions

Lower-level classification

Regardless of the concepts by which soils are grouped in the higher levels of a classification system, problems remain at the lower tiers which, unless resolved, limit the practical uses to which

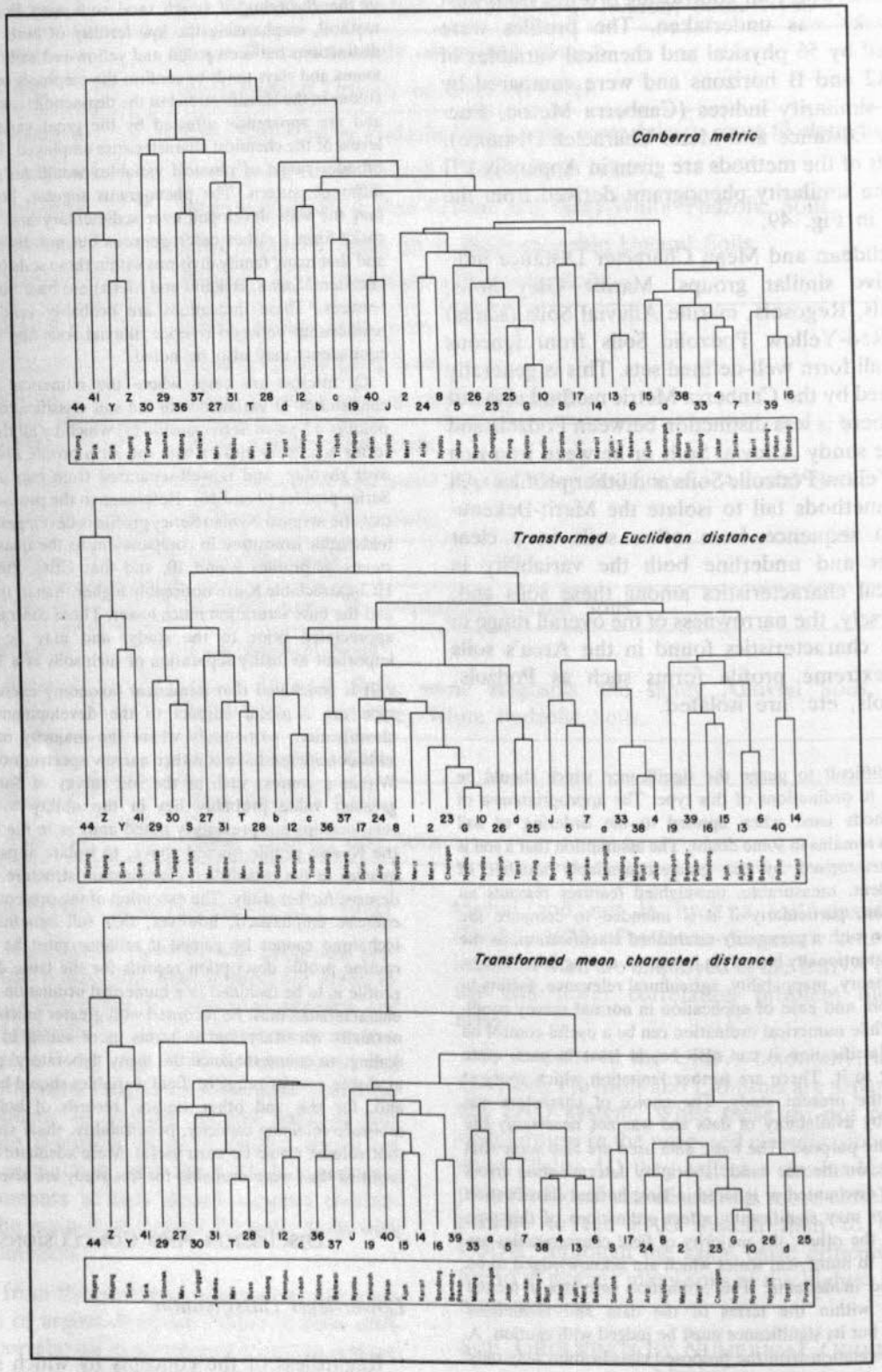


Fig. 49 Similarity phenograms of 42 profiles using three similarity indices

the classification can be put. Many revolve around the consistent identification (and therefore mapping) of Family or Series units. Such difficulties are particularly severe in many 'Third World' situations where information on the soil mantle is largely gathered in a development context and involves rapid, and sometimes rather cursory, field investigations over large areas by workers with a varied level of training and experience. There is commonly less than adequate provision for correlation control, through time constraints and lack of experienced senior manpower. Field identification of Family and Series units within the classification adopted – which is itself generally established in advance of a sufficiently broad base of chemical data or an adequate knowledge of the range of profile forms to be accomodated – is thus made with a less than satisfactory degree of consistency and standardisation. More controlled studies may be undertaken from various viewpoints on specific profiles but their results are of reduced practical value if there is uncertainty regarding the distribution of the profile form concerned even in areas covered by survey.

The proposed classification scheme for the soils of the Area is, at Family and Series level, devised with these problems in mind. The adoption of a control section and a general limit of 1 metre, together with the treatment of texture by USDA particle-size class groupings and the emphasis on field parameters such as colour, help to ensure that lower–tier units are accurately identified (by auger inspection in the case of most Series covered) both by experienced surveyors and by assistants with rather less training.

The classification scheme is not fully developed, although it allows for a number of profile forms known from elsewhere in Sarawak which are not present in the Area. Further elaboration will obviously be necessary, particularly as more detailed investigations are undertaken in interior Sarawak where new profile forms are likely to be encountered, some being at high elevation under cooler temperature regimes than the lowlands. Series divisions established in the lowlands will also require critical review when more chemical and agronomic data are available.

There are specific problems in the soils of the three main physiographic divisions of the Area which will require future attention. On the coastal plain salinity, acidity and peat depth limitations are adopted which are somewhat arbitrary. They have the advantage of preserving continuity with divisions used in the previous Sarawak soil classification but other divisions may have more practical relevance. There is at present, however, a lack of adequate data on crop agronomy in these areas and on both the effectiveness of drainage in these soils and the soil changes which result from it.

The shallow skeletal soils of steep-land interior tracts present fewer classification problems and elsewhere in Malaysia have commonly been ignored in the soil classification structure and have been mapped as steep-land units without further differentiation. They require greater consideration in Sarawak as such areas are extensively used for shifting hill rice cultivation and support a significant population of Iban and other indigenous groups. Families and Series have therefore been differentiated on parent material, texture and rooting depth. Priority needs concerning these soils concern erosion susceptibility and conservation measures, together with more data on the nutrient cycle under shifting cultivation and a greater emphasis on hill rice agronomy. The Series classification may require revision when such data are gathered.

More chemical and agronomic data are also required to support the lower-tier classification divisions used for the deeper hill soils of the dissected lowland belt in which most agricultural development is concentrated. In the context of the present study there are particular problems in classifying these soils satisfactorily at higher levels, however, and these are considered below.

The treatment of Families and Series divisions in the proposed classification may be compared with the strategy adopted in Sabah (LRD, 1975) where soils similar to most of those encountered in the Area are present. In Sabah the primary division is in terms of FAO Units and Subunits, which causes difficulties in placement at the outset. Families within each Subunit are largely separated on parent material groupings. Further divisions are then made on a number of criteria giving unnamed lower-tier units which, it is to be presumed, are intended to provide a framework for a future Series classification. As in the proposed classification for the Area emphasis below the Family level is given to texture, colour and other parameters but, in mineral soils beyond an entic stage of development, most of the criteria used refer not to the subsoil or a specific depth limit but to the subsurface diagnostic horizon required by the FAO Unit classification concerned. This leads to two difficulties. Firstly, for classification in the field the investigator must not only decide which diagnostic horizon(s) is present (a problem which concerns the higher-level grouping) but also which depths it lies between. In upland soils which become redder

with depth and are presumed to have an oxic or argillic horizon a difference in interpretation here may lead to a difference in Series classification. Secondly, the diagnostic horizon involved may only be present at some depth in the profile but, although subdivisions within the Family are made on a number of criteria (five, including depth to rock, in Acrisols and Cambisols), no consideration is given to the character of the soil above this level. In the lowest division of the classification scheme, therefore, many units have an undefined texture (and other parameters) to a varied, but possible considerable, depth. In the proposed classification for the Area the texture of the whole subsoil within control section limits is defined within quite a narrow band by the particle–size subclass and the topsoil texture is also indicated by a suffix to the Series name.

It is considered that the Sabah strategy in the lower tiers is of comparable complexity to that proposed here but gives less precision and, at least in covering upland soils similar to those of the Area, omits some important variables required for Series characteristion. As an operationai classification for use in a regional survey programme it also involves too many interpretative decisions to be applied with a reasonable degree of consistency without a more intensive correlation input than is likely to be available.

Higher-level classification and the concept of Podzolic Soils

The decision to organise lower-tier classification units in Great Soil Groups on the Thorp and Smith model is explained above. The difficulties of correlating many of the Area's soils in this system, and in the USDA and FAO schemes, have also been outlined (see also Appendices V and VIII). While a number of soils present problems the main difficulties concern the suite of upland soils classed as Red-Yellow Podzolic Soils which are dominant throughout the uplands wherever terrain allows a deep and freely-draining solum to develop. The problems of classifying these soils in the context of either Thorp and Smith or USDA are considered in more general terms in this section.

Considering firstly the USDA taxonomy (and remarks at this level of classification also apply to the FAO scheme), some local Red–Yellow Podzolic Soils must be classed as Oxisols by present definitions (Table 40 and Appendix V). Many more have subsurface horizons which fail to meet the oxic criteria only on thickness. Yet few have sola thicker than 1.5 metres and most are on sloping sites where surface losses through erosion can be expected. These are not old soils and oxic characteristics, where developed, are likely to be inherited from the acid, base-poor parent materials. This is particularly the case in soils over sedimentary rocks but also applies to those over some igneous rocks. Profile 10 in Appendix IV has a negligible clay increase with depth, a low CEC and a very low base saturation. There are only traces of water-dispersible clay and the dominant clay minerals are reported to be fairly well-crystallised kaolinite. The profile is classed as a Haplorthox. It is, however, on a 20° slope. Tavernier and Eswaran (1977) would consider that, on permanent charge and Δ pH data, it is in a cambic stage of soil formation.

Such anomalies are not uncommon and Buol (1978) notes that although Oxisols are associated with old stable land surfaces, particular parent materials or the preweathering of parent materials in transport may, in some situations, give profiles qualifying for this Order on flooding river terraces or in steep upland positions. Within the Area similar soils have been recorded on similar terrain, and commonly in close juxtaposition, which may, on a slight difference in one parameter, be classed in the USDA taxonomy under Orders indicating either a cambic (entic in the case of some sandstone-derived soils) or oxic stage of development. This limits the usefulness of the taxonomy in this Area in view of the connotations attached to these terms.

The difficulties of recognising argillic horizons in marginal situations has been discussed above. Even where all possible weight is given to the the limited evidence for illuvial clay coatings the lack of an adequate clay increase for the argillic definition in many profiles (Fig. 48) means that, within the present terms of the taxonomy, at least one Order division cuts across the local Red-Yellow Podzolic Group. The taxonomy may serve to correlate individual profiles but cannot be usefully be taken as the basis for a local classification unless the argillic criteria are revised.

Moormann (1978) considers that the usefulness of the argillic horizon as a diagnostic property is problematic in soils with low-activity clays, particularly under udic or perudic moisture regimes. Isbell (1977) notes that many of the justifications for the use of this diagnostic horizon at the highest level in the taxonomy are only partially correct. He suggests that its importance could be downgraded and that problems of identification could be overcome if the present clay-increase requirement were widened and the need for illuviated clay were dropped. Such a revision would greatly simplify correlation of the

Red-Yellow Podzolic soils of the Area with the taxonomy and would class them as Inceptisols with rather less uncertainty than at present.

An Inceptisol classification for these soils is probably appropriate if Alfisol/Ultisol definitions are revised to cover only the more extreme profile forms now in these Orders. Without such revision the Inceptisol connotation of immaturity is less certainly applicable to these soils. While they have many young features which may be related to their typical occurrence in Sarawak on dissected terrain the profile form does not show any clear contrasts where these soils mantle gentle slopes. It has been suggested above (Chapter 10) that the continuously moist environment and the importance of faunal mixing in many of these soils play a part in maintaining weak horizonation and homogenised, poorly-structured profiles. These effects are found on all terrain facets and also suggest than even on gentle slopes with reduced surface wastage, time will not automatically lead to strongly differentiated horizons and the profile form of the Red-Yellow Podzolic Soils described from the United States. It is on the latter that the Thorp and Smith definition of the Group heavily relies, as do definitions in local derivatives of that system.

Reports from elsewhere in the region support the view that weakly-developed subsoil structure and a sparsity of illuvial cutans are common in well-drained acid soils where there is no extended seasonal moisture deficit. This is the case in west and north Sarawak (Andriesse, 1972; 1975; HTS & Ho, 1974) as well as the present Area. While some soils in southern Sumatra qualify for Ultisols on these criteria (Dai et al., 1975) others do not (Buurman and Dai, 1976). Argillic horizons in Red-Yellow Podzolic Soils are reported to be present throughout Thailand (Panichapong, 1973; Moncharoen, 1975) but this is less true in the more uniformly wet climate of West Malaysia, where they are commoner in upland soils in Kedah than in less seasonal areas farther south (Paramananthan et al., 1975). The weak development of illuvial clay coatings in many west Malaysian soils has been reported for a number of Series (e.g. Eswaran, 1969) and Allbrook (1973) has considered argillic horizon to be rare in Malaya.

There are also, however, a number of reports suggesting well-developed argillic horizons in some West Malaysian soils (e.g. Sooryanara and Eswaran, 1975) and the majority of Podzolic Soils there are considered to correlate with Ultisols (Law and Tan, 1973; 1975; Paramananthan, 1977) as are most soils over acid parent materials in Singapore (Ives and Cowie, 1975). Some profiles over iron-rich shales in Singapore are, in fact, reported to have abundant and prominent cutans (Wells and Leamy, 1977). Soils with argillic horizons are also reported to be the most widespread soils in Sabah (LRD, 1975; 21) but the extent to which this is supported by thin section examination is not reported and in at least one locality this has not been borne out by the writer's investigations (Scott, 1978).

The variety of these reports may stem partly from the difficulty of recognising argillic horizons in a standardised manner in marginal situations. More rigorous correlation exercises are necessary in the region and a particular study is needed of profile distribution in relation to landform and moisture regime. At present it can be suggested that the profile form which is dominant in the Area is also found elsewhere in Borneo, parts of West Malaysia and, perhaps more locally, elsewhere in the region, and that it is not necessarily confined to young dissected surfaces. It may be associated with areas which have a perudic moisture regime and be absent from areas with a distinct seasonal moisture deficit, but this requires confirmation.

The profile form departs from that considered 'typical' of Red-Yellow Podzolic Soils in some respects, and may be described as follows:

(a) There is a weakly-differentiated A–B–C profile, a thin A1 overlying a horizon which generally shows little contrast in colour or texture with the underlying B and which may be better designated A3 and A2, although the latter is used in this study; horizon boundaries are indistinct;

(b) There is some loss of sesquioxides from the A (particularly iron) but absolute accumulation in the B is not marked, if evident at all; The clay Si:A1 ratio is generally above 2 as is the Si:R in most profiles; Si:R ratios decrease with depth;

(c) The B may be redder than the A but subsoil colour contrasts are usually not pronounced; The subsoil is generally yellow or red; There is no albic horizon: where the profile has a pallid A2 the B and C horizons are also pallid and the profile is developed over parent materials low in iron (and is classed in this study as a Grey-White Podzolic Soil);

(d) The clay percentage increases with depth but this increase is commonly inadequate to meet argillic horizon criteria; there is no pronounced textural B and the clay profile has a 'pale–' form; illuvial clay skins are either absent or are thin and sparse;

(e) Subsoils are friable to firm, commonly becoming firmer with depth; the B is massive to weakly coarse or medium subangular blocky; fine stable aggregates are not developed.

Soils with the above profile form may be Tropept, Orthox or Udult in the present USDA taxonomy. In the Thorp and Smith classification they are more closely related to the Red-Yellow Podzolic Soils than to the Latosols, particularly if emphasis is given to the profile characteristics under (b) and (e) above. The point is somewhat arguable, as the Latosol label has been applied to a broad range of soils in different regions and now offers little more precision in classification than the Lateritic term which it replaced.

The usefulness of the Thorp and Smith model is at present limited by the lack of standardisation in application of the Group concepts in different parts of the region. A common approach to the more precise definition of Soil Groups is required and to criteria for defining taxa at lower levels. The suggestions embodied in the proposed classification of the Area's soils offer only one of a number of possible approaches. Verheye et al. (1977) have suggested ortho- meso- and ultra-subgroups of Podzolic Soils and Latosols on Indonesian data. Their subgroups indicate progressive weathering stages and emphasise CEC, silt: clay ratios, pH and base saturation. The levels adopted are those which simplify correlation with the USDA taxonomy. The profile forms covered by Verheye et al. do not include those outlined above which are dominant in the present Study Area and which require accommodation in the system, but their suggestions illustrate a line of research which is likely to be of more immediate relevance to ordering the soils of the region than a conversion to the USDA taxonomy as the basis of operational classification.

CHAPTER 12

THE SUITABILITY OF THE SOILS FOR AGRICULTURE

The primary objective of this study is to characterise and classify the soils of the Area and thereby provide a basis for more detailed soil studies. The emphasis has therefore been placed on inherent soil properties. their relationship to soil- forming factors, and their applicability as differentiating criteria in an operational soil classification. No consideration has so far been given to the agricultural potential of the soils described (although present use is summarised in Appendix II). In this Chapter the land capability is briefly outlined.

Land Capability Classification

Various land capability classifications have been applied in Malaysia, but for some years Peninsular Malaysia has standardised on the system developed by Wong (1974). This has also been extensively used in Sarawak. More recently a system has been developed specifically for Sarawak soils (Maas et al., 1979) and it is this which is adopted in the present study, to allow consistency with other current work in Sarawak. It contrasts with Wong's system in the treatment of organic soils, but is closely similar to it in other respects.

Land capability classes

The Maas system rates the capability of the land (land = soil + topography + flood hazard in this system) within five Classes, ranging from highly suitable (Class 1) to unsuitable (Class 5) for agriculture. The rating is dependent on the degree of severity with which a range of limiting factors are present. Some types of limitation are applicable to all soils; some are specific to either mineral or organic soils. The limitations considered in this system, together with the letter symbol used to indicate them, are listed in Table 42.

The degree of severity with which a limitation is present is considered to be at one of five levels: none, minor, moderate, serious, or very serious, (Tables 43 and 44). The Class rating is dictated by the number of limitations present and the degree of their severity. The five Classes are briefly defined as follows:

Class 1: Land with either no limitations or only one minor limitation to crop growth. Class 1 land is suitable for the widest range of climatically adapted crops.

Class 2: Land with either two to three minor limitations or one moderate limitations restricting the range of crops, and/or requiring moderate drainage or some conservation practice. Class 2 land is suited for a narrower range of crops than Class 1 land but has considerable potential and can be managed and cropped with little difficulty.

Class 3: Land with either at least four minor limitations, or two or three moderate limitations or one serious limitation that either restricts the range of crops, or the degree of possible mechanisation or that entails special conservation measures. Class 3 land is suited to a narrower range of crops than Class 1 or Class 2 land but the range remains quite broad provided rather higher inputs and/or rather lower returns are accepted than might be expected from the same crop on Class 1 or 2 land. Certain Class 3 land is well-suited to selected crops: some Class 3 land

with a major wetness limitation is, for example the best land for wet rice, although it is poorly-suited for most other crops.

Class 4: Land with either at least four moderate limitations or two to three serious limitations that severely restrict the range of crops or that entail special conservation practices, or both. Lands in this Class are either only suitable for a few crops, or are associated with low yields, or are lands on which the risk of crop failure (through droughtiness or flooding) is high. Agriculture is difficult on Class 4 land and it is not recommended for agricultural use where better land is available. Where the main limitations are salinity or drainage, land improvement may be envisaged which might upgrade such areas considerably, but the necessary improvements are difficult and expensive.

Class 5: Land with either at least four serious limitations or one or more very serious limitations, that precludes the use of the land for agriculture.

For the purposes of rating its capability, the land is judged in its present condition, i.e. in advance of any improvements which can be anticipated. The ease with which improvements can be effected depends partly on the type of limitation. Thus the depth to an impervious or massive clay layer (a 'd' or 'c' limitation) cannot be easily altered whereas a fertility limitation (f) can usually be corrected if it is not too severe. In considering the options for future use of a land unit, therefore, both the Capability Class and the dominant limitation(s) which dictate the rating must be considered.

The soil/terrain land units of the Area are rated in this system in Table 45. Where more than two limitations occur, only two are designated. The rating applied may not agree in all instances with that applied to the same series/terrain combination elsewhere. Well-drained riverine alluvial soils (Seduau, Bemang, etc.) are given a high rating here, for example, but a lower rating is commonly applied in interior Sarawak where the hazard of intermittent deep flooding on these soils is greater than in the lowland zone. The ratings indicated in Table 45 do not cover all possibilities for all soil series but do indicate the main range of land capability associated with each unit.

In Table 46 land capability ratings are applied to the soil association mapping units. These ratings are much more approximate than those applied to soil series. Many of the soil associations which have been mapped comprise a number of series having a broad range of capability and mantling complex terrain which further confuses the picture. Land capability classifications are more easily applied to detailed and semi-detailed soil mapping where the within-unit variation is minimised. In applying such systems to reconnaissance mapping some gross generalisation is commonly necessary, as in this case. The soil associations have, as far as possible, been rated in relation to their soil and terrain characteristics, but where these indicate a very broad range of capability the rating has been given which indicates the main 'development opportunity level' of the unit as a whole.

Map 5 shows the distribution of capability classes within the Area, together with subclass subscripts indicating the dominant limitations present. Map 5 stems directly from Table 46, with the exception that for the compound mapping units of Soil Associations 37 – 40 the lower rating of the organic component has been applied to the whole of the unit concerned.

The Agricultural Potential Of The Area

Less than 3 per cent of the Area has a Class 1 or 2 rating (Table 46 and 47). The bulk of the land which can be recommended for agriculture has a Class 3 capability. This comprises land of two broad categories, (a) riverine tracts with some drainage and flooding limitations, and (b) dissected lowlands, where the main limitations are slope, erosion hazard and, in some tracts, soil depth. Low fertility levels are also limiting but as this is a constraint common to almost all soils in this high-leaching environment it is given a low emphasis in the rating system unless the deficiency is acute, as in sands and some organic soils.

Land in Classes 1 – 3 totals only some 24 per cent of the Area, while 56 per cent comprises the estuarine soils of the Rajang delta and the more extensive organic swamp soils of the coastal plain. All these soils have serious drainage limitations. In addition the estuarine mineral soils generally have salinity constraints and, more importantly, potential acid sulphate characteristics, while most of the organic soils comprise raw fibric materials with associated serious fertility limitations. These soils have been given Class 4 and 5 ratings respectively. The possibilities of developing them in any specific locality initially hinges on the feasibility of drainage. A serious sulphidic limitation will, however, remain difficult to correct.

The balance of the area (about 20 per cent) largely comprises steeply sloping land in the interior, where topography, erosion hazard and soil depth generally dictate a Class 4 or 5 rating. Within the interior steepland zone there are,

Table 42

Land Capability Limitations used as subclass divisions in the system of Maas et al., (1979)

	Limitation	*Symbol*
(a) Mineral soils	Depth to masive clay	c
	Soil depth to impervious layer	d
	Erosion hazard	e
	Moisture-holding capacity	m
	Stoniness	r
	Slope (topography)	t
	Wetness	w
(b) Mineral or Organic soils	Depth to sulphidic layer (potential acid-sulphate)	a
	Fertility	f
	Inundation hazard	i
	Depth of organic layer	o
	Salinity of groundwater	s
(c) Organic soils	Depth of groundwater-table	g
	Degree of humification	h
	Nature (texture) of mineral subsoil	n

Table 43

Limitations to Crop Suitability on Mineral Soils

Symbol	*Type of Limitation*	*Degree of Limitation*				
		None	*Minor*	*Moderate*	*Serious*	*Very Serious*
a	Depth to sulphidic layer (cm)	> 100	75 – 100	50 – 75	< 50	–
c	Depth to massive clay (cm)	> 75	50 – 75	25 – 50	< 25	–
d	Soil depth to impervious layer or 50% rock fragments (cm)	> 100	75 – 100	50 – 75	25 – 50	< 25
e	Erosion hazard	none	low	medium	high	very high
f	Fertility	medium	–	low fertility, low retention	acute deficiency, very low retention	–
i	Inundation hazard (frequency and duration)	none	infrequent, short	frequent, short	infrequent, long	frequent and long or submerged
m	Moisture-holding capacity	high (loam to clay)	–	medium (sandy loams)	low (fine and medium sands)	very low (coarse sand)
o	Depth of organic layer (cm)	< 25	–	25 – 50	–	–
r	Stoniness (% rock fragments or stone within top 25 cm)	< 0.1	0.1 – 3	3 – 15	15 – 50	> 50
s	Salinity of groundwater (umhos/cm)	< 1000	–	–	1000 – 4000	> 4000
t	Slope (topography)	0 – 6°	6 – 12°	12 – 25°	25 – 33°	> 33°
w	Wetness	well drained	moderately well drained	imperfectly drained	poorly to very poorly drained	–

(from Maas et al., 1979)

Table 44

Limitations to Crop Suitability on Organic Soils

Symbol	*Type of limitation*	*Degree of Limitation*				
		None	*Minor*	*Moderate*	*Serious*	*Very Serious*
a	Depth to sulphidic layer *(cm)	> 100	75 – 100	50 – 75	< 50	–
f	Fertility of the organic layer	medium (loamy *2 muck)	–	–	very low (peat or sandy muck)	–
g	Depth to ground water-table (cm) Natural	–	–	30 – 60	0 – 30	–
	Drained	60 –100	–	30 – 60	100	–
h	Degree of humification	hemic–sapric	–	–	fibric	–
i	Inundation hazard (frequency & duration)	none	infrequent, short	frequent, short	infrequent, long	frequent and long, or submerged
n	Nature (texture) of mineral subsoil at 50 - 100 cm	fine loamy to clayey	–	–	sandy to coarse loamy	–
o	Depth of organic layer (cm)	–	–	50 – 100	> 100	–
s	Salinity of groundwater (umhos/cm)	< 1000	–	–	1000 – 4000	> 4000

(from Maas et al., 1979)

*1 Depth after reclamation; allow 25 cm more for subsidence of virgin organic soils.

*2 The clay content of the mineral component must be greater than 18%.

Table 45

Soil Families and Series: Land Capability Rating

Family	*Series*	*Slope Range (°)* 0–6	6–12	12–25	25–33	>33
Red-Yellow Podzolic Soils						
Merit	Merit	1, 2w	2t	3te	4te	5te
	Jakar	1, 2w	2t	3te	4te	5te
	Lupar	1, 2w	2t	3te	—	—
Bekenu	Bekenu	1, 2w	2t	3te	4te	5te
	Sarikei	1, 2w	2t	3te	4te	5te
Nyalau	Nyalau	2f	3ef	4te	4te	5te
	Pasai	2f	3ef	4te	4te	5te
	Sabangang	2f	—	—	—	—
Serin	Nyaroh	1	2t	3te	—	—
	Piring	1	2t	3te	—	—
Abok	Arip	1	2t	3te	4te	—
Gading	Changgan	1, 2d	2t, 3d	3te, 4d	4te, 4d	—
Grey-White Podzolic Soils						
Kerait	Kerait	3cw	3ct	3ct	4te	—
Bandang	Bandang	2f	3ft	3te	4te	—
Saratok	Durin	3fm	3ef	4ef	—	—
	Saratok	3fm	3ef	4ef	—	—
Podzols						
Miri	Bako	4fm, 5fd	4fm, 5fd	—	—	—
	Miri	4fm, 5fd	—	—	—	—
Silantek	Silantek	4fm	4fm	—	—	—
	Tunggal	4fm	4fm	—	—	—
	Buso	4fm	—	—	—	—
	Grang	4fd	—	—	—	—
	Bakau	4fm	—	—	—	—
	Metading	4fm	—	—	—	—
Hydromorphic Upland Soils						
Ajoh	Ajoh	3iw	—	—	—	—
Timang	Timang	3iw	—	—	—	—
Penipah	Penipah	3fw	—	—	—	—
Gley Soils						
Rajang	Rajang	5sa	—	—	—	—
Paloh	Paloh	5sa	—	—	—	—
Pendam	Pendam	5s	—	—	—	—
	Jol	5s	—	—	—	—
Sirik	Sirik	5s	—	—	—	—
Bijat	Bijat	3w	—	—	—	—
	Sebandi	3w	—	—	—	—
Pakan	Pakan	3w	—	—	—	—
Plan	Plan	4wf	—	—	—	—
	Luis	4wf	—	—	—	—

Table 45

Soil Families and Series: Land Capability Rating *(continued)*

Family	*Series*	*Slope Range (°)*				
		0–6	*6–12*	*12–25*	*25–33*	*33*
Tatau	Tatau	4wf	—	—	—	—
	Matu	4wf	—	—	—	—
Alluvial Soils						
Seduau	Seduau	1	—	—	—	—
	Malang	1	—	—	—	—
Bemang	Bemang	1	—	—	—	—
	Semilajau	3fm	—	—	—	—
Kayan	Kayan	4fm	—	—	—	—
Kabong	Kabong	4fm	—	—	—	—
	Belawai	4fm	—	—	—	—
Regosols						
Peninjau	Peninjau	4fm	4fm	4fm	—	—
	Sebaya	4fm	—	—	—	—
Tika	Tika	4fm	—	—	—	—
	Bintulu	4fm	—	—	—	—
Lithosols						
Meluan	Meluan	5d	5d	5d	5d	5de
Kapit	Kapit	5d	5d	5d	5d	5de
	Buri	5d	5d	5d	5d	5de
	Binatang	5d	—	—	—	—
	Kelupu	5d	—	—	—	—
	Lalis	5d	5d	5d	5d	5de
	Suka	5d	5d	5d	5d	5de
Organic Soils						
Mukah	Mukah	04hg	—	—	—	—
	Patok	04nh	—	—	—	—
	Manat	04nh	—	—	—	—
Igan	Igan	05fn	—	—	—	—
Anderson	Anderson	05ho	—	—	—	—
	Luk	04nh	—	—	—	—

NOTE: Ratings are based on the observed range of topography, flooding hazard and other limiting factors associated with the soil series in the Area. The soil may not be confined to this range in other localities.

Table 46

Soil Associations: Land Capability Rating

Soil Association		*Dominant Rating*	*Other Rating Levels locally important*
1.	Meluan	5dt	5de
2.	Meluan/Merit	5dt	3te
3.	Meluan/Tunggal	5dt	4fm
4.	Kapit/Lalis	5dt	4d
5.	Lalis/Merit	4te	5d, 3te
6.	Piring	5te	2t, 3te
7.	Arip	5te	2t, 3te
8.	Merit	3d (Arip)	2w
		3dt (Sarupai, Machan, Saratok)	2t, 3te
		2t (Piring)	
9.	Merit/Jakar	3dt	3te
10.	Merit/Bekenu	3te	3ct, 3dt, 2t
11.	Merit/Nyalau	3te	2t
12.	Merit/Kerait	3dt	3ct
13.	Bekenu/Kerait	3te	3fe, 4fe
14.	Bekenu/Saratok	3ef	4fe
15.	Saratok/Kerait	3cw (Kemena, Lemai, Sikat)	
		4fm (Machan, Selalang)	
16.	Ajoh/Penipah	3iw	4fm
17.	Nyalau/Silantek	3ef	
18.	Silantek/Bako	4fm	
19.	Tika	4fm	
20.	Buso/Tika	4fm	
21.	Buso/Metading	4fm	
22.	Buso/Tatau	4fm	5fd
23.	Miri	4fm	2w
24.	Seduau/Lupar	1	3w, 1
25.	Seduau/Bijat	2w	04hg
26.	Bijat/Mukah	3w (elsewhere)	4fm
27.	Tatau/Kabong	4wf	05fn
28.	Tatau/Igan	4wf	4wf
29.	Tatau/Pendam	5s	5s
30.	Rajang/Pendam	5sa	
31.	Mukah	04gh	
32.	Igan	05gn	
33.	Luk	04nh	
34–36.	Anderson	05ho	2t, 3te
37.	Bekenu/Anderson	05ho	4fm
38.	Buso/Anderson	05ho	3w
39.	Bijat/Anderson	05ho	5s
40.	Pendam/Anderson	05ho	

Table 47

Area distribution of Capability Classes and Subclasses (in hectares)

Dominant Subclasses (limitations)	*Class*						
	1	*2*	*3*	*4*	*5*	*04*	*05*
—	6,400	—	—	—	—	—	—
d, t, e	—	300	276,700	60,000	246,560	—	—
f, m	—	—	—	23,000	12,420	—	—
w, i, c	—	27,000	35,040	15,900	—	—	—
s, a	—	—	—	—	103,100	—	—
g, h, n, o	—	—	—	—	—	33,100	762,200
total	6,400	27,300	334,740	88,320	349,660	33,100	762,200
% of Area	< 1	2	21	6	22	2	48

however, small scattered tracts of better land, and these may be agriculturally important in a local context.

The main agricultural possibilities lie firstly, therefore, in the dissected lowlands which form a belt between the interior highlands and the swamp plain, with extensions into the interior centred on the main river valleys, and secondly in the riverine tracts of mineral alluvial soils which strike across all landform units from the interior to the coast. More limited possibilities also exist in the coastal belt itself. Not surprisingly, these are the areas in which the present population is concentrated and where most past agricultural development has taken place. This development is detailed in Appendix II. Further agricultural planning in these areas is commonly complicated by problems of land acquisition and the need to accommodate existing land use patterns in the proposed plan.

In a reconnaissance study of this nature it would not be appropriate to discuss cropping options in any great detail. Such discussions are more useful when a particular locality is under consideration, where semi-detailed soil survey has been completed, and where the operational type and level of management of the proposed agricultural development has been decided. The land capability ratings and the crop options which they indicate can then be defined in detail, and the possible alternatives compared from the viewpoint of economic returns and in relation to prevailing development priorities. Such priorities may emphasise self-sufficiency, the maximising of farm incomes, the generation of rural employment, or other aims, and the emphasis which is given will affect to some degree the choice of agricultural use which can be promoted within a capability unit. These priorities, like the economic forecasts for many major crops, are subject to change, and evaluation of crop options can therefore most usefully be pursued only in the context of a current development proposal to be implemented in conformity with current development priorities.

Some general indication of the crops which can be recommended on specific soil series may however be given here, and this is done in Table 48. Only those soil-terrain combinations with a capability rating of Class 3 or higher are considered, although many soils with a lower rating are under agricultural use. In the case of upland soils the subclasses quoted refer to the moderately deep and deep phases (these being generally most widespread); shallower phases will have a lower rating and a narrower range of crop suitability. The crop choices given assume smallholder management; the options for estate farming are generally narrower. Table 48 is derived from Maas et al., 1979. Other sources suggest somewhat different limits of crop tolerance; much depends on the level of management assumed and the returns which are considered adequate.

Table 48

Soil Series, Capability Subclass and crop suitability correlations (from Maas et al., 1979)

Soil Series	*Capability Subclass*	*Suitable crops*
Merit, Jakar, Lupar,	1	2 – 18, 20
Bekenu, Sarikei,	2w	2 – 4, 7 – 10, 12, 13, 15 – 20
Nyaroh, Piring, Arip,	2t	2, 3 – 5, 7 – 11, 12 – 18, 20
Changgan	3te	2, 3, 7, 8, 12 – 18, 20
Nyalau, Pasai, Sabangang	2f	2 – 5, 7 – 18, 20
	3ef	4, 5, 9, 10, 11, 13, 17, 18, 20
Kerait	3cw	2, 10, 16 – 18, 20
	3ct	2 – 4, 7 – 10, 13, 15, 17, 18, 20
Bandang	2f	2 – 5, 7 – 18, 20
	3ft	7, 13, 17, 18, 20
	3te	2 – 3, 7, 8, 12 – 18, 20
Saratok, Durin	3fm	4 – 6, 9 – 11, 13, 17, 18, 20
	3ef	4, 5, 9, 10, 11, 13, 17, 18, 20
Ajoh, Timang, Penipah, Bijat	3iw	1, 2, 19
	3w	1, 2, 19
Seduau, Malang, Bemang	1	2 – 18, 20
Semilajau	3fm	4 – 6, 9 – 11, 13, 17, 18, 20

1: Wet rice
2: Upland rice
3: Maize, sorghum
4: Soyabean, vegetables
5: Groundnut, tapioca
6: Watermelon
7: Banana
8: Sugar cane
9: Fodder crops
10: Forage crops
11: Pineapple
12: Cocoa
13: Oil palm
14: Pepper, papaya
15: Coffee
16: Fruit trees
17: Coconut
18: Cashew
19: Sago
20: Rubber

Part III
REFERENCES

REFERENCES

AHMED, M.I. and SIM, E.S. 1973 Titanium content of some Sarawak soil profiles. *Symp. on fert. and chem. of trop. soils,* Kuala Lumpur.

ALEXANDER, F.E.S. 1959 Observations on tropical weathering: a study of the movement of iron, aluminium and silicon in weathering rocks at Singapore. *J. Geol. Soc.,* 115 (2): 123–144.

ALLBROOK, R.F. 1973 The argillic horizon — does it exist in Malaysia? *Proc. 2nd ASEAN soils conf.,* Jakarta, 1: 51–55.

ANDERSON, J.A.R. 1961 The ecology and forest types of the peat swamp forests of Sarawak and Brunei in relation to their silviculture. Ph.D. thesis, Univ. of Edinburgh.

——— 1964a The structure and development of the peat swamps of Sarawak and Brunei. *J. Trop. Geog.,* 18: 7–16.

——— 1964b Observations on climatic damage in peat swamp forests in Sarawak. *Comm. For. Rev.,* 43: 145–158.

ANDRIESSE, J.P. 1962 Report on a reconnaissance soil survey of the Saratok-Jakar road area, 2nd and 3rd Divisions. *Sarawak Dept. of Agric.,* Soil Survey Rpt. 20. Kuching (mimeo).

——— 1968 Note on the cause of black colouration of weathered carbonaceous shales in the Sadong Formation (52nd mile, Serian-Simanggang Road) west Sarawak. *Borneo Reg., Malaysia, Geol. Survey,* Bull. 9: 51–53.

——— 1969 A study of the environment and characteristics of tropical podzols in Sarawak (East Malaysia). *Geoderma,* 2: 201–227.

——— 1970 The development of podzol morphology in the tropical lowlands of Sarawak (East Malaysia). *Geoderma,* 3: 261–279.

——— 1972 Soils of West Sarawak (East Malaysia). *Sarawak Dept. of Agric.,* Res. Br. Mem. 1. Kuching.

——— 1974 Tropical lowland peats in Southeast Asia. *Roy. Trop. Inst., Amsterdam,* Dept. of Agric. Res. Comm. 63.

——— 1975 Characteristics and formation of so-called Red-Yellow Podzolic Soils in the humid tropics (Sarawak, Malaysia). *Roy. Trop. Inst. Amsterdam,* Comm. 66.

———, van BREEMAN, N. and BLOKHUIS, W.A. 1972 The influence of mudlobsters (Thallasina anomala) on the development of acid sulphate soils in mangrove swamps in Sarawak (East Malaysia). *Int. Symp. on Acid Sulphate Soils,* Wageningen.

——— and SIM, E.S. 1968 Report on soil investigations in the proposed Sungei Sarawak padi scheme area, 1st Division. *Sarawak Dept. of Agric.,* Soil Survey Rpt. 125.

ANON 1961 Rainfall statistics of the British Borneo Territories. *Brit. Borneo Territories, Dept. of Civil Aviation and Met. Services.*

ASHTON, P.S. 1958 Notes on the primary vegetation and soils of Brunei. *Proc. Symp. Humic Tropic Vegetation,* Tjiawi, Indonesia, 149–154.

——— 1964 Ecological studies in the mixed Dipterocarp forests of Brunei State. *Oxford Univ. Mem.* 5.

——— and ASHTON, M. (ed). 1972 *The Quaternary era in Malesia – Transactions of the 2nd Aberdeen-Hull symp. on Malesian ecology,* Univ. of Hull, Dept. of Geog.

BAILLIE, I.C. 1978 Studies of site-forest relationships in the mixed Dipterocarp forest of Sarawak, Malaysia. Ph.D. thesis, Univ. of Aberdeen.

BALDWIN, M., KELLOGG, C.E. and THORP, J. 1938 Soil classification. *Soils and Men* (USDA 1938 Yearbook): 979–1001.

BECKINSDALE, R.P. 1957 The nature of tropical rainfall. *Trop. Agric.,* 34: 76–98.

BIE, S.W. and BECKETT, P.H.T. 1970 The costs of soil survey. *Soils and Fert.,* 33 (3): 203–217.

BIRD, E.C.F. and HOPLEY, D. 1969 Geomorphological features on a humid tropical sector of the Australian coast. *Austr. Geog. Studies,* 7 (2): 89–108.

BIROT, P. 1968 *The cycle of erosion in different climates.* Batsford, London.

BLACKBURN, G. and BAKER, R.M. 1958 A soil survey of part of Brunei, British Borneo. *CSIRO,* Soils and Land Use Series, 25.

BOTELHO DA COSTA, J.V., CARDOSO FRANCO, E.P. and PINTO RICARDO, R. 1964 Generalised soil map of Angola (Second Approximation). *Proc. 8th Int. Cong. Soil Sci.,* Bucharest, 5: 153–162.

BREWER, R. 1964 *Fabric and mineral analysis of soils.* Wiley, New York.

BRUNIG, E.F. 1969 The classification of forest types in Sarawak. *Malayan Forester,* 32 (2): 148–179.

——— 1971 On the ecological significance of drought in the equatorial wet evergreen (rain) forest of Sarawak (Borneo). *Trans. 1st Aberdeen-Hull symp. on Malesian ecology:* 66–88.

BUOL, S.W. 1978 Geomorphology of some Oxisols. *Int. Soil Class. Workshop, Malaysia and Thailand.* Bangkok. (Preprint summary).

———, HOLE, F.D. AND McCRACKEN, R.S. 1973 *Soil genesis and classification.* Iowa State Univ. Press.

BUURMAN, P. and DAI, J. 1976 Research on Podzolic Soils in central and north Lampung and its bearing on agricultural development. *Peat and Podzolic Soils and their potential for agriculture in Indonesia,* (Proc. ATA 106 midterm seminar). Soil Res. Inst., Bogor, Bull. 3: 117–149.

CPCS (Commission de Pedologie et de Cartographie des sols). 1967 *Classification des sols.* Lab. Geol. Pedol. Ecole Nat. Super. Agron., Grignon.

CROMPTON, E. 1962 Soil formation. *Outlook on agriculture,* 3: 209–218.

DACKNOWSKI-STOKES, A.P. 1930 Report to the Subcommission for peat soils of the International Society of Soil Science. *Roc. 2nd Int. Cong. Soil Sci., 4.*

DAMES, T.W.G. 1955 The soils of east central Java. *Contr. Gen. Agri. Res. Sta., Bogor,* No. 141.

——— 1962 *Soil research in the economic development of Sarawak.* FAO Rpt. 1512. Rome (mimeo).

DAI, J., SUDIHARDJO and BUURMAN, P. 1975 Red-Yellow Podzolic soils from Lampung and South Sumatra provinces (Sumatra, Indonesia). *Proc. 3rd ASEAN Soils Conf.,* Kuala Lumpur.

DAVIES, J.L. 1964 A morphogenic approach to world shorelines. *Zeit. fur Geomorph.,* 8: 127–142.

van DELDEN, J.M. and de HAUT, J.P.Y.M.L. 1966 Results of a repeated sampling survey, offshore Baram delta, Sarawak. *Borneo Reg., Malaysia, Geol. Survey,* Geol. Papers: 43–52.

DID (Drainage and Irrigation Department, Sarawak). 1968 *Sarawak Hydrological Yearbook for the water-year 1967–1968.* Kuching.

DOUGLAS, I. 1969 The efficiency of humid tropical denudation systems. *Trans. Inst. Brit. Geog.,* 46: 1–16.

DRIESSEN, P.M. and SOEPRAPTOHARDJO, M. 1974 *Soils for agricultural expansion in Indonesia.* Soil Res. Inst, Bogor, ATA 106 Bull. 1.

DUDAL, R. 1972 Discussion, 2nd ASEAN Soils Conf., Jakarta.

——— and MOORMAN, F.R. 1964 Major soils of southeast Asia. *J. Trop. Geog.,* 18: 54–80.

——— and SOEPRAPTOHARDJO, M. 1957 Soil classification in Indonesia. *Contr. Gen. Agri. Res. Sta., Bogor,* No. 148.

DUMBLETON, M.J. 1965 Clay mineralogy of Borneo soils in relation to their origin and their properties as roadmaking materials. In CLARE, K.V. and BEAVER, P.V.: *Roadmaking materials in northern Borneo.* HMSO, London.

van der EIJK, J.J. and HENDRIKS, H.A.J. 1953 Soil and land classification in the coastal plain of Surinam. *Neth. J. Agric. Sci.,* 1: 278–298.

ESWARAN, H. 1969 Pedological studies on some Malaysian soils. *Mal. Agric. J.,* 47 (2): 275–287.

FAO (United Nations Food and Agriculture Organisation). 1968 *Report on the findings of an IBRD/FAO technical working party on land classification with special reference to feasibility studies for irrigation projects.* Rome (mimeo).

——— 1970 *Key to soil units for the Soil Map of the World.* Rome.

——— 1974 *FAO-UNESCO Soil Map of the World,* Vol. 11. Unesco, Paris.

FITCH, F.H. 1953 Tertiary to recent sea-level changes and their effect on British Borneo physiography. *Brit. Borneo Geol. Survey,* Ann. Rpt.: 20–37.

FOLK, R.L. and WARD, W.C. 1957 Brazos River bar: a study in the significance of grain size parameters. *J. Sediment. Petrol.,* 31: 514–529.

FREEMAN, J.D. 1955 *Iban agriculture: a report on the shifting cultivation of hill rice by the Iban of Sarawak.* Colonial Research Studies, No. 18. HMSO, London.

GEIGER, M.E. 1963 Paleogeography of the late Cretaceous-Eocene geosyncline in northwest Borneo. *Borneo Reg. Geol. Survey,* Ann. Rpt.: 179–197.

HAANTJENS, H.A., REYNDERS, J.J., MOUTHAAN, W.L.P.J. and van BAREN, F.A. 1967 *Major soil groups of New Guinea and their distribution.* Roy. Trop. Inst., Amsterdam, Dept. Agric. Res. Comm. 35.

HAILE, N.S. 1954 The geology and mineral resources of the Strap and Sadong valleys, west Sarawak, including the Klingkang Range coal. *Brit. Borneo Geol. Survey,* Mem. 1.

——— 1961 The Cretaceous-Cenozoic northwest Borneo geosyncline. *Proc. Brit. Borneo Geol. Conf.:* 1–12.

HARDON, H.J. 1936 Podzol profiles in the tropics. *Natuurk. Tijd-schr. Ned-Indie,* 96: 25–41.

HATCH, T. 1978 Preliminary results from soil erosion and conservation trials at Semongok A.R.C. *Sarawak Dept. of Agriculture,* Misc. Paper.

de HEINZELIN, J. 1955 Observations sur la genese des nappes de gravats dans les sols tropicaux. *INEAC (Ser. Sci.),* 64.

——— and HO (Hoff & Overgaard). 1974 *Miri-Bintulu Regional Planning Study.* Consultancy report, Sarawak, Malaysia.

HTS (Hunting Technical Services) 1969 *Land capability study; Report to the Government of Brunei.* Consultancy report, Brunei.

——— and HO (Hoff & Overgaard). 1974 *Miri-Bintulu Regional Planning Study.* Consultancy report, Sarawak, Malaysia.

HUDSON, N. 1971 *Soil conservation.* Batsford, London.

ISBELL, R.F. 1977 The argillic horizon concept and its application to the classification of tropical soils. *Conf. on classification and management of tropical soils (CLAMOTROPS),* Kuala Lumpur.

IVES, D.W. and COWIE, J.D. 1975 The correlation of seven representative soils from Singapore with those of Peninsular Malaysia. *Proc. 3rd ASEAN soils conf.,* Kuala Lumpur.

JACKSON, A. 1962 Sea-bed sampling off northwest Borneo. *Brit. Borneo Geol. Survey,* Ann. Rpt.: 51–55.

JACKSON, M.L. and SHERMAN, G.D. 1953 Chemical weathering of minerals in soils. *Adv. in Agron.,* 5: 219–318.

JEEPS, M.D. and GATES, R.I. 1963 Physical aspects of the January–February, 1963, floods in Sarawak. *Sarawak Hydrological Yearbook for the water-year 1962–1963;* 40–95.

KARIM, A. 1953 The pedological significance of titanium. *J. Soil Sci.,* 4 (1): 56–58.

KELLOGG, C.E. 1948 Preliminary suggestions for the classification and nomenclature of Great Soil Groups in tropical and equatorial regions. *Proc. 1st Comm. Conf. on Trop. and Subtrop. soils,* Comm. Bur. Soil Sci. Tech. Commun. 46.

——— 1950 Tropical soils. *Trans. 4th Int. Cong. Soil Sci.,* Amsterdam, 1: 266–276.

van der KEVIE, W. 1969 Report on a visit to the proposed Sungei Sarawak padi scheme area, 18–27 June, 1969. (Unpublished report to FAO and Sarawak Government).

KIRK, H.J.C. 1957 The geology and mineral resources of the upper Rajang and adjacent areas. *Brit. Borneo Geol. Survey,* Mem. 8.

KLINGE, H. 1964 *Report on tropical Podzols.* FAO, Rome. (Draft).

LAW, W.M. and TAN, M.H. 1973 Chemical properties of some Peninsular Malaysian soil series. *Proc. Conf. on Chem. and Fert. of Trop. Soils,* Kuala Lumpur. Malaysian Soc. Soil Sci.

——— 1975 Range in properties of Peninsular Malaysian soils. *Proc. 3rd ASEAN soils conf.,* Kuala Lumpur.

LEAMY, M.L. and PANTON, W.P. 1966 Soil survey manual for Malayan conditions. *Min. Agric. and Coop., Div. of Agric., Kuala Lumpur,* Bull. 1.

de LEMOS, R.C. 1968 The main tropical soils of Brazil. *FAO World.*

LIECHTI, P., ROE, F.W. and HAILE, N.S. 1960 The geology of Sarawak, Brunei and the western parts of North Borneo. *Brit. Borneo Geol. Survey,* Bull. 3.

LRD (UK Min. of Overseas Dev., Land Resources Div.) 1975 *The soils of Sabah,* 1: Classification and description. Land Resources Study 20.

MAAS, E.F., TIE, Y.L. and LIM, C.P. 1979 Sarawak land capability classification and evaluation for agricultural crops. *Sarawak Dept. of Agric.,* Res. Br. Tech. Paper 5.

McCALEB, S.B. 1959 The genesis of the Red-Yellow Podzolic Soils. *Proc. Soil Sci. Soc. Amer.,* 23: 164–168.

McMANUS, J. and TATE, R.B. 1976 Volcanic control of structure in north and west Borneo. *SEAPEX Program, Offshore SE Asia Conf.,* Feb., 1976.

METEOROLOGICAL SERVICES, MALAYSIA. 1964–1967 Unpublished record compilations.

MILLER, A.A. 1953 *Climatology.* Methuen, London. (8th edition).

MOHR, E.C.J. and van BAREN, F.A. 1954 *Tropical soils.* Van Hoeve, The Hague.

——— and van SCHUYLENBORGH, J. 1972 *Tropical soils.* The Hague.

MONCHAROEN, L. 1975 The Red-Yellow Podzolic soils in Thailand: their distribution, characteristics, genesis and classification. *Proc. 3rd ASEAN soils conf.*, Kuala Lumpur.

MONEY, D.C. 1965 *Climate, soils and vegetation.* Univ. Tutorial Press.

MOORMANN, F.R. 1963 Acid sulphate soils (cat-clays) of the tropics.

——— 1978 An overview of taxonomic problems in LAC Alfisols and Ultisols. *Int. Soil Class. Workshop, Malaysia and Thailand.* Bangkok. (Preprint summary).

NOSSIN, J.J. 1965 Analysis of younger beach ridge deposits in eastern Malaya. *Zeit. fur Geomorph.*, 9: 186–208.

NORTHCOTE, K.H. 1974 *A factual key for the recognition of Australian soils.* Rellin Tech. Publications, Adelaide.

OLLIER, C.D. 1959 A two-cycle theory of tropical pedology. *J. Soil Sci.*, 10: 137–148.

PANICHAPONG, S. 1973 The application of the comprehensive system of soil classification in northeast Thailand. *Proc. 2nd ASEAN* soils conf., Jakarta, 1: 11–19.

——— 1977 Soil genesis on igneous and metamorphic rocks in Malaysia. D. Sc thesis, Univ. of Ghent.

———, DAUD, N. and ESWARAN, H. 1975 A preliminary appraisal of the soils of Kedah, Malaysia. *Proc. 3rd ASEAN soils conf.*, Kuala Lumpur.

PARISEK, E.J. and WOODRUFF, J.F. 1957 Description and origin of stone layers in soils of the southeastern States. *J. Geol.*, 65: 24–34.

PIMM, A.C. 1964 Seabed sediments of the South China Sea. *Borneo Reg., Malaysia, Geol. Survey,* Ann. Rpt.: 122–146.

——— 1965 Serian area, west Sarawak, Malaysia. *Borneo Reg., Malaysia, Geol. Survey,* Rpt. 3.

——— 1967 Bau mining district, west Sarawak, East Malaysia. *Borneo Reg., Malaysia, Geol. Survey,* Bull. 7.

PONS, L.J. and ZONNEVELD, L.S. 1965 *Soil ripening and soil classification.* Int. Inst. for Land Reclamation and Improvement, Wageningen.

RUHE, R.V. 1959 Stonelines in soils. *Soil Sci.*, 87: 223–231.

RUXTON, B.P. 1967 Slope under mature primary rainforest in northern Papua. *Landform studies from Australia and New Guinea* (ed. by Jennings, J.J. and Mabbutt, J.A.): 85–94. Aust. Nat. Univ., Canberra.

SCHMIDT, F.H. and FERGUSEN, J.H.A. 1951 Rainfall types based on wet and dry period ratios for Indonesia with western New Guinea *Kementerian perhubungan djawatan meteorologi dan geofisik,* Jakarta, Verhandelingen 42.

van SCHUYLENBORGH, J. 1957 Investigations on the classification and genesis of soils derived from acid tuffs under humid tropical conditions. *Neth. J. Agric. Sci.*, 5: 195–210.

——— 1958 Investigations on the classification and genesis of soils derived from andesitic tuffs under humid tropical conditions. *Neth. J. Agric. Sci.*, 6: 99–123.

SCOTT, I.M. 1967 Report on a semi-detailed soil survey of the Tanjong Jol area, 3rd Divison. *Sarawak Dept. of Agric.*, Soil Survey Rpt. 113, Kuching (mimeo).

——— 1969 Report on a semi-detailed soil survey of the Tg. Sirik area, 3rd Division. *Sarawak Dept. of Agric.*, Soil Survey Rpt. 130. Kuching (mimeo).

——— 1970 Report on a detailed reconnaissance soil survey of the Metading-Balingian-Sarupai area, 3rd Division. *Sarawak Dept. of Agric.*, Soil Survey Rpt. 141. Kuching (mimeo).

——— 1973 A draft reclassification of soils in central and north Sarawak. *Sarawak Dept. of Agric.*, Res. Br. Tech. Paper 3.

——— 1977 (in) *The Joinville Plantation Study.* Consultancy report, Brazil.

——— 1978 *The soils of the Mandalom area.* Consultancy report, Sabah, Malaysia.

SEAL, J. 1958 Rainfall and sunshine in Sarawak. *Sarawak Museum J.*, 8 (26 in new series): 500–544.

SIMONSON, R.W. 1950 Genesis and classification of Red-Yellow Podzolic Soils. *Proc. Soil Sci. Soc. Amer.*, 14: 316–319.

SOEPRAPTOHARDJO, M. 1976 Jenis tanah di Indonesia (3rd edition). *Soil Res. Inst.*, Bogor. (mimeo).

SOIL SURVEY STAFF. 1966 A classification of Sarawak soils. *Sarawak Dept. of Agric.*, Res. Br. Tech. Paper 2.

SOMBROEK, W.G. 1966 *Amazon soils.* Centre for Agric. Publications and Documents, Wageningen; Agric. Res. Rpt. 672.

SOORYANARAYANA, V. and ESWARAN, H. 1975 Pedological studies on Malaysian soils — Bukit Lunchu, Rengam and

Kampong Kolam Series; II: mineralogy and micromorphology. *Proc. 3rd ASEAN soils. conf.*, Kuala Lumpur.

STACE, H.C.T., HUBBLE, G.D., BREWER, R., NORTHCOTE, K.H., SLEEMAN, J.R., MULCAHY, M.J. and HALLSWORTH, E.G. 1968 *A handbook of Australian soils.* Rellim, Glenside, South Australia.

SWAN, S.B.St.C. 1968 Coastal classification with reference to the east coast of Malaya. *Zeit. fur Geomorph.*, Suppl. Band 7: 114–132.

——— 1970 Relationship between regolith, lithology and slope in a humid tropical region, Johor, Malaysia. *Trans. Inst. Brit. Geog.*, 51: 189–200.

TAN, K.H. and van SCHUYLENBORGH, J. 1959 On the classification and genesis of soils derived from andesitic volcanic material under a monsoon climate. *Neth. J. Agric. Sci.*, 7: 1–19.

——— 1961a Classification and genesis of soils over acid volcanic material. *Neth. J. Agric. Sci.*, 9: 41–54.

——— 1961b On the organic matter in tropical soils. *Neth. J. Agric. Sci.*, 9: 174–180.

TATE, R.B. 1971 Radiocarbon ages from Quaternary terraces — pre-history in Brunei. *Brunei Museum J.*, 3 (3): 108–123.

TAVERNIER, R. and ESWARAN, H. 1977 Soil property change as a function of soil genesis in the humid tropics. *Conf. on classification and management of tropical soils (CLAMOTROPS)*, Kuala Lumpur.

TAVERNIER, R. and SYS, C. 1965 Classification of the soils of the Republic of Congo (Kinshasa). *Pedologie*, Intern. Symp. 3, Soil Classification: 91–136.

THOMAS, P. and ALLEN, A.W. 1966 A provisional soil map of Sabah. *Proc. 2nd Malaysian soils conf.*, Kuala Lumpur: 13–32.

THORP, J. 1949 Effects of certain animals that live in soils. *Scientific Monthly*, 68: 180–191.

——— and SMITH, G.D. 1949 Higher categories of soil classification: Order, Suborder and Great Soil Groups. *Soil Sci.*, 67, 117–126.

TIE, Y.L. 1976 Some preliminary results of soil erosion trials. Sarawak Dept. of Agric. (Unpublished).

TOULIATES, P. and ROTH, E. 1971 Hurricanes and trees, the lessons from Camille. J. Forestry, 69 (5): 285–289.

USDA (United States Dept. of Agric., Soil Survey Staff) 1951 *Soil Survey Manual.* USDA Agric. Handbook 18.

——— 1960 *Soil classification, a comprehensive system, 7th Approximation.* USDA, Washington.

——— 1975 *Soil taxonomy.* USDA Agric. Handbook 436.

VERHEYE, W., TESSENS, E. and ISMANGUN. 1977 The latosol and Podzolic Soil concepts in Indonesia. *Conf. on classification and management of tropical soils (CLAMOTROPS)*, Kuala Lumpur.

VINK, A.P.A. 1963 Planning of soil surveys in land development. *Int. Inst. for Land Reclamation and Improvement, Wageningen*, Pub. 10.

WALL, J.R.D. 1961a Report on a detailed reconnaissance soil survey of the Mukah area. *Sarawak Dept. of Agric.*, Soil Survey Rpt. 31. Kuching (mimeo).

——— 1961b Detailed report on a reconnaissance soil survey of the Kabong-Grigat area, 2nd Division *Sarawak Dept. of Agric.*, Soil Survey Rpt. 29. Kuching (mimeo).

——— 1962 Progress report on the coastal reconnaissance survey, Miri-Igan, 3rd and 4th Divisions. *Sarawak Dept. of Agric.*, Soil Survey Rpt. 43. Kuching (mimeo).

1966 The Bekenu-Niah-Suai area. Ph.D. thesis, Univ. of Reading.

——— and LIM, C.P. 1962 Report on a reconnaissance soil survey of the Igan-Grigat area, 3rd Division. *Sarawak Dept. of Agric.*, Soil Survey Rpt. 43/6. Kuching (mimeo).

WELLS, N. and LEAMY, M.L. 1977 Genetic properties of Singapore soils and their implications for soil management. *Conf. on classification and management of tropical soils (CLAMOTROPS)*, Kuala Lumpur.

WENTWORTH, C.K. 1930 A simplified method of determining the average slope of land surfaces. *Amer. J. Sci.*, 20: 184–194.

WILFORD, G.E. 1955 The geology and mineral resources of the Kuching-Lundu area, west Sarawak, including the Bau mining district. *Brit. Borneo Geol. Survey*, Mem. 3.

——— 1961 The geology and mineral resources of Brunei and adjacent parts of Sarawak with descriptions of Seria and Miri oilfields. *Brit. Borneo Geol. Survey*, Mem. 10.

——— 1968 Notes on the geomorphology of Sabah. *Borneo Reg., Malaysia, Geol. Survey,* Bull. 9: 1–22.

——— and KHO, C.H. 1965 Penrissen area, west Sarawak. *Borneo Reg., Malaysia, Geol. Survey,* Rpt. 2.

WILFORD, G.E., COLLENETTE, P. and KIRK, H.J.C. 1966 Radio-carbon determinations on specimens from Sabah. *Borneo Reg., Malaysia, Geol. Survey,* Rpt. 2.

WISCHMEIER, W.H., JOHNSON, C.B. and CROSS, B.V. 1971 A soil erodibility nomograph for farmland and construction sites. *J. Soil and Water Conservation,* Sept–Oct.

WOLFENDEN, E.B. 1960 The geology and mineral resources of the lower Rajang valley and adjoining areas. *Brit. Borneo Geol. Survey,* Mem. 11.

——— 1965 Bau mining district, west Sarawak, Malaysia; Part I: Bau. *Borneo Reg., Malaysia, Geol. Survey,* Bull. 7.

WONG, I.F.T. 1974 *Soil-crop suitability classification for Peninsular Malaysia.* Min of Agric. and Fish., Malaysia.

WOOD, T.W.W. and BECKETT, P.H.T. 1961 Some Sarawak soils, II: soils of the Bintulu coastal area. *J. Soil Sci.,* 12: 218–233.

WYATT-SMITH, J. 1956 Discussion in *Proc. Symp. on Study of Trop. Veg.,* Kandy. UNESCO.

WYCHERLEY, P.R. 1963 Variation in the performance of Hevea in Malaya. *J. Trop. Geog.,* 17: 143–171.

Part IV

APPENDICES

APPENDIX I

EVIDENCE FOR HIGH-LEVEL EROSION SURFACES IN THE AREA

As stated above the evidence for a high-level peneplain in the Area is largely confined to approximately concordant summit heights in the strongly dissected hill zone. There are no bevelled summits and no records of high-level superficial deposits. It is dangerous to suggest a prior peneplain on the evidence of concordant summits alone but a number of geologists have recognised peneplain levels in adjacent areas from rather more convincing evidence. Before considering the Area in this context, therefore, the evidence from north and west Sarawak is reviewed.

The highest reported erosion surface in Sarawak is an apparent summit-plain truncating many high-level structures in the north (Liechti, 1960: 304–305; Wilford, 1961: 125), in the Rajang hinterland (Liechti, 1960: 305) and in west Sarawak (Liechti, 1960: 307; Pimm, 1965: 65; 1967: 50). Flat-topped mountains in the Kelabit highlands and the Sarawak-Sabah border area are considered (Wilford, 1961: 125) to be probable remnants of this surface but elsewhere the evidence is largely confined to summit concordance. Such concordance is, however, also noted in Sabah (Fitch, 1953: 22) and 'there is proof that large parts of Kalimantan, particularly the coastal belt . . . have been similarly peneplained' (Liechti, 1960: 310). The evidence is thus sufficiently widespread for there to be general agreement among geologists that regional peneplanation did take place and that it reached a mature stage before the cycle – termed the Peneplanation Cycle by Liechti – was halted by uplift, but there is less confidence in ascribing apparent gipfelflurs in any specific locality to this peneplain, as subsequent uplift was complicated by warping. Liechti (1960: 304) considers the surface to have been lifted 200–300 feet (60–90 metres) above present datum near the coast but to 3,000–4,500 feet (900–1400 metres) in the Kelabit highlands and Rajang hinterland. Wilford (1961: 125–129) views the north Sarawak evidence as presenting two cycles, citing accordant summits at 6,000–7,000 feet (1800–2100 metres) in the Kelabit highlands as evidence of his Cycle 1 and a surface now at 200–300 feet (60–90 metres) in coastal Brunei and near Marudi, rising to 2,000–3,000 feet (600–900 metres) in the east, as his Cycle 2. In west Sarawak Pimm (1965: 65) records evidence of a gipfelflur truncating a variety of rock types at 1,500 feet (450 metres) in the Serian area and a similar apparent summit-plain is found in the Penrissen area (Wilford and Kho, 1965: 156).

If the west Sarawak evidence relates to Liechti's Peneplanation Cycle then it would appear that relative uplift of some 2,000 feet (600 metres) has taken place en bloc there without the marked tilting described from north Sarawak. There are, however, also apparent remnants of a surface at 150–350 feet (45–105 metres) in many parts of west Sarawak which on the basis of their present elevation, may equally well be related to this Cycle as remnants ascribed to the Peneplanation Cycle in north Sarawak are, in coastal areas, found at this general level. If the existence of a widespread Peneplanation Cycle is accepted it is a reasonable assumption that the evidence in the west and north correlates in some manner. Three possibilities may be suggested: (a) the surface was uplifted and tilted in the north but uplifted en bloc in the west; surfaces below 1,000 feet (300 metres) in the west relate to later cycles; (b) the surface was uplifted some 200–300 feet (60–90 metres) in both areas but tilting was confined to the north and the evidence at 1,000–2,000 feet (300–600 metres) in the west either relates to a higher surface not recognised in the north of may be part coincidence and part structural control; or (c) that, following Wilford, two cycles were involved giving surfaces at two general levels but relative uplift in the west was rather less than in the north and was without marked tilting. At present it can only be stated that the evidence for high level surfaces is difficult to interpret in both areas and the relationship between the evidence in the west and that in the north cannot be established without more quantitative details of the tectonic history. As west Sarawak forms a discrete geological unit underlain by 'Sunda Shielf' material, while central and north Sarawak largely form a continuum of Tertiary geosynclinal deposits, it is likely that the tectonic history of central Sarawak is more similar to that of the north than the west and that, for correlations with high level erosion features in the Area, one should therefore look northward.

In discussing the Peneplanation Cycle in relation to central Sarawak Liechti (1960: 306) observes: 'the fact that the relief decreases gradually towards the Lower Rajang, where it comes down to 200–300 feet a.s.l. is further evidence for regional peneplanation and subsequent warping of the Rajang hinterland. However, the decrease is not linear. It appears that the former plain now completely dissected is undulating, showing a gentle warping . . . the regular decrease of height in the Lower Rajang

area appears definitely not the incidental result of denudation alone, but is strongly suggestive of former base-levelling'. The interpretations of Liechti and other workers in this and surrounding areas were based largely on spot heights and visual evidence of summit accordance. Photogrammetric contour plots are now available for the Area – 1:50,000 scale (100-foot contour interval) for the entire Area and 1:10,000 scale (25-foot contour interval) for large tracts south of the Batang Rajang – and a more quantitative analysis is now possible.

A ½-mile square grid was overlain on the 1:50,000 scale contour data and the highest contour in each grid square plotted. Generalised summit contours were interpolated from these entries. As the contour interval is wide and only a broad degree of accuracy possible, considerable generalisation was allowed. For land below 500 feet (150 metres) elevation these summit lines are plotted on Map 3. Two features are evident. Firstly, while there is a general decrease in maximum altitude towards the coastal plain and a sloping surface at 300–500 feet (90–150 metres) is suggested by the contour plots, strike ridges are still apparent at this level of generalisation and lateral changes in summit elevation are quite marked for this reason. Secondly, upland tracts with summits consistently below 100 feet (30 metres) elevation are virtually absent. At least some summits remain above this level even on the fringe of the uplands and in many localities, particularly to the south of the Rajang delta, the swamp flats abut hill tracts the summits of which rise quickly to over 200 feet (60 metres) above sea level. To the north of the Batang Rajang the increase in elevation back from the swamp is rather more gradual and in the hills extending towards the coast between the Batang Mukah and Batang Balingian no hills have been recorded with summits above 200 feet (50 metres).

The more detailed contour data available in the southern portion of the Area also suggests a high-level summit plain at 350–450 feet (100–140 metres) above sea level but, in addition, offers evidence which suggests a lower surface. The tract from the Julau headwaters in the Pakan area northwest to Selalang is particularly interesting, (Figs. 50 and 51). In the south a well-dissected summit plain extends beyond the Area into the upper Julau, where it is at approximately 450–500 feet (140–150 metres), and drops to 350–400 feet (100–120 metres) between Pakan and the Wuak River. In some localities between the Sarikei-Pakan road and the southern extension of the Sebankoi ridge, however, the isolated hills with summits at about 350 feet (100 metres) rise from undulating and only weakly dissected country at 200–250 feet (60–75 metres) elevation. (Fig. 51A). These areas are separated by tracts in which dissection is greater but summit frequency remains dominantly at these two levels, and to the north are bounded by a narrow zone extending from the Sarikei headwaters through Sg. Rusa to the Stras headwaters in which the summit frequency pattern is still preserved but dissection is extreme and most valley bottoms are at below 100 feet (30 metres) elevation, (Fig. 51B). The sequence is completed in the Selalang area where relicts of the higher summit plain are few and are at 250–300 feet (75–90 metres), the lower summit plain is at approximately 200 feet (60 metres), and dissection is pronounced; this terrain gives way abruptly in this locality to lowlands with all summits at 75–125 feet (20–40 metres) above sea level and most hill tracts separated by narrow extensions of the swamp plain, (Fig. 51C).

Analysis of the frequency of closed-contour summits on the 1:10,000-scale mapping also suggests a polycyclic relief. The frequency on all sheets studied is very irregular (Fig. 50) but there is a concentration evident at 150–200 feet (45–60 metres), higher summits are mainly at 300–400 feet (90–120 metres) with summits above this elevation confined to major strike ridges, and on the hill zone fringes a lower concentration of summits at below 125 feet (40 metres).

Major streams in areas covered by 25-foot contouring have lowered their floodplains to less than 100 feet (30 metres) above sea level. River long profiles in the Area do not, therefore, help in reconstructing erosion cycles. A study was, however, made of some drainage basins to the east of the Area, where the amplitude of relief is greater. Sixteen major streams in the Katibas, Poi and Ngemah basins were roughly plotted in long profile from the 1:50,000 scale/100-foot contour interval sheets. Even on this poor data all profiles showed one marked change of grade and ten showed two, the pattern of possible knick points being unrelated to the strike and suggesting that some, at least, of these irregularities reflect rejuvenation. Projection of curves gave moderately consistent end-points at some 250 and 450–550 feet (75 and 140–170 metres) above present datum. No reliance can be placed on long profiles drawn from such rough data but the close agreement between base levels suggested by these curves and accordant summit data in the Area (allowing for the interior location of these drainage basins) does appear worthy of note. When more adequate levelling data are available for the Katibas-Ngemah area a study of river long-profiles in that locality should prove useful in this context.

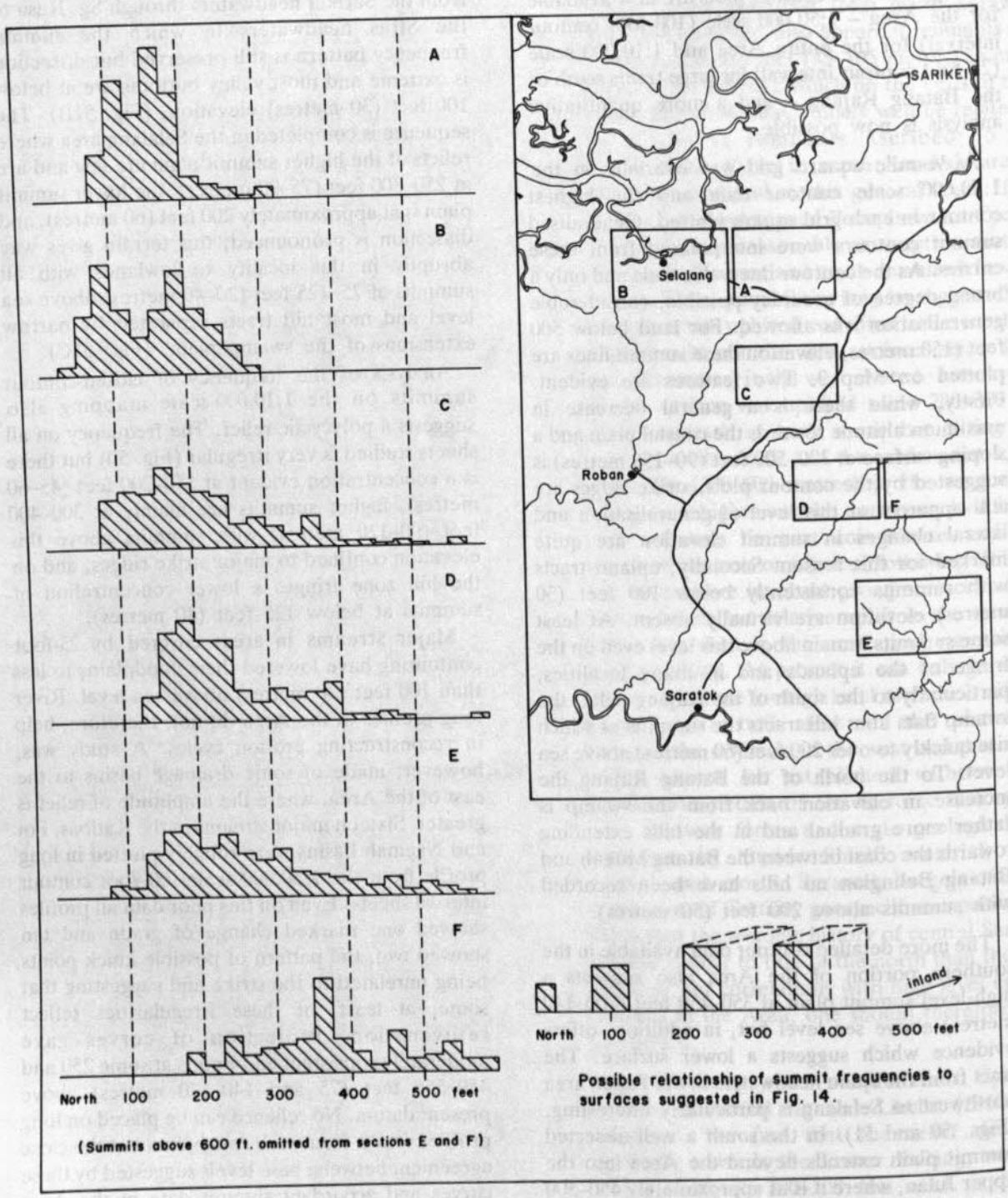


Fig. 50: Summit frequency in six localities

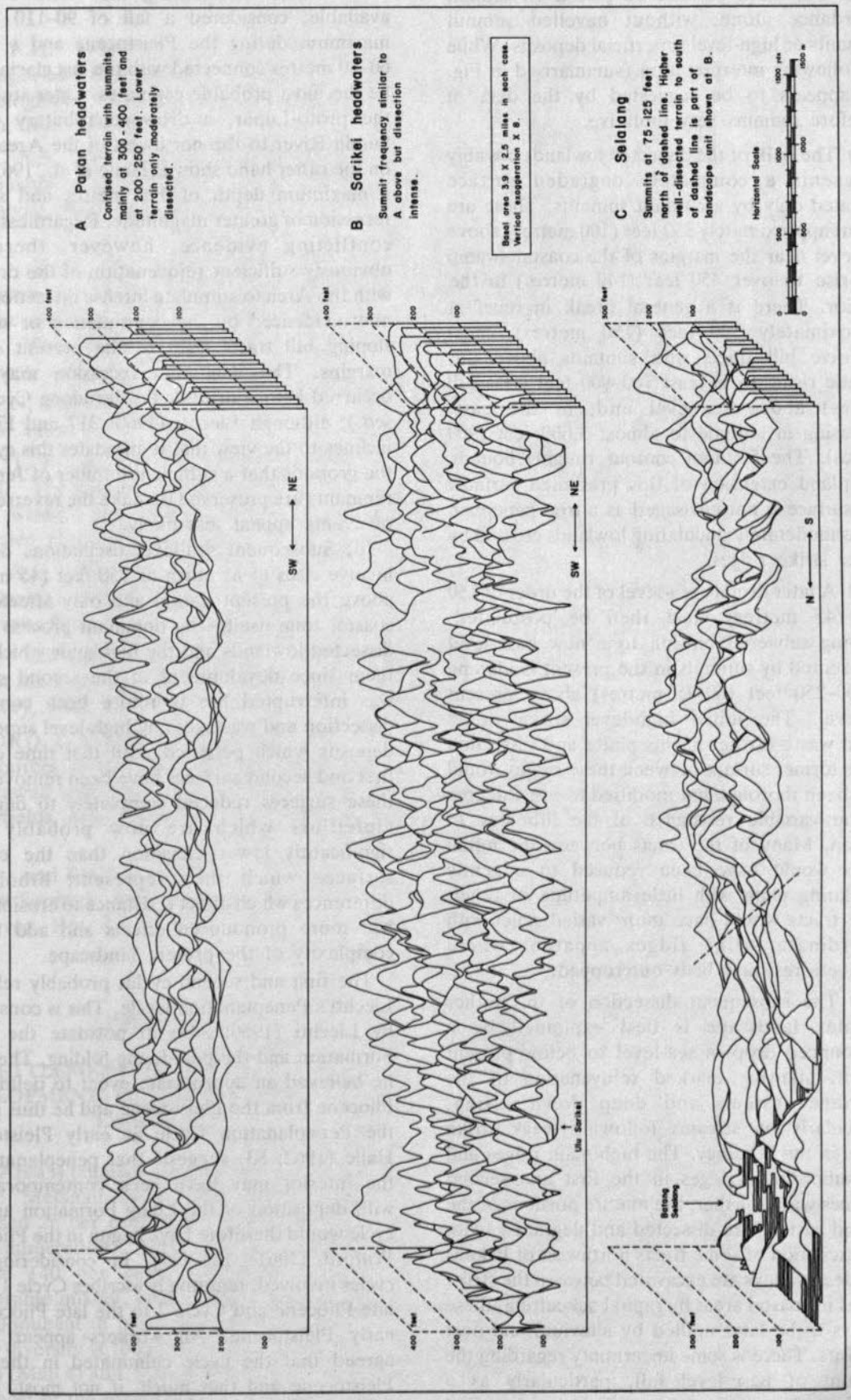


Fig. 51: Projected profiles from three localities in the dissected lowlands

Nor can much reliance be placed on summit accordance alone, without bevelled summit remnants or high-level superficial deposits. While the following interpretation (summarised in Fig. 11) appears to be suggested by the data, it therefore remains very tentative:

(a) The bulk of the dissected lowlands possibly represents a completely degraded surface indicated only by accordant summits. These are now at approximately 350 feet (100 metres) above sea level near the margins of the coastal swamp and rise to over 450 feet (140 metres) in the interior. There is a general break in relief at approximately 500 feet (150 metres), most extensive hill tracts with summits above this altitude rising to at least 700–900 feet (200–270 metres) above sea-level and, in the east, increasing in altitude to almost 3,000 feet (900 metres). The 500-foot contour roughly bounds the inland extension of this presumed surface. The surface is not envisaged as a true peneplain but as moderately undulating lowlands crossed by higher strike ridges.

(b) A later drop in sea-level of the order of 150 feet (45 metres) must then be postulated, allowing subaerial erosion to a new base-level represented by summits in the present landscape at 200–250 feet (60–75 metres) above present sea-level. The initial high-level strike ridges would waste further in this phase and dissection of the former surface between these ridges would have been thorough but modified to some degree by the variable resistance of the lithology to erosion. Many of the tracts between the initial ridges would have been reduced to a gently undulating plain with little amplitude of relief; other tracts would have more varied relief with subordinate strike ridges apparent where relatively resistant beds outcropped.

(c) The subsequent dissection of this rather complex landscape is best explained by a pronounced drop in sea-level to below present datum, allowing marked rejuvenation of the drainage systems and deep down-cutting, particularly by streams following weak strike zones in the lithology. The high main ridges and the subordinate ridges in the first and second surfaces waste further, the mature portions of the second surface are dissected and degraded (with the exception of some tracts northwest of Pakan) and deep valleys are excavated between the strike ridges in coastal areas by rapid backcutting, these valleys to be later infilled by alluvium and peat deposits. There is some uncertainty regarding the amount of base-level fall, particularly as a number of oscillations in sea-level accompanied seccessive phases of the glacial period. Kuenen (1950: 536), summarising the world evidence available, considered a fall of 90–110 metres maximum during the Pleistocene and a fall of 60–80 metres connected with the last glaciation to be the most probable estimates. Later studies of the proto-Lupar, a drowned tributary of the Sunda River to the northwest of the Area, have on the other hand shown (Haile et al., 1963: 126) a maximum depth of 170 metres and suggest recession of greater magnitude. Regardless of this conflicting evidence, however, there was obviously sufficient rejuvenation of the drainage with the Area to stimulate intense dissection, as is now evidenced by the continuation of steeply-sloping hill tracts right to the present swamp margins. The maximum recession may have occurred before or after the Jerudong Cycle, (et seq.), although Liechti (1960: 317 and Fig. 30) inclines to the view that it antedates this cycle on the grounds that a sufficient number of Jerudong remnants are preserved to make the reverse order of events appear less likely.

(d) Subsequent sea-level oscillations did not involve rises to as much as 150 feet (45 metres) above the present datum and only affected the coastal zone itself. The dominant process in the dissected lowlands and the highlands which back them since development of the second surface was interrupted has therefore been continued dissection and wastage; any high-level superficial deposits which persisted until that time on the first and second surfaces have been removed and these surfaces reduced completely to degraded gipfelflurs which are now probably at a significantly lower elevation than the erosion surfaces which they represent; lithological differences which affect resistance to erosion have had more pronounced effects and add to the complexity of the present landscape.

The first and second cycles probably relate to Liechti's Peneplanation Cycle. This is considered by Liechti (1960: 309) to postdate the Liang Formation and the post-Liang folding. The latter he believed an appropriate event to delimit the Pliocene from the Pleistocene and he thus placed the Peneplanation Cycle as early Pleistocene. Haile (1962: 83) suggests that peneplanation in the interior may have been contemporaneous with deposition of the Liang Formation and the cycle would therefore have begun in the Pliocene. Wilford (1961: 125–129), in considering two cycles involved, tentatively ascribes Cycle 1 to the late Pliocene and Cycle 2 to the late Pliocene or early Pleistocene. All workers appear to be agreed that the cycle culminated in the early Pleistocene and that much, if not most, of the region had reached a mature stage of peneplanation at that time.

REFERENCES

FITCH, F.H. 1953 Tertiary to recent sea-level changes and their effect on British Borneo physiography. *Brit. Borneo Geol. Survey,* Ann. Rpt.: 20–37.

HAILE, N.S. 1962 The geology and mineral resources of the Suai-Baram area, north Sarawak. *Brit. Borneo Geol. Survey,* Mem. 13.

———, KEIJ, A.J. and PIMM, A.C. 1963 Preliminary report on the oceanographic cruise of HMS 'Dampier' in the South China Sea, 1963, *Borneo Reg., Malaysia, Geol. Survey,* Ann. Rpt.: 119–145.

KUENEN, P.H. 1950 *Marine geology.* Wiley, New York.

LIECHTI, P., ROE F.W. and HAILE, N.S. 1960 The geology of Sarawak, Brunei and the western parts of North Borneo. *Brit. Borneo Geol. Survey,* Bull. 3.

PIMM, A.C. 1965 Serian area, west Sarawak, Malaysia. *Borneo Reg., Malaysia, Geol. Survey,* Rpt. 3.

——— 1967 Bau mining district, west Sarawak, East Malaysia. *Borneo Reg., Malaysia, Geol. Survey,* Bull. 7.

WILFORD, G.E. 1961 The geology and mineral resources of Brunei and adjacent parts of Sarawak with descriptions of Seria and Miri oil-fields. *Brit. Borneo Geol. Survey,* Mem. 10.

——— and KHO, C.H. 1965 Penrissen area, west Sarawak. *Borneo Reg., Malaysia, Geol. Survey,* Rpt. 2.

APPENDIX II

THE SETTLEMENT OF THE AREA AND THE DEVELOPMENT OF ITS AGRICULTURAL LANDSCAPE

The Area is populated mainly by three cultural groups: Melanau (who, with some Malays, comprised 26 per cent of the population in the 1970 enumeration), Iban (34 per cent) and Chinese (40 per cent). Although there is considerable mixing, each of these groups tends to be dominant in particular areas (Fig. 52). A similar diversity is found in the general land use pattern (Map 4) and, although all cultural groups grow most of the main crops found in the Area, there is a tendency for each to be associated with particular land use types. Thus the Melanau/Malay group are associated particularly with sago, swamp rice and coconut cultivation, the Chinese with pepper planting and rubber, and the Iban with hill rice. It is therefore convenient in this chapter to consider the land use pattern together with the population (which, in large measure, is agriculturally based).

It is also necessary to view the present population and land use patterns in a historical perspective as few components of either pattern are of long standing. Pepper and rubber, which made up 93 per cent of the State's agricultural exports in 1972 (Department of Agriculture, 1972: 6), date only from the early years of the present century as crops of any significance in the Area. Most of the Chinese population also arrived after 1900. Even the Iban hill rice cultivators were, prior to about 1830, established only in the extreme south of the Area and their spread through most of the hill zone occurred mainly between 1840 and 1900. The Melanau are the one group with strong claims to be considered indigenous in the Area and sago and swamp rice the only important cultivated crops which were not introduced in relatively recent times. One may also add that the timber industry, which now generates twice as much export value as agriculture in most years and which provides a significant cash income to many Iban and Melanau otherwise largely dependent on agriculture, dates on its present scale from the 1950's. Before considering the present distribution of population and land use types the history of the Area will therefore be reviewed.

HISTORICAL GEOGRAPHY OF THE AREA

The pre-Brooke period

Knowledge regarding the Area is sketchy prior to its incorporation within the Brooke Raj, which occurred in stages between 1853 and 1861, but the broad picture can be reconstructed with fair accuracy.

The coastal zone was populated then as now by Melanau. The origin of the Melanau is obscure but their language links them with the Kayan peoples of the interior and with the Land Dayak of west Sarawak (Noakes, 1949: 99; Aikman, 1959: 86). They have traditions of originating in the hill zone where they processed sago flour from wild palms (Morris, 1953: 150), but their present coastal distribution is of long standing.

Melanau traditions go back to a period 500 years ago (Aikman, 1959: 87), before Islam reached Brunei, when all Melanau were pagan and were ruled by their own chiefs. After they were conquered by Muslim Bruneis (Lawrence,

1911) these were largely replaced by Brunei nobles, one such pengiran being established as the authority of the Brunei Sultan at the mouth of most main rivers (Morris, 1953: 6). Government was confined to exacting taxes and was, in effect, not extended to the interior. An 1837 list of the peoples which the Sultan considered were under him did, however, include the Kanowits (a group related to the Melanau), indicating both some awareness of the interior and the importance even at that time of jungle produce from the Rajang drainage system (Pringle, 1970: 44–55n).

In 1820 (Anon, 1824: 3) some 30–40 Brunei pengirans were established in coastal settlements nominally under the Sultan, although Saribas and, before 1849, the Rajang were under local Muslim leaders (Pringle, 1970: 56; Mundy, 1848: I, 365). Revenue was precarious and comprised tribute paid in the commodity of the district (Anon, 1824: 3).

While the Melanau planted swamp rice and depended much on fishing, they were mainly noted for sago production. Borneo sago flour was considered second only to that of north Sumatra in the early 19th Century and was exported to Europe, India and China (Crawfurd, 1820: III, 348; 1856: 372).

The Melanau area was, perhaps due to the sago revenue, sufficiently important to be recorded by 16th Century European cartographers (Broek, 1964 and undated notes, Sarawak Museum). The most important centres were apparently the lower Batang Oya and Batang Mukah, partly because they were sufficiently near Brunei to be heavily taxed in comparison with areas farther west (Mundy, 1848: I, 189), but the Melanau distribution was very similar in the early 19th Century to that at present and many of the present delta kampongs were noted at that time or a little later (e.g. Leyden, 1837: 94; Low, 1848: 337–340; Mundy, 1848: I, 316; 1848: II, 127; Anon, 1867: 61–62). Sago production appears to have been concentrated in the Mukah-Petanak area and there is some negative evidence to suggest that it was not important in Kalaka and Saribas Districts in the 18th and early 19th Century (Hunt, 1820: 57; Parnell, 1911; cf. Mundy, 1848: I, 189).

Southwest of the delta the present population is dominantly Malay (in the Kabong-Grigat area and inland to Saratok along the Sungai Krian), this area forming on outlier of the Malay concentration in west Sarawak. The Malays (in Sarawak) are a mixed stock representing a fusion of 'indigenous' groups with a small number of early immigrants, bonded together by Islam over the past 500 years (Goatly, 1959; Harrison, 1964). The Malays in the southwest of the Area are apparently derived from a pagan group related to the Melanau, Seru captives from Iban war-parties, some intermarriage with the Iban and a few immigrant Muslims from elsewhere (Pringle, 1970: 40, 58; Sandin, 1964; 1967: 77–78).

Groups related to the Melanau or to the Kayans of the interior, such as the Tanjongs, Seduans and Kanowits, were scattered up the Batang Rajang itself and also largely practised a sago economy with some swamp rice cultivation and jungle collection. Elsewhere, however, the Melanau did not extend far inland and remained an essentially coastal people. Crocker estimated their number at 30,000 in 1876 (SG 120, 1876: 7), compared with estimates of between 35,000 and 45,000 in the census enumerations of 1939, 1947 and 1960 (Jones, 1962: 55). Doubt is cast on all these census figures by the unavoidable confusion between Melanau and Malay, but indications are that the Melanau coastal zone was, even in the pre-Brooke period, an area of relatively dense settlement and that the population concentrations in the lower Oya and Mukah shown on Fig. 53 also occurred then.

The coastal population density was in marked contrast to that of the interior hill country at that time. Except for the scattered Melanau and other groups near the Batang Rajang, and the well-populated Kabong-Saratok area which is discussed below, the hill zone of the Area was at the beginning of the 19th Century largely untouched by farmers, remained under virgin forest, and was occupied by nomadic groups practicing a hunting and collecting economy. The interior of the Oya, Mukah and Balingian basins may have been completely uninhabited. These nomadic peoples, such as the Bukitans, Ukits and Seru, did not grow rice (Pringle, 1970: 39), subsisted on wild sago to a large degree, and were comparable in many respects to the Punans now still partly nomadic in the Sarawak interior. Some jungle produce was traded to the coast but the permanent penetration of settlers and traders into the hill zone from the coastal ports was discouraged by the insecurity of the area. Kayan peoples of the upper Rajang on occasion raided the downriver settlements from their territory beyond Kapit, (Low, 1848: 322–323) and the Iban by sea from their bases in 2nd Division (Pringle, 1970: 48).

In Kalaka the situation was rather different. The Iban were already established in the Lupar and Saribas basins in the early 18th Century, cutting and burning primary forest for hill rice cultivation. They were and are, a vigorous and mobile people, were not strongly opposed by the

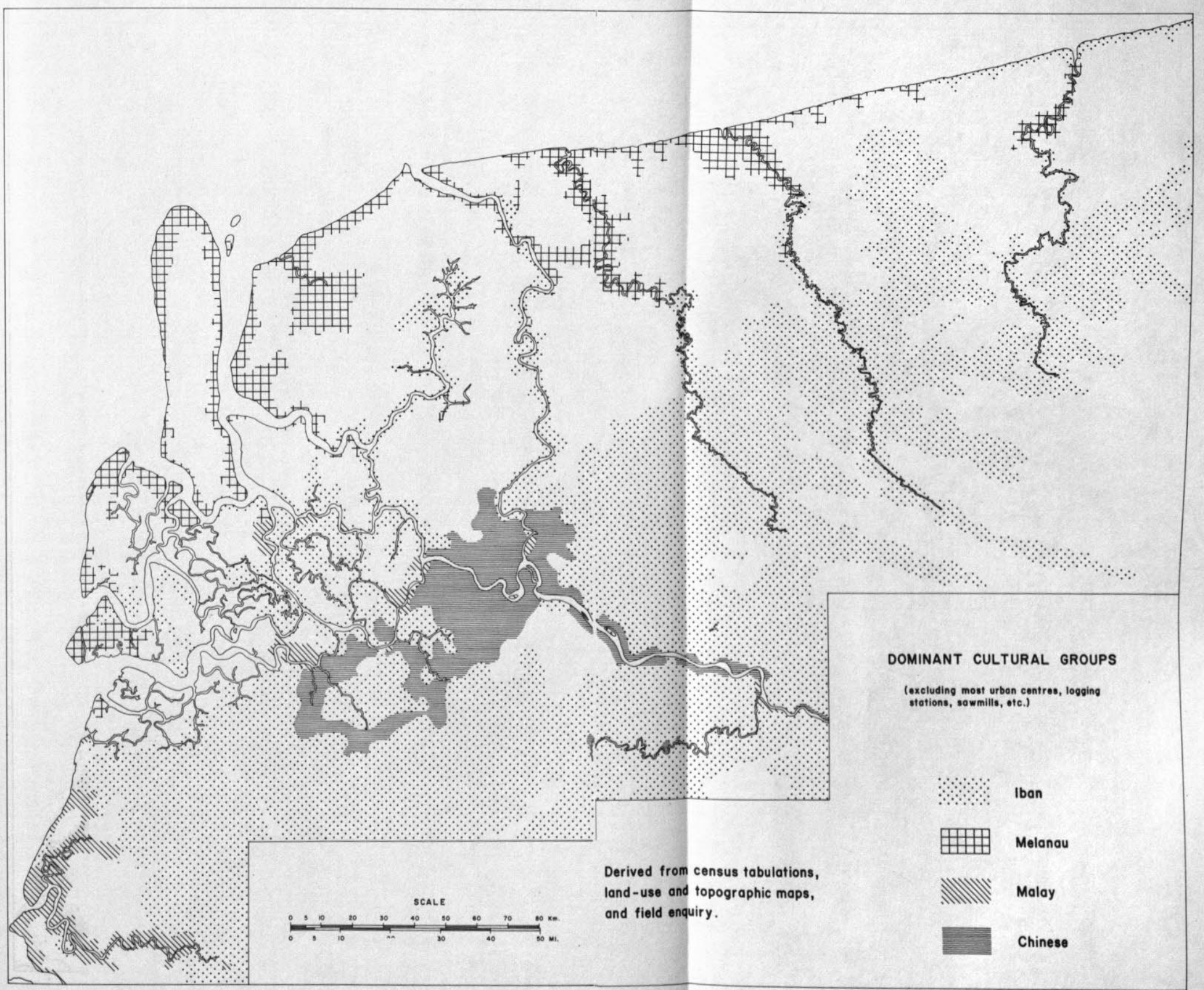


Fig. 52 Distribution of the main cultural and language groups

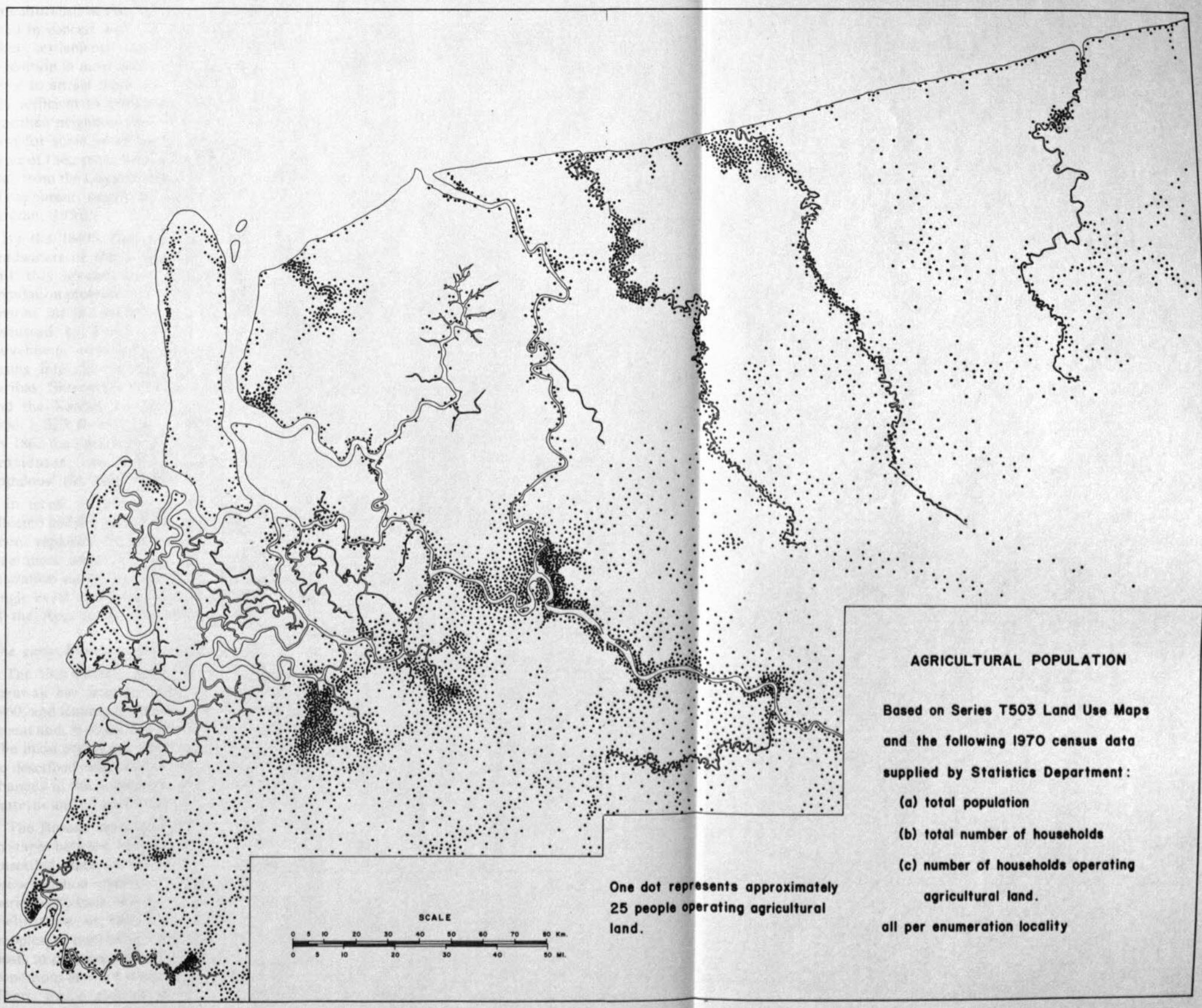


Fig. 53 Distribution of agricultural population

sparse interior population or the settled agriculturalists of the coast, and, on the contrary, acted in concert with Malay groups in attacking other settlements (Earl, 1836: 9). With no opposition in most areas and vast tracts of virgin forest to attract them, even a mild land pressure was sufficient to encourage groups to leap-frog over their neighbours into new areas, to clear and farm for some years before moving again. The route of their piece-meal migration can be traced back from the Lupar through the Kapuas basin to an apparent origin in southeast Kalimantan (Sandin, 1956).

By the 1840's they were spreading into the headwaters of the Rajang southern tributaries and this spread soon became very rapid. Population pressure was probably only one of the reasons for this trend, the causes of which are discussed by Pringle (1970: 52). The main movements were from the Saribas and Krian basins into the Sarikei and Julau, and from Saribas, Skrang and Lemanak into the Kanowit and the Katibas system farther east (Brooke, 1866: I, 327; Roth, 1896: I, 7; Pringle, 1970: 252). By 1862 the Kanowit and Katibas river basins, in particular, could be described as 'very populous' (St. John, 1862: I, 37).

In terms of the area which they have now affected and the amount of virgin forest which has been replaced by a patchwork of hill rice clearances under a secondary cover, the Iban migration can be considered the most important single event modifying the agricultural landscape of the Area in the 19th Century or later.

The early Brooke period (1850–1900)

The 19th Century history of the Brooke raj in Sarawak has attracted many historians (Payne, 1960, and Runciman, 1960, being among the most recent and, in relation to the Iban, Pringle, 1970). The main events are well known. Here they will be described only to the extent needed to explain changes in the population distribution, land use patterns and economic development of the Area.

The Brooke authority over the Area occurred in stages between 1853 and 1861. Due to the very unsettled state of the area the Rajah's main preoccupation over the following decade, and periodically later, was to control the headhunting inclinations of the Iban and other interior peoples, to establish a framework of Government posts to preserve law and order and to create the conditions in which trade could operate and grow. There was a growing shortage of cheap rice. Pringle notes 'As late as 1864-5 the country as a whole was still producing a rice surplus, derived mainly from Iban areas, but by 1874-6 Sarawak was a net importer of rice and has remained one ever since. The Sarawak Gazette blamed this change on a growing Iban inclination to seek jungle produce for cash sale, instead of diligently farming; (SG 130; 16 April 1877). But it seems more likely that the real cause was growth in urban population' (Pringle, 1970: 63n).

In 1880 an Order was announced under which Chinese groups were encouraged to emigrate to the State to open farms in Sarawak (SG 169: 1880) and this was tabled mainly with rice production in mind. Other aspects of agriculture also received some attention during the period. Chinese were encouraged to enter to plant gambier and pepper (SG 76, 1874; SG 115, 1876; Treacher, 1890: 27). Improvements in cattle and poultry were planned (Trevenen, 1891, 3). Experiments were conducted with trial plantings of mulberry, coffee and sugar cane but mulberry and sugar cane proved disappointing and coffee, which was initially successful in 2nd Division, was then hit by a price slump. As far as the Area was concerned, little change in agriculture took place until the 1900's apart from progressive clearance of forest for hill rice by the Iban.

The economic bases of the Area thus remained sago production and jungle produce collection, the latter taking precedence in the export figures. Gutta percha alone represented 88 per cent of exports other than minerals in the first half of 1870 and 55 per cent in the same period of 1871 (SG 23, 1871). Other jungle produce from the Area included bees' wax, bezoar stones, illipe nut, jelutong, and rotans. 'Between the years 1876 and 1910 jungle produce regularly accounted for about one-third of Sarawak's total exports. The remaining two-thirds consisted mainly of sago and various minerals . . .' (Pringle, 1970: 267n).

Sago production increased considerably, as a result of good prices, more settled conditions, and encouragement from the Government in Kuching, which required the revenue from the sago trade. By 1860 Malay traders were carrying raw sago to Chinese factories in Kuching from Oya and Mukah rather than sailing direct to Singapore (Pringle, 1970: 111). In 1890 Sarawak was said to supply half of the world's sago (Treacher, 1890: 28). Mukah and Oya remained the main centres but sago production was also important at Matu, Daro and other coastal localities (Boyle, 1865: 104; Denison, 1883: 180–186; Trevenen, 1891: 1). Sago expansion at Balingian was noted in 1875 (SG 96, 1875).

Such trade as had previously existed was largely in the hands of Malays, and Malay traders

continued to be important. In 1870, following a period of Iban unrest, it was noted, with reference to the Batang Rajang area that 'the inland trade, which is of considerable importance, has been resumed; and Malays are now venturing into the district in search of the valuable articles it produces' (SG 2, 1870).

As settled conditions developed, however, and particularly where Government forts and outstations were established, Chinese traders from west Sarawak entered the Area, built small bazaars, and quickly took over many of the trading functions. Following the establishment of the fort on an island at Sibu in 1862 a visitor wrote 'the only people on it, beside the Resident, were Chinese; who, although the place had not been occupied by the Government for more than a year, . . . had erected a bazaar and were importing every article, no matter how minute, which was likely to be useful, while they bought up any native commodity upon which they would calculate to make a cent . . .' (Anon, 1867: 63–64). The same description would have applied to a varied degree to many other small centres (Boyle, 1865: 99; Brooke, 1866: I, 327; Denison, 1883: 187; SG 46, 1872; SG 96, 1875; SG 1088, 1948: 218). Sibu, however, grew rapidly to promimence and was described as the 'largest outstation in Sarawak' in 1891 (de Windt, 1882: 64; Denison, 1883: 188; Trevenen, 1891: 3).

A population estimate of 1871 (SG 31, 1871) gave, for the Kalaka, Rajang and Mukah Residencies 596 Chinese, 20,852 'Dayaks' and 28,280 'Malays' (including Melanau). No great accuracy was claimed for this estimate at the time (the second figure quoted is certainly a gross underestimate) but the count of Chinese was probably close to the truth. The figures indicate that the Chinese population remained very small but had grown significantly over the previous 20 years. Of the 1871 total, 415 Chinese were in Rajang Residency and most of these were probably in Sibu. (Sutlive's reference to an unreasonably low' 45 Chinese in Rajang (1972: 92) at this time appears to come from a later misprinted source).

The Iban population grew considerably in this period. In about 1863 only four longhouses were noted on the Batang Rajang between Sibu and Kanowit, although 1,200 Iban were reported to be in the Kanowit drainage basin by that time (Anon, 1867: 67). In the Rajang area as a whole the Iban were said to have increased from 3,000 to 8,000 families between 1871 and 1909 (Baring-Gould and Bampfylde, 1909: 386). They had crossed the northern watershed of the Batang Rajang by 1870 (Pringle, 1970: 265) and many had settled in the Oya and Mukah headwaters by 1872 (Dension, 1883: 183). A few families reached the Balingian basin in this period but the main migration to that river took place in 1900 (Pringle, 1970: 273-274). The nomadic groups and settled communities previously in the Area either fled before the Iban advance, were attacked and decimated by Iban war parties, or, in some cases, continued to live alongside the Iban and were eventually absorbed by them. The Iban migration proceeded northward beyond the Area well into the present century and, wherever land regulations allow the opportunity, continues intermittently at present.

The late Brooke period (1900-1941)

Agriculture in the Area took on a new dimension following 1901 with the introduction of large groups of Chinese immigrant farmers of (T'ien and Ward, 1956; Sutlive, 1972: 90 et seq.) under contract agreements stemming from the Rajah's Order of 1880, referred to above. The first group of 603 Foochow arrived in 1901, and a group of 500 Cantonese in the same year. A further 500 Foochow came in 1902, and two Henghua groups in 1912 and 1914. All these immigrants were directed to the Sibu area. The present Chinese population in the Area (over 100,000 in 1970) largely stems from these groups or from relatives and others from the same areas who joined them from China later. The Foochow are particularly strongly represented. They are now the dominant Chinese dialect group in Sibu, Binatang, Sarikei, Julau and Kanowit Districts. Of the Foochow population in Sarawak, 77 per cent were within the Area in 1970.

The initial Foochow settlers were established at Sungei Merah, to the north of Sibu, but due to insufficient land, were allowed to extend to other localities nearby. They were directed to concentrate on rice cultivation as part of their agreement with the Rajah's Government. This was not a success for a number of reasons, important among which was the settlers' unfamiliarity with local farming conditions, flooding from the Batang Rajang and pests. Accounts of this endeavour are given by Hoover (1919), Chiang (1955) and Lin (1966).

The Cantonese group were more successful in planting pepper and the Henghuas spread their activities between rice, vegetables and rubber, (Sutlive, 1972: 94, 99).

While Hevea rubber was a new crop to the State at this time, pepper had a long previous history. It has formerly been a staple commodity of many parts of Borneo (Logan, 1848: 525-526) but falls in prices in the early 19th Century led to the abandonment of many gardens (Crawfurd,

1820: III, 358-359; Mundy, 1848: II, 348). In Sarawak its cultivation was largely confined to the Kuching area, where it was grown in conjuction with gambier by Malays and, more particularly, by the growing Chinese population. Within the Area it does not seem to have been planted to any large extent prior to the period of Chinese immigration described above.

Rubber, on the other hand, was a new introduction. One seedling was introduced to Kuching in 1882; a few seeds were planted out at Kapit in about 1900; the first commercial planting (in Bau District) was made in 1902; and by 1908 previous small-scale experimental plantings in the Sibu area were supplemented by large-scale seed production in west Sarawak, much of which was sent to Sibu (Anon, 1948; Tremer, 1964; Sutlive, 1972: 21-22).

From about 1908 there was a explosion of rubber planting in the Area, particularly in localities farmed by Chinese near Sibu. The initial Foochow colony, having abandaned rice cultivation, concentrated on pepper for a few years (following the example of nearby Cantonese farmers) but in 1908 turned to rubber as that crop, in addition to being obviously profitable, was both more tolerant of poor soil and drainage conditions and less demanding on the farmers' time and expertise. Pepper continued to be planted in areas with suitable soil conditions and its production became particularly concentrated in Foochow and Cantonese gardens in the Sarikei area.

The expansion of, and interest in, both rubber and pepper was highly dependant on the world prices for these commodities. The period of most rapid spread in rubber planting was probably 1910-1920, there being a slump in 1921, a boom in 1925, and a further slump in 1928, following which restrictions on tapping were legislated. The estimated acreage under rubber in the State as a whole had reached 220,000 acres by the mid-1920's (Sutlive, 1972: 23), but increased only to some 239,000 acres by 1937 (Anon, 1948) and to an estimated 240,000 acres in 1941 (Hepburn, 1949: 121). Of the 1941 acreage over 95 per cent was smallholding rubber. As a result of the Rajah's policies only five estates were in existence and totalled 10,580 acres. None of the estates were sited within the Area.

Pepper (SG 1088, 1948: 219; Kay, 1949; Ong, 1949; Sandford, 1952; de Waard, 1964) brought a high price until 1923 and encouraged many Chinese farmers to establish gardens where suitable soils occured. From 1923 onwards, however, violent price fluctuations affected this crop, the Singapore price for white pepper (per pickul) being $22 in 1923, $103 in 1929, and $22 in 1933 (Ong, 1949: 54). Gardens were abandoned when prices were low while there was a rapid expansion of land under pepper during a boom period, when farmers with little experience in growing pepper also cleared land for this crop.

Pepper was susceptible to a number of diseases, particularly an algal infection (called 'Black Berry' or Black Pod') which, in that period, could only be countered by abandoning the garden and planting a fresh area. The life of a pepper farm was considered to be about 6-8 years and after the Black Pod infection had taken hold entire localities might be abandoned for this crop, (Ong, 1949: 54). The centre of pepper production changed from Kuching District to 2nd Division, and then to the Sarikei-Binatang area as a result of these difficulties.

The labour requirements, financial outlay for planting material and poles, and the high risk factor due to disease entailed that pepper had little attraction to Iban or Melanau farmers and remained almost entirely a crop planted by Chinese during this period. The same was not true of rubber. Many Iban in the Area were quick to take up rubber planting. As Spurway (1937: 124) and Sutlive (1972: 22 et seq.) have emphasised, this crop had profound effects on the traditional economy of this group. A shift in values occurred, a new avenue to economic security was opened up, conflicts between the demands of rubber planting and traditional hill rice cultivation developed — commonly resolved by reference to the current market price for rubber sheets — and mobility was reduced (Sutlive, 1972: 24-29). The last point was particularly important to the development of the land-use pattern. Once Iban rubber gardens had been established, they were a disincentive to further migration and, to some degree, led to stabilising the distribution of the Iban and the land cleared by them within the Area. Many social and economic changes resulted; land shortage developed in some areas. One advantageous result was the opportunity for settled Iban to expand into other permanent crops during the post-War period.

These changes affected the downriver Iban most, however, and the Iban in the remoter areas continued to be oriented around traditional hill rice cultivation. Migration into such areas also continued but at a slower pace than in the 19th Century. In the mid-1920's Iban were planting rubber in the relatively isolated Balingian Basin but the exports from the Balingian interior remained largely rice and jungle produce (especially jelutong). Beyond the area to the north the

Niah river basin was first entered by the Iban to settle and clear for hill rice only in 1934 and they found there a prior population of aboriginal Punan nomads (Sandin, 1957), a situation similar to that on the southern Rajang watershed a century previously.

Sago continued to command a good market until the world recession and was encouraged by Government. An indication of the official priorities in the 1920's is the number of references to Iban clearing swamp land along the Batang Igan and Batang Oya for rubber, approval being given only after it had been confirmed that the land had not proved suitable for rice or sago (e.g. SG 868, 1926: 14; SG 869, 1926: 41). After the slump set in, however, there was a tendency for Melanau sago gardens in some areas, such as Matu (SG 1112, 1950: 287), to be cut out for replanting with rubber. Extraction of the starch continued to be done by traditional methods and remained largely a cottage industry, the raw starch being directed to Chinese refineries in Binatang, Saratok, Bintulu and Kuching (Ong, 1948: 212). The traditional methods of extraction are described in detail by Morris (1953: 23-32).

Rice production continued to fall short of demand and was affected by the world price for the export crops. When the rubber price was high all communities tended to abandon some of their rice cultivation in order to tap more rubber. In years when the sago price was particularly attractive, some Melanau sacrificed good rice soil to plant up more sago. When world prices were low, on the other hand, even Chinese rubber planters would abandon tapping to plant rice, which was then more profitable.

1942-1946

The Japanese Occupation affected some branches of agriculture more than others. There was a big local demand for starch of all kinds and, according to Ong (1948: 214), sago production continued under the control of a Japanese sago monopoly. It was reported to Morris, however, (1953: 155, 157) that many gardens were abandoned in the lower Oya in this period. Rice and rubber production were also encouraged. The bulk of the rubber in tapping was now old seedling material giving rather low yield. There is some doubt whether or not the acreage under rubber increased to any extent during the occupation (Hepburn, 1949: 121; Sarawak Government, 1960: 20).

Pepper gardens were neglected, on the other hand and by the end of the Occupation many pepper gardens had died out completely, although large stocks of berries were held by the farmers (de Waard, 1964: 24).

There was a steady drift from the urban centres into rural areas as the Occupation proceeded and subsistence cropping expanded to some extent as a result (Harrison, 1950: 355). In many localities soils which would not have previously been considered by farmers were patchily cleared for rice and other crops. Many abandoned clearances on Podzols (Buso and Miri Series) in the hill fringe zone probably date from this period. In the majority of cases cultivation of these unsuitable soils was abandoned at the end of the Occupation.

Post—1946 trends

Sarawak became a British colony in 1946 and gained independence as a State within the Federation of Malaysia in 1963. The colonial and subsequent State Governments have concentrated to a large degree on agricultural improvement and rational land development. A development plan was drawn up for the period 1947-1956, and was later revised to cover the period 1951-1957. A Rubber Planting Scheme was started in 1956 to introduce high-yielding planting material and expand the rubber acreage, an Assistace to Padi Planters Scheme in 1958, a Coconut Panting Scheme in 1959, and Land Development Schemes under the First and Second Malaysian Plans introduced in 1964. Two development schemes based on rubber were established within the Area at Meradong and Sibintek. A number of drainage schemes for improvement of present or potential wet rice or coconut areas have been implemented. A research Branch was added to the Department of Agriculture. Within this Branch, a Soil Survey Division was created in 1959 and an increased emphasis was subsequently given to soil survey prior to development decisions. A structure of development committees at District, Division and State level was instituted to channel requests and to coordinate agricultural planning with other aspects of development.

The pepper industry was reestablished soon after the Liberation and, despite pressure from Chinese farmers to open up new land, it remained concentrated in the pre-war pepper areas, such as Sarikei, as Government experimental work indicated that it was possible to develop techniques to rehabilitate such areas (Ong, 1949: 55). High pepper prices after the War encouraged rapid replanting of many abandoned gardens. By 1949 over 150,000 healthy vines were reported in Sarikei District and export of new berries resumed in that year (SG 1098, 1949: 215; SG 1107, 1950: 148; Hepburn, 1949: 121). Pepper exports prior to that had been of berries held by farmers through the Occupation (de Waard, 1964: 24).

There has been a general expansion of the pepper industry during the post-War period but it has not been regular. Prices have been variable and problems of disease continued, particularly a root disease ('foot rot') which became serious in 1953 and has remained a problem since then. Foot rot attack has been combatted mainly by cutting out the affected vines and those surrounding them.

Pepper cultivation has also spread to Iban areas. The high cost of establishing a garden has kept the gardens small but some pepper is now grown by Iban in many parts of the dissected lowland zone.

Rehabilitation of rubber land following the Liberation was rather slow, as rubber prices were erratic and generally not attractive. Most of the existing rubber was old and low yielding; much of it had been planted on deep peat — and the unsuitability of this medium was now recognised (SG 1090, 1949: 1-2; SG 1094, 1949: 117; Morris, 1949: 289). A boom in rubber in the early 1950's encouraged rehabilitation, however. The old rubber was brought back into tapping and new areas were planted up. In the last 20 years there has been a continuing trend to plant rubber, much of it being high-yielding material planted in Iban hill areas under Government assistance. Replanting of old rubber on the swamp plain has been negligible.

Rubber production has been highly dependant on the market price, and both old and new rubber tends to be tapped when the price is attractive and ignored in favour of other activities when the price is low. Tapping is especially variable in Iban areas as rubber and all other crops tend to be neglected during the hill rice planting and harvesting periods.

Sago production (Ong, 1948; Morris, 1953) was stimulated by a post-War shortage but this was followed by a slump and sago prices have been erratic but generally low for most of the period. The difficulties of the sago trade were compounded by a major client for Sarawak sago turning to maize flour as a starch source and by Sarawak sago developing a reputation for low quality. Further complications were added by the degree to which Melanau in some areas had become both completely dependant on sago for their income and indebted to Chinese middlemen. Mechanical raspers had been developed in the 1930's and many small sago mills were set up in the sago areas by Chinese during the post-war boom. The mill replaced the traditional method of starch extraction to an increasing degree, Melanau selling the log direct to the Chinese factory. The problems of the Melanau sago areas have received considerable attention from Government in recent years.

Some attention has been given to improvements in hill rice production by the isolation of improved rice varieties and experimental work with fertilizers, but most concern has been directed to opening up areas for increased swamp rice production. Government assistance has been employed at many levels, including both assistance to present wet rice farmers in riverine tracts and the construction of large drainage schemes in coastal areas. The latter include four schemes within the Area. None of these have yet reached the stage where their efficiency can be judged.

There has also been an increased emphasis on coconut development in coastal areas. Three drainage scheme projects within the Area, in localities where the dominant soils (Tatau, Matu and Igan Series) are unsuitable for rice, have been implemented with coconut planting in view.

The majority of the soil surveys which the writer undertook at a semi-detailed level were requested by the Divisional Development Committees or the Ministry, in order to assess the viability of proposals for development within the scope outlines above. Most such survey projects concerned proposals for swamp rice, coconut or rubber development.

One must also mention, in connection with the post-War period, the development of the timber industry. Sporadic export of timber from the Batang Rajang area occurred as early as the 1960's and this developed into a steady trade in the present century, growing particularly in periods when the rubber price was low, (SG 1049: 143; Sutlive, 1972: 34-38). After the Second World War changing demand focussed attention on the *ramin* softwoods (*Gonystylus spp.*) of the peat swamp forests. These had previously been ignored in favour of harder *meranti* (*Shorea spp.*) and *kapor* (*Dryobalonops spp.*). There was increased investment in logging and milling plant and the State's *ramin* exports rose from 17,000 tons to 336,000 tons between 1950 and 1960 (Sutlive, 1972: 39). The extraction of *ramin* is largely concentrated in the extensive swamp forest tracts of the Area and although the timber industry is monopolised by Chinese companies logging and sawmill operations provide employment to a large number of Iban and Melanau and for the rural male population offer the main alternative to agricultural employment in the Area (Fig. 54).

The growth of the timber industry to prominence can be indicated by the following export figures for the State: the percentage of exports provided by agricultural and timber exports respectively were 26.0 and 10.4 in 1962, 25.2 and 19.1 in 1965,

11.5 and 30.0 in 1968 and, following a slight recession in the timber trade, 12.8 and 22.3 in 1972 (from figures supplied by the Department of Statistics). The balance of exports in these years were largely provided by the oil industry in north Sarawak.

Land Ownership And Legal Status

Pressure for land by both Iban and Chinese, coupled with differing attitudes to land ownership among each cultural group, led to the growth of a complex system of land laws. The development of these has been detailed by Porter (1968). The present structure of land status has been summarised in a number of publication (e.g. Department of Lands and Survey, 1967). The land categories are described briefly below; the legal definitions are given in the Laws of Sarawak (Sarawak Government, 1958; 4: 177-350). For the purposes of land legislation a distinction is made between natives (Malay, Melanau, Iban, etc.) and non-native (including Chinese).

Land is at present considered to be in one of five legal categories (the Land Code);:

Native Area Land: only natives can occupy and hold title to land in this category.

Mixed Zone Land: Both natives and non-natives may occupy and hold in this category.

Within both these categories are parcels of land held by natives under customary tenure which are unsurveyed and without title. On title being issued they would be classified as Mixed Zone or Native Area Land, whichever applies.

In addition, however, there are large tracts outside both these categories held by natives under customary tenure. Such land is considered to be in a third category:

Native Customary Land: It is the future intention to survey and issue title in areas within this category, following which they will be classified in either Native Area or Mixed Zone Land categories. With regard to restrictions on ownership Native Customary Land is similar to Native Area Land until such time as its status is defined otherwise.

Reserved Land: Land reserved by Government for various reasons, largely comprising Forest Reserves and Protected Forests. The former are fully protected, subject to any rights and privileges conceded when the Reserve was Gazetted. Reserves may not be entered without official authority. Protected Forests are open to the public but only natives may remove timber or other produce without a licence (SG 1099, 1949: 269).

Interior Area Land: Land which does not fall in any of the four categories detailed above. Under recognised Iban (and other) customary laws a native establishes rights to land if he clears it from primary forest and it may be expected that Native Customary Land would extend at the expense of Interior Area Land through continued clearance. It has, however, been made illegal for many years for natives to clear any remaining primary forest without Government authority and this authority is now rarely given. Interior Area Land largely comprises forest tracts on the swamp plain and in the mountainous interior which have not been gazetted as Protected Forests or Forest Reserves.

Agricultural use is confined to the first three categories listed. Within those categories there is generally no limitation (outside land parcels in urban areas) on the type of use and there is theoretically no reason for the legal category to affect the land use pattern within these areas. In practice the restriction of Chinese land ownership to Mixed Zone Land does influence the land use pattern considerably, as the grestest diversification of agriculture and intensity of use is found in Chinese farming areas.

Not all Mixed Zone Land areas are dominated by Chinese as there is commonly strong resistance among natives to sell their land. It may be noted (Fig. 55) that the area centred on Mukah is Mixed Zone but that this is almost exclusively populated by Melanau farmers (Fig. 52).

The effects of the Land Code are instanced by present trends in areas crossed by new roads. Where a road has been put through Native Area Land or Native Customary Land agricultural development stimulated by the improved access to markets has been slow, and the basic agricultural pattern largely remains traditional subsistence cultivation with some rubber. It is to be expected, of course, that this will change with time.

The distribution of land categories within the Area is shown in Fig. 55. It is apparent that many of the Mixed Zone units were created in acknowledgement of an already existing situation. Native Customary Land units do this in all cases. But many divisions do not reflect these realities in any obvious fashion. Nor, except for Reserved Land, do they conform to either natural features, land potential, or the present aims and opportunities for development. The pattern of land categories has apparently grown over the years following decisions taken in the light of factors considered important at the time; many of these factors no longer apply. The Land Code, therefore, is yet another component of the cultural landscape in the Area which modifies the land use pattern but is unrelated to soil potential.

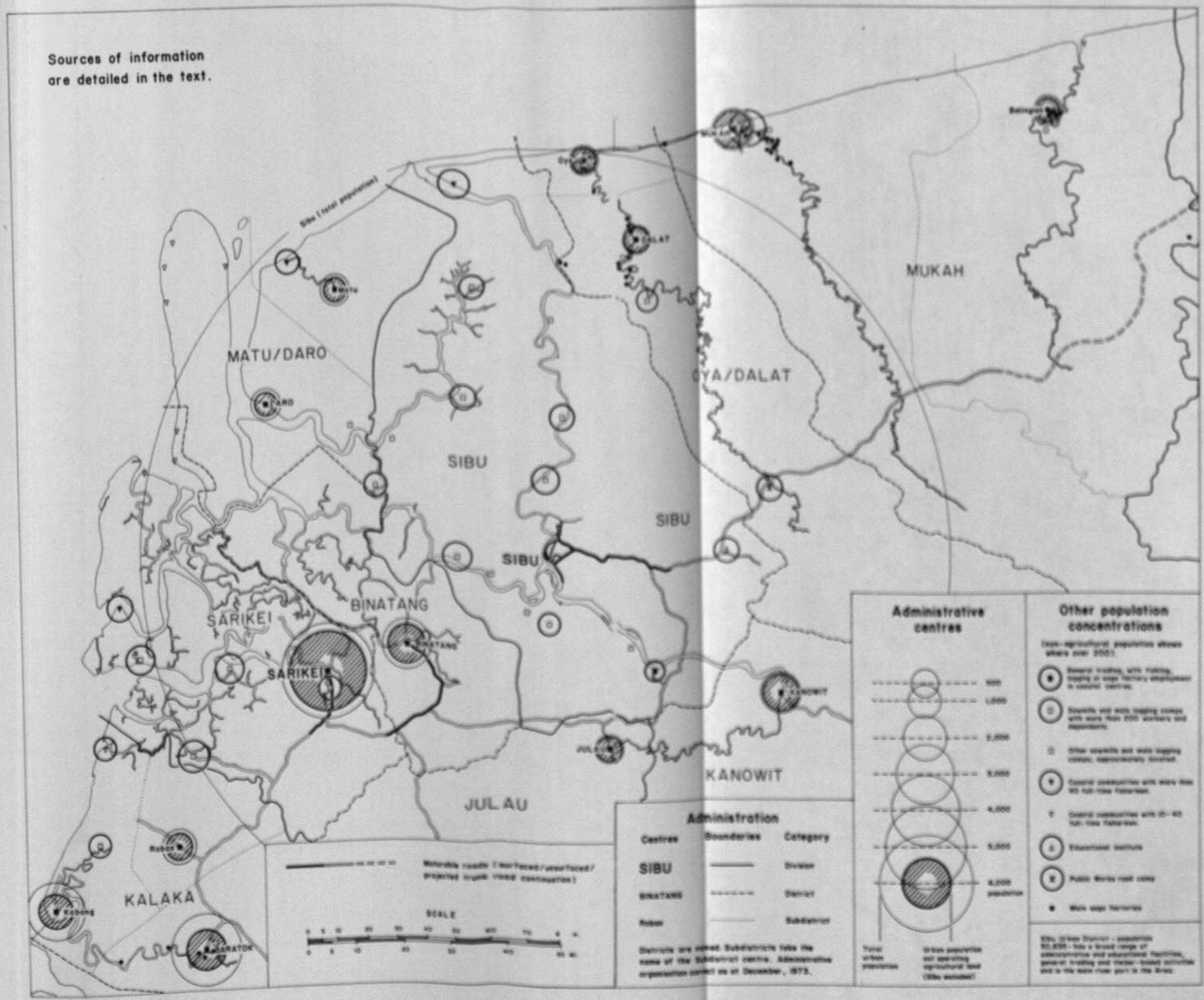


Fig. 54 Urban and other non-agricultural population concentrations

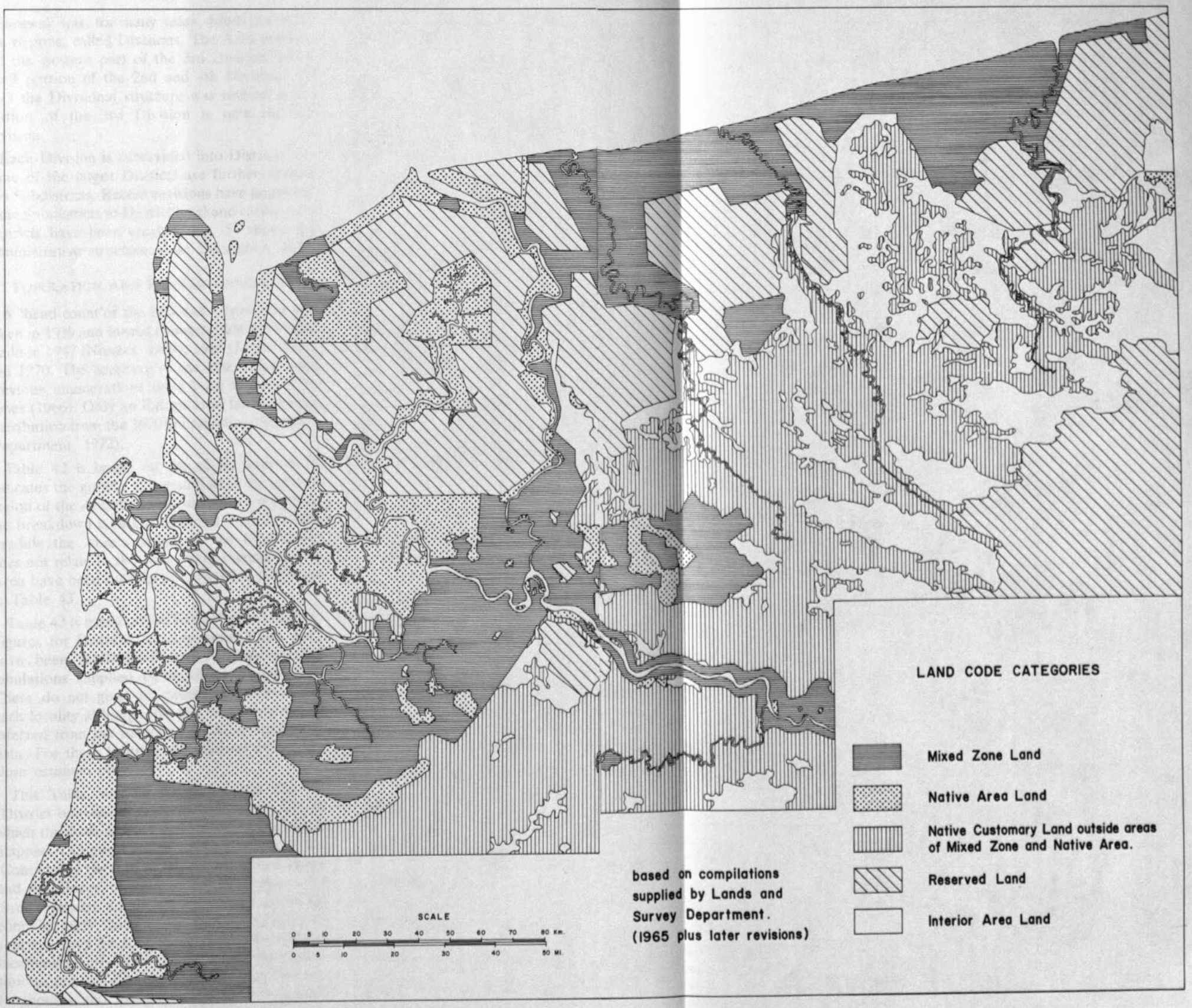


Fig. 55 Land classification

Administration

Sarawak was, for many years, administered in five regions, called Divisions. The Area comprised the western part of the 3rd Division and a small portion of the 2nd and 4th Divisions. In 1973 the Divisional structure was revised and a portion of the 3rd Division is now the 6th Division.

Each Division is subdivided into Districts and some of the larger Districts are further divided into Subdistricts. Recent revisions have upgraded some Subdistricts to District level and certain new Districts have been created. Fig. 54 shows the administrative structure as at December, 1973.

Population And Present Land Use

A 'head-count'of the Sarawak population was taken in 1939 and formal enumerations have been made in 1947 (Noakes, 1950), 1960 (Jones, 1962) and 1970. The accuracy of the 1960 census and previous enumerations have been discussed by Jones (1966). Only an Extract is so far in general distribution from the 1970 enumeration (Statistics Department, 1972).

Table 42 is based on the above sources. It indicates the growth in population in the general region of the Area but it should be noted that, as the breakdown is in Districts and some Districts straddle the Area's boundary, the total figure does not relate to the Area itself. Figures for the Area have been recalculated from the 1970 data in Table 43.

Table 43 is based on the Extract quoted above. Figures for Districts partially outwith the Area have been recalculated from original locality tabulations supplied by Statistics Department. These do not give the cultural breakdown for each locality although this can be approximately inferred from the names of headmen and other data. For these Districts the cultural details are close estimate only.

This Table may be compared with Fig. 52 (District boundaries being shown on Fig. 54), in which the dominant cultural or language group is mapped. ('Cultural groups' are equivalent to the 'Community Groups' of the census nomenclature and the 'Races' of Registration Department: all three terms are unsatisfactory.) The writer has compiled this distribution from a number of sources, using the framework of the enumeration localities. Names of headmen given in the tabulations were a useful guide. The distinction between longhouses and kampongs on the topographic maps generally equates with Ibans as opposed to Malays and Melanau. The separation of Melanau and Malays is more difficult. For this purpose Malays are taken to be those who speak Malay rather than Melanau and who consider themselves, and are generally considered by others, to be Malay. The locality tabulations made available to the writer give no assistance on this point and the writer has mainly relied on the knowledge of three Soil Survey Assistants, two Malays (one from Kabong) and one Melanau (from Matu), who have been engaged on survey projects in many coastal and delta localities.

Distribution in Fig. 52 has been mapped in relation to agricultural land, not settlements. Chinese bazaar communities are present in all settlements of any size and have been ignored except in the case of the main towns where the bazaar and kampong can be differentiated at this mapping scale.

Of the 'indigenous' groups, 84 per cent of the Melanau in the State live within the Area but, although more numerous in Sarawak as a whole, only 39 per cent of the Iban are found here, an indication of the degree to which the Iban have spread throughout the State. Less than 14 per cent of Sarawak's Malays are found in the Area, where they comprise less than 10 per cent of the population and, as Fig. 52 shows, are confined

Table 49

Trends in total population in selected Districts.

	1939[1]	1947[1]	1960[2]	1970[3]
Mukah	31344	34627	38724	29377
Oya/Dalat				18057
Sibu (urban)	42328	9983	29630[4]	50635
Sibu (rural)		40102	47652	47679
Kanowit	23117	26564	41588[4]	25937
Julau				21929
Sarikei	47658	52450	28154[4]	34405
Binatang			34693	25428
Matu/Daro				14174
Kalaka	19682	21262	24612	30010
Total	164129	184988	245053	297631

(1) Noakes (1950); (2) Jones (1962); (3) Statistics Dept., (1972); (4) boundary change since previous enumeration.

largely to Kalaka District and near the main towns.

The Chinese population is varied. Foochow predominate in Sibu, Binatang and Matu/Daro Districts, Cantonese and Foochow in Sarikei, Julau and Kanowit, Hokkien in Kalaka, and Hokkien and Foochow in both Mukah and Oya/Dalat. Although one dialect group tends to be dominant in each locality all are present in each District and there is considerable mixing. Hakkas, Henghua, Teochew and Hainanese are also present, among others.

The main centre is Sibu with a population of over 50,000 (75 per cent Chinese) and the economic life of the Area tends to revolve round this town. Other District centres are much smaller (Table 1.6 and Fig. 54): only 24 per cent of the Area's population live in the six largest centres (19 per cent are in Sibu itself). The population is thus predominantly rural.

The agricultural population and main land-use types

Statistics Department kindly allowed the writer access to certain locality tabulations from the 1970 census. These include the following details from which an estimate of the agricultural population can be made: the total population of the enumeration locality, the total number of households, and the number of households operating land. By definition 'operating land' included households working on agricultural land, whether or not they owned it, and excluded households owning agricultural land if they were not 'operating' it at the time of the census (such as mature rubber land which was not being tapped). Also excluded were owners of land operated by others, if the owner's main income came from elsewhere (as in the case of a Sibu businessman owning a pepper garden and paying labour to work it).

On a household basis, therefore, the 'operating land' category should give a realistic reflection of that part of the population dependent directly on the land for the major part of its living.

The approximate 'agricultural population' for each locality was derived from this data by assuming households of equal size and reducing the total population in proportion to the number of 'agricultural households'. This estimate is not sufficiently accurate for tabulation but is close enough to the truth to show relative population densities when converted to a dot map (Fig. 53). This was prepared on 1:50,000 scale plots of the enumeration localities, on which the boundaries between localities could be approximately estimated from land use and topographic data.

To complete the population picture the main non-agricultural population concentrations and the centres of commercial and other activities offering alternatives to dependence on agriculture are indicated in Fig. 54. Sawmills and logging camps are based on a map supplied by Forest Department, the main fishing communities plotted from Marine Fisheries Department data (Marine Fisheries Department, Sarawak, 1972) and sago factories from data compiled by the Agricultural Economist. Population circles and the distinction of urban population 'not operating agricultural land' are based on the same 1970 census source as the agricultural population plot of Fig. 53. Only one educational institute is shown. At least one other rural institute is probably of sufficient size to warrant inclusion but is not specifically identified in the enumeration locality tabulations.

The isolation of the 'agricultural' component of the population justifies location of the population dots on Fig. 53 in relation to the land used by community rather than to the location of their permanent settlements. This gives a closer approach to reality than previous maps of this kind as, while most cultural groups operate land over a wide area, their permanent settlements are commonly rather nucleated. The Iban typically live in longhouses sited near rivers and built temporary huts which are occupied in the farming season near the land cleared that year for hill rice. This may be some miles away from the longhouse. The Melanau and Malays live in villages of individual houses which are normally clustered, particularly in Malay areas, near the bazaar or river mouth while they farm land extending back some distance from the settlement. In the case of the larger bazaars this 'suburb' is considered part of the urban unit although its population is essentially agricultural. In Malay areas the agricultural kampong may comprise most of the urban unit (cf. the 'urban' and 'agricultural' populations of Kabong and Saratok, for example, with those of Balingian and Kanowit in Fig. 54). Only rural Chinese tend to live in individual permanent houses on their own land and only in the case of this group does the settlement pattern generally reflect the location of holdings.

The distribution of the agricultural population may be compared with that of land use (Map 4). Map 4 is based, with a few amendments, on 1:250,000 land use maps published by the Department of Lands and Survey (Sarawak Series No. 22). For sheets covering the Area, this series shows the land use pattern in 1965. Apart from the inevitable generalisation at this scale, some

Table 50

Population of the Area by cultural groups, main urban centres and Districts (1970)

	Indigenous					Chinese	Other	Total
	Malay	Melanau	Iban	Other	Total			
Kalaka District (part) and Saribas District (small part)								
Saratok	2445	13	425	19	2902	1151	13	4066
Rest*	7137	27	11280	9	18453	1437	15	19905
Sarikei District								
Sarikei	1599	92	142	35	1868	3470	105	5443
Rest	1225	5515	8111	40	14891	14046	25	28962
Binatang and Matu/Daro Districts								
Binatang	95	24	320	10	449	1826	13	2288
Rest	2804	13324	8716	44	24888	12409	17	37314
Sibu District								
Sibu	7385	1816	2350	395	11946	38161	528	50635
Rest	1379	4633	16647	98	22757	24906	16	47679
Kanowit (part) and Julau Districts								
Kanowit	275	16	170	12	473	1244	21	1738
Rest*	118	192	20660	562	21532	3442	111	25085
Mukah, Oya/Dalat and Bintulu (small part) Districts								
Mukah	90	192	52	11	345	1342	30	1717
Rest	420	18867	22673	572	42532	3517	34	46083
Total	24972	44711	91546	1807	163036	106951	928	270915
per cent frequency	9.2	16.5	33.8	0.7	60.2	39.5	0.3	

* total correct; other data estimated.

misrepresentation results from the fact that the detail is derived largely from air photo interpretation. Areas mapped under secondary growth, for example, include some land near the main rivers which was fallow at the time of photography but used for swamp rice later in the year. With these reservations, however, the dominant land use over broad localities is clearly brought out.

The population density is high where swamp rice is grown on the same land in most years (as at Saratok, Matu, middle Batang Oya, for example). It is also high where pepper is an important crop (as near Sarikei and Binatang). The density in swamp rice and pepper areas is in marked contrast to that in areas which are exclusively devoted to the shifting cultivation of hill rice.

In interior areas close to a main river, however, the density rises even though the population is dominantly Iban and hill rice the main crop. In such areas riverain tracts of alluvial soils (Seduau, Bemang, Bijat and Mukah Series, in particular) are present and some rubber, fruit trees and pepper are grown, together with a little swamp rice in suitable locations. A higher population density is therefore possible.

Where rubber is dominant the position is rather complex, as the main areas are near Sibu and have been affected by recent security problems. The population density shown in Fig. 53 for the Binatang-Sibut-Bawang Assan area reflects the situation at mid-1970 but not necessarily at other times. When the census was taken the security problem was not great and a large population was resident in the area. The rubber price was low, however, and much of the rubber was not being tapped. Many of the male population had left for

Sibu, logging camps, or other places where paid work was available and part of the resident population in these localities was dependent on money sent home by them. Such households were not 'operating land' when enumerated. A census at an earlier date when rubber-tapping was more attractive would have indicated a much higher 'agricultural' population although the actual total population had changed to only a small degree. For a period during 1972, on the other hand, the security situation in some of these localities deteriorated to the point where the population as a whole abandoned their holdings temporarily and moved to Sibu or other riverbank settlements. A census at that time would have shown almost no households 'operating land' in such areas.

It must also be noted that a significant proportion of the population living in old rubber areas on deep peat near Sibu raise pigs and poultry for the Sibu market and that the rubber is a secondary consideration to them.

Estimating the 'agricultural population' of Sibu itself presented difficulties. Sibu Urban District was tabulated in a different form from other non-urban units and the writer did not have access to data on households operating agricultural land. A number of rubber and pepper gardens are within the urban boundary. In 1960 a total of 8094 'farm population' were recorded in Sibu but the agricultural holdings within the urban area, totalling 11276 acres, were largely under rubber (Sarawak Government, 1960: Tables 4, 7 and 13). 'Farm population' was not fully defined, it was not stated whether the agricultural land worked by them was exclusively within the urban area and, in view of the rubber market in mid -1970, it is likely that the number of people engaged in rubber-tapping at that time was much less than in 1960. A nominal 100 dots (2,500 people) were entered for the Sibu Urban District in Fig. 53. The immediate hinterland of the town is thus emphasised considerably. This is probably justified. The actual figure is likely to be higher than the arbitrary one chosen, rather than lower.

Population densities related to different forms of agriculture are difficult to establish from the information availabe but some estimates can be made from the 1970 census data. A number of localities were selected in which (a) the land use did not vary much, (b) the boundaries to the locality could be established with reasonable accuracy (in each case a number of adjacent enumeration localities were grouped as one for this exercise) and (c) the dominant cultural group or mixture of groups was the same throughout. The acreage of the selected area was calculated from the 1:50,000–scale topographic maps and referred to the estimated agricultural population derived from the household data as described above. Calculated population densities for these localities are given in Table 44.

These figures must be treated with reserve. Households operating land are not necessarily without other sources of employment and income although, as Fig. 54 indicates, such opportunities are greatest in downriver areas. An Iban community recorded as operating land in the interior is more likely to be an exclusively agricultural group than an equivalent Melanau community on the coast. In Table 44 the high figures for the Paloh and Telian localities are particularly suspect for this reason. At Paloh there is a significant fishing population and some opportunity for timber work. At Telian fishing and sago factory employment are both possibilities. Such work may overlap with the operation of agricultural land. As stated above, the definition of 'households operating land' aimed to exclude such households unless agriculture was the main employment and much depends on the accuracy with which this rather difficult definition was applied during the enumeration. It is possible that the agricultural land used by these communities has been underestimated by the writer. At present it can only be said that the figures for these localities seem a little high.

The figures for Kenyana and Pakan, on the other hand, seem very low. It is probable that in these localities the writer has included some land under secondary growth which is, in fact, abandoned and no longer part of the land-rotation system. The population density in relation to the land which the farmers consider as 'agricultural' is probably higher than calculated. The same may apply to ulu Buloh.

Nevertheless, considering that the calculated densities are derived from a number of approximate or tangential variables, it is noteworthy that where the cultural group and land use types are broadly comparable the density figures are also quite consistent in most cases. This suggests that this exercise has some validity and that the following statements can be made with a fair degree of confidence:

(1) In Iban areas where shifting cultivation of hill rice is dominant the agricultural population density is generally 30–40 per square mile of agricultural land.

(2) Where the land potential or proximity to more developed areas has encouraged diversification into rubber, pepper and swamp

Table 51

Approximate density of agricultural population in selected localities

Subdistrict	*Locality*	*Soil mapping units*	*Dominant cultural group*	*Main Crops* (1)	*Agricultural population density* (2)
Dalat	ulu Tamin	11, 39	Iban	H.R.P.	30
Mukah	Kenyana	11, 17	Iban	H.R.p.w.	16
Balingian	ulu Buloh	10	Iban	H.R.p.w.	21
Julau	Pedanum	5	Iban	H.r.p.	32
Julau	Pakan	5, 13	Iban	H.r.p.	10
Mukah	Selangau	5	Iban	H.r.p.	18
Dalat	ulu Oya	4, 11	Iban	H.r.	38
Mukah	ulu Mukah	4, 11	Iban	H.r.	33
Saratok	ulu Awik	8, 26	Iban	H.R.p.w.	60
Roban	ulu Seblak	13	Iban	H.R.p.w.	39
Kanowit	Ranan	5, 39	Iban	H.W.R.p.	67
Sibu/Julau	ulu Naman	5, 25	Iban	W.R.h.	48
Dalat	ulu Baoh	11, 16, 17	Iban	H.W.R.p.	28
Binatang	Loba Semah	30, 31	Iban/Malay	W.c.r.s.	55
Dalat	middle Oya	26	Melanau/Chinese	W.R.	98
Mukah	middle Mukah	25, 31	Iban	W.R.	137
Saratok	Lower Krian	30, 31, 34	Malay/Iban	W.c.	118
Pusa/Kabong	Batang Marau	27, 31, 34	Malay	W.c.	133
Matu	Matu	26, 31	Melanau	W.c.	114
Binatang	Tekajong	30, 31, 34	Melanau	W.c.	259
Sarikei	Paloh	30, 31	Melanau	W.c.	340
Mukah	Telian	25, 31	Melanau	S.c.	279
Binatang	Kelupu	13, 15	Chinese	P.R.w.	248
Sarikei	Bulat road	15	Chinese	P.R.w.	258

(1) Upper case: general crops of the area; lower case: restricted, some households only. H - hill rice. W - swamp rice. R - rubber. P - pepper. S - sago. C - coconut.

(2) per square mile of agricultural land.

rice, the density tends to rise, but as shifting hill rice cultivation remains part of the agricultural pattern it generally does not rise above 80.

(3) Regardless of the cultural group involved, where swamp rice is the main crop and no hill rice is grown the density rises to 100–150. In some Melanau areas it may apparently exceed 200 but this requires further investigation.

(4) Where the population is dominantly Chinese and pepper and rubber are the main crops a density of about 250 persons per square mile can be expected.

While the foregoing discussion is confined to the crops of major importance in the Area it must be emphasised that agriculture is not restricted to these crops. An indication of the diversity of minor crops grown is given in Table 45. This is compiled from a report on an agricultural census (Sarawak Government, 1960) carried out in conjunction with the 1960 population census. It was based on a sample of some 11,000 holdings within the State. The results were not of great accuracy (the notes attached to Table 45 are taken from the report itself) and the figures are only of comparative value. While, for example, it is probably correct that very little pepper was grown in Mukah District at that time, it is unlikely that there was absolutely none.

The undifferentiated temporary crops include groundnut, soya bean, sweet potato and tobacco. Tapioca is commonly grown following hill rice in some areas. Some vegetables are grown by most communities but the main concentration is near the urban centres. The high figure for citrus in

Binatang District results from extensive plantings of tangerines near Binatang itself, on Pendam Series and shallow peat soils. These plantings support a local soft drink bottling industry.

Relationships Between Crop and Soil

Pepper

Pepper is sensitive to soil and drainage conditions and requires a well-drained medium with low acidity and high fertility. The practice in Sarawak is to achieve this by restricting the crop to moderately well-drained and well-drained (rarely imperfectly drained) soils with fine silty or clayey (rarely fine loamy) textures, and by planting on mounds of improved material.

The soil series most associated with this crop within the Area are Merit, Jakar, Bekenu and Sarikei. As there is no tap root, the root system is weak, and the use of mounds decreases the limitations of shallow rooting depth, Lalis and Kapit Series are also used for pepper in some areas, particularly where they occur in complex association with deeper soils. On the levee of the Batang Rajang pepper gardens are established on Seduau and Bemang Series on sites where they are at risk from only very rare flooding. Lighter-textured soils such as Nyalau Series tend to be avoided where medium-and heavy-textured soils are available but they are used in some localities. The grey upland soils (Kerait Series, Bandang

Table 52

Crop acreage estimates for selected Districts in 1960 (from Sarawak Government, 1960)

	Kalaka	*Sarikei*	*Binatang; Matu/Daro*	*Sibu*	*Mukah; Oya/Dalat*	*Kanowit; Julau*	*Notes*
Swamp rice							
irrigated	-	46	31	-	21	-	
not irrigated	5063	1719	4381	3698	1331	2446	(1)
Hill rice	6488	3182	1758	691	18700	15906	(1)
Maize	993	337	43	24	125	1334	
Tapioca	694	37	27	53	24	928	
Vegetables	171	52	91	236	48	35	
Other temporary crop	210	128	93	40	21	93	
Coconut	1246	131	85	168	230	11	(2)
Pepper	86	1183	362	178	-	78	
Sago	1199	853	1281	459	28261	46	(2)
Ordinary rubber,							
immature	6789	4525	9977	114	15874	36348	(2, 3)
mature	18531	10831	21622	48065	9428	22321	(2, 3)
Clonal rubber,							
immature	1632	5488	1778	284	618	2075	(3)
mature	15	110	64	416	161	15	(3)
Coffee	1	48	-	-	-	8	
Bananas	94	9	143	64	132	24	
Citrus	8	45	579	136	6	2	
Pineapple	36	131	152	41	87	27	
Other fruit	104	176	358	545	144	186	
Fallow land	344	4279	7282	1488	38122	1544	(4)
Grazing land	64	43	2012	360	488	30	
Jungle land	2383	3085	14275	611	2959	759	(5)

Notes:

(1) census figures adjusted against other information.

(2) believed to be underestimated.

(3) 'accurate data for dividing the rubber acreage into mature and immature is not availale for the time of the census'.

(4) land previously cultivated, now in fallow; period of rest not more than 3 years.

(5) Unused but part of a holding or owned jungle land set aside for timber, wood, or other forest produce. This unit does not include fallow hill rice land, which is not covered by the Table.

Series, etc.) are generally avoided. It is reported by some farmers that the pepper poles supporting the vines suffer more from termite attack in these soils than in more iron-rich series. (If correct, this is an important limitation as the cost of hardwood poles for a pepper garden was at January, 1974, approximately M$ 1,750 per acre). Material from a 'good' pepper soil may be transported to build mounds for a garden on a 'poor' pepper soil, and the crop is heavily dependent on added fertilizer; occasional gardens are therefore seen on most soils, including coastal sands (Fig. 35) and peat. In general, however, the pepper farmer seeks a well-drained, upland, iron-rich clay loam or clay: a 'red soil' is a 'pepper soil'.

Traditionally, pepper mounds were built from a mixture of topsoil and subsoil combined with 'burnt earth'. The latter is mixed wood ash and baked topsoil material, giving a greater available nutrient supply and a higher pH than the unbaked material. In recent years 'burnt earth' has been largely replaced by commercial additives and is generally only supplied in small quantities in the first 18 months of growth. It is stated (de Waard, 1964: 28) that until 1941 it was normal to apply some 40 lbs 'burnt earth' per vine twice a year, plus bean cake, prawn refuse, gambier leaves and other sources of nitrogen. At present mature vines generally receive (per vine per annum) 3–4 lbs blood-and-bone meal, 1.5 lbs groundnut cake, bean cake, fish meal or prawn refuse, and 0.5–1 lb inorganic fertilizer.

In optimum conditions a yield of 7,000 lbs per acre green pepper can be expected in the first harvest (third year), rising to 12,000–16,000 lbs in the sixth or seventh harvest, after which yields decline. No close correlation between yield and soil series has been seen. The low natural fertility of Sarawak soils, combined with the heavy applications of additives required by this crop, indicates that the character of the initial soil is a relatively minor factor in influencing performance provided the appropriate texture and drainage requirements are met. A well-drained surface soil is particularly important, however, as once a garden is attacked by foot-rot the disease is spread more quickly where contaminated surface water moves freely.

The susceptibility of pepper to disease, especially on poorly drained sites, and the need for appropriate material for 'burnt earth' production, led pepper farmers to develop strong opinions on what was and was not a good pepper soil. Despite the fact that most nutrient requirements are now derived from added fertilizers and organic compounds, there is a close relationship between the distribution of pepper gardens and that of red or yellow upland clays and clay loams.

Rubber

Rubber, on the other hand, was considered — with some justification — to grow in almost any soil medium. The distribution of pre-War rubber plantings reflects land availability at the time, the distribution of Chinese farmers and of those Iban farmers settled in areas without much hill land for shifting rice cultivation (such as near the Batang Igan). It bears little relation to the soil pattern.

The largest rubber tracts extend back from both banks of the Batang Rajang between Sibu and Bawang Assan. Here the zone of well-drained riverain alluvium is generally confined to the river bank itself and is rarely more than 100 yards broad. The transition through poorly-drained alluvium to deep peat is rapid and most of the rubber is growing on peats deeper than 3 metres. This is also the case near Matu and Daro. Where more appropriate hill tracts occur rubber may also be established but in many cases isolated hills in peat areas had already been located and claimed by Iban for rice cultivation or, if very small (cf. Plate 16), have been used to site the farmhouse, pepper gardens or orchards.

Drains were dug through the swamp following clearance of the forest for rubber but these were, judging by their present condition, usually shallow and ineffective. Some peat shrinkage has occurred and rubber roots are exposed at the surface in many localities but, in general, the trees are growing in an almost permanently waterlogged medium. It is to be expected that drainage measures were more effective near the main river than in the interior of the swamp but the riverine tracts are also those most subject to periodic inundation from the river itself during flood periods. Near Durin some rubber tracts were reported to suffer flooding to a depth of 5 feet at least once in most years.

Post-war plantings, particularly those under the Rubber Planting Scheme, have been confined largely to hill soils, and terracing is generally practised. Many of these plantings are also of improved clonal material and fertilizer is applied. Where the planting is established under a Government assistance scheme some control over the choice of site is exercised and this was made a routine requirement for large-scale consolidated plantings under Rubber Planting Scheme 'B'. Most such schemes were established following semi-detailed soil survey. Recommended areas for planting were confined to moderately deep red and yellow soils in the Merit, Bekenu and Nyalau Families or to well-drained alluvium.

Slopes were limited to 25°, and to 20° in the case of light-textured soils such as Nyalau Series. It was recommended that the grey and white upland soils be avoided unless in complex association with other more suitable soils.

In practise, while a number of semi-detailed soil surveys have been conducted with rubber schemes in mind, both of the R P.S. 'B' schemes in the Area were established without prior investigation at this level. The scheme at Meradong includes many tracts of leached light-textured soils and that at Sibintek extends onto excessively steep slopes.

In 1966, when rubber prices were attractive and most mature trees were in tapping, the writer conducted a rough survey of yield in relation to soil characteristics from old rubber in the Oya Road and Julau areas. Yield data were based on the farmer's estimate of the number of trees and the katis of sheet produced per month. They are thus of limited accuracy but in relative terms the survey was interesting as all trees were 20–30 years old (in a few cases 40–50 years), no fertilizer was applied, and the yield is thus likely to strongly reflect inherent soil characteristics and drainage. Relative yield for those gardens which proved to be sited entirely on one soil series are given in Table 53.

Table 53

Approximate relative yield of old rubber on various soil series

Soil Series	*No. of farms sampled*	*Reported yield in relative units*
Merit; Lupar	3	100
Seduau; Bemang	17	94
Bijat; Pakan	7	87
Kerait; Bandang	13	76
Bekenu; Nyalau	8	75
Anderson	17	56
Buso	3	35

The results support the assumption that yield is lower on peat land and Podzol terraces than on upland soil and that, within the latter, light-textured upper subsoils tend to be droughty and reduce latex flow, a point confirmed by some farmers interviewed.

Actual yields vary considerably from year to year, both in seedling and high-yielding rubber gardens. The number of tapping days is dependent on the time given to other crops and on the incidence of early morning rain, in addition to the state of the rubber market. A number of studies in selected gardens (in none of which was a relationship between yield and soil investigated) suggest an average annual yield of between 220 and 300 lbs per acre for unselected seedling rubber and between 500 and 880 lbs per acre for high-yielding material (Department of Agriculture, Sarawak, 1972: 27; Agricultural Economist, unpublished data).

Sago

Like rubber, sago tolerates a wide range of soil and drainage conditions and can be grown on well-drained riverine alluvium (Seduau and Bemang Series), poorly-drained clays (Pendam and Bijat Series) and shallow and deep peats (Mukah and Anderson Series). It is general Melanau opinion, however, that mineral soils are a better medium than peat (Morris, 1953: Appendix A). Palms grow taller on peat but mature more slowly (20 years rather than 15 years on riverine alluvium) and have less starch content. The Melanau also consider that no soil exhaustion results from sago cultivation and that old gardens are as productive as new ones. No formal experimental trials have been undertaken to confirm these opinions, although spot analyses (Agricultural Chemist, unpublished data) do suggest a lower starch content from palms on peat than on alluvium.

Despite these views the attractive returns from sago in the past have encouraged the Melanau to plant sago on all available soils on which it is likely to grow. Only sands and strongly saline clays are avoided. The practical difficulty of extracting the log after the palm is cut appears to be a more important factor in limiting the spread of gardens away from the main streams than the increasing depth of peat. Where deep peats approach close to a meander of the main river, as commonly occurs in the lower courses of the Batang Oya (Fig. 14) and Batang Mukah, they are likely to be used for sago together with mineral alluvial soils, but most gardens are located within one mile of a major waterway regardless of the soil pattern.

Yield data are difficult to estimate. A new garden may be cleared completely of forest and suckers planted on a 24 × 24 or 36 × 36 feet grid. This is highly variable, however. In an old garden maintained by selective thinning the palm spacing may be very close or, on the other hand, most of the garden may have reverted to swamp forest. Morris (1953: 22) states that a close initial spacing is frequent because 'the owner reckons on reaping only one crop in his lifetime and foresees that most of the suckers will be destroyed by monkeys'. From a study of selected gardens Morris suggests (1953: 158) a possible average annual production of 4–6 mature palms per acre, giving roughly 0.7–1.0 tons sago flour. Yield

differences due to soil characteristics cannot be deduced from the gardens selected, as their history was very varied.

Swamp rice

Localities in which there is a long history of swamp rice cultivation show a close adjustment of the farm pattern to the soil distribution. This was probably developed by trial and error. Most swamp rice in such areas is grown on Bijat, Pakan, and Sebandi Series, or on shallow phases of Mukah Series. Near the coast it may extend into areas of Pendam Series. Deep peat and saline clays under mangrove are both generally avoided.

Elsewhere, however, other soils have been used. There are a number of scattered clearances on Rajang and Anderson Series in the Rajang delta which are now under a poor secondary cover. Early air photography (1926) of the delta shows that many of them date from more than 50 years ago and are apparently clearances for swamp rice. They were probably abandoned after a short period as a result of low yields due to saline water incursions or large losses from pests. The latter is very prevalent in isolated rice clearances surrounded by forest.

On the fringes of the hill zone it is also common for Iban settlers attracted to the hill soils for shifting rice cultivation to clear the adjacent zone of bottomland for swamp rice. This may be mantled by mineral alluvium appropriate to this crop but is more commonly deep peat.

Most of the swamp rice is grown without formal water control, with no mechanical cultivation and without fertilizer. Insecticides are, however, used on many farms. Improved cultivation practices are now spreading under the encouragement of various official assistance schemes and a number of drainage schemes have also been implemented.

Only a single crop is taken and some land is normally left fallow each year. Much of the land indicated as under secondary growth in Map 4 is, if adjacent to a major river, likely to be intermittently used for swamp rice.

Yields are highly erratic from year to year. Crop-cutting experiments have been conducted for a number of seasons on a randomly selected group of farms (e.g. Statistics Department; 1970) and the writer has referred to the original records from farms studied in the Area. While an average yield of some 1,800–2,000 lbs dry grain per acre is obtained, some farms achieve much higher yields and others fail completely. No convincing relationship is found between yield and either application of insecticide or manure, use of improved varieties, soil characteristics, drainage control or inclusion in a Government-assisted scheme. There is a slight indication that, where no water control or fertilizer is applied, yields are somewhat higher on Sebandi and Mukah Series than on Bijat Series (which is more susceptible to water shortage in a dry year) or an Anderson Series (where low fertility is probably combined with a greater incidence of pest attack).

Hill rice

While soil characteristics are directly considered by the Iban hill rice farmer, judgements on whether or not to clear a new area for a rice field appear to have rested in the past mainly on the luxuriance of the primary forest cover. (Theoretically all areas in present use for this crop have been cleared before and the decision is now based on the maturity and development of the secondary forest.) The importance given to the cover is perhaps less because of any assumed relationship between good forest growth and soil fertility (although this enters into it) than the knowledge that a good rice crop is heavily dependent on the efficiency of the 'burn' following the forest clearance. A good 'burn' is itself dependent on a long dry spell prior to firing (and the lack of this, or a wrong judgement on its length in the rather erratic rainfall pattern of the Area, has led to many poor harvests) but it also obviously requires an adequate amount of cut-over brush.

However the decision is arrived at, hill rice farmers consistently avoid Podzols under heath forest or other sandy or poorly drained upland soils (such as Tika, Triboh and Saratok Families) with a thin forest cover wherever alternative upland soils are available. The normal soils used for hill rice as those in the Merit, Bekenu and Nyalau Families, together with intergrades to Kapit Family.

There is, on the other hand, little discrimination regarding slope. Hill rice clearances are found on all slopes in the dissected lowlands and interior highlands up to a maximum of about 40°. This is partly forced on the cultivators by the lack of alternative land but the pattern of clearance in interior pioneer areas with a low population density suggests that even where more freedom was available to select the better slopes, the disadvantages of farming on steep land did not weigh heavily with the Iban and all slopes below 40° were likely to be cleared within the locality chosen for clearance. In the case of steep gullies crossing otherwise gentler terrain there is a practical reason for this. Islands of forest left within the complex of rice farms offer a refuge for squirrels, pigs, birds and other pests which may add to the inevitable damage to the crop during the season. Any such tracts of forest left

uncleared are likely to be preserved for ritual reasons, the presence of graveyards, or to confirm an important ownership boundary not otherwise obvious from the terrain.

In most hill rice areas no insecticide or fertilizer is used. The ash from the burn is left to lie where it falls and no attempt is made to spread it evenly (Freeman, 1955: 47). Yields are highly erratic but crop-cutting experiments (Statistics Department, 1970) indicate that average yields are only 50–60 per cent of those from swamp rice farms sampled in the same season.

REFERENCES

ANON 1824 Borneo Proper. *Singapore Chronicle,* Dec. Reprinted in Moor (1837: 1–4).

——— 1867 *A few months in Borneo* (ed. by M.B.B.). S.P.C.K.

——— 1948 Side lights on rubber. *Sarawak Gazette,* 1087: 104.

AIKMAN, R.G. 1959 Melanaus. *The peoples of Sarawak* (ed. by Harrison, T.): 85–94. Sarawak Museum.

BARING-GOULD, S. and BAMPFYLDE, C.A. 1909. *A history of Sarawak under the two white Rajahs.* London.

BOYLE, F. 1865 *Adventures among the Dayaks of Borneo.* London.

BROCK, J.O.M. 1964 Borneo on maps of the 16th and 17th Centuries. *Sarawak Museum J.,* 11 (23–24 in new series): 649–654.

BROOKE, J. 1866 *Ten years in Sarawak.* London.

CHIANG, L. 1955 Chinese pioneers, AD 1900: the new Foochow settlement of Sarawak. *Sarawak Museum J.,* 6 (21 in new series): 536–548.

CRAWFURD, J. 1820 *History of the Indian Archipelago.* Edinburgh.

——— 1856 *A descriptive dictionary of the Indian Islands and adjacent countries.* London.

DENISON, N. 1883 Journal (from 29th April to 25th May, 1872) when on a trip from Serawak to Meri on the NW coast of Borneo in the Brunei territory. *J. Roy. Asiatic Soc. (Straits Br.),* 10: 173–188.

DEPARTMENT OF AGRICULTURE, SARAWAK. 1972 *Agricultural statistics of Sarawak, 1972.* Kuching (mimeo).

EARL, G.W. 1836 Narrative of a voyage from Singapore to the west coast of Borneo . . . *J. Roy. Asiatic Soc. (Straits Br.),* 3: 1–24.

FREEMAN, J.D. 1955 *Iban agriculture: a report on the shifting cultivation of hill rice by the Iban of Sarawak.* Colonial Research Studies, No. 18. HMSO, London.

GOATLY, J. 1959 The Malays. *The peoples of Sarawak,* (ed. Harrison, T.): 103–113. Sarawak Museum.

HAILE, N.S. 1962 The geology and mineral resources of the Suai-Baram area, north Sarawak. *Brit. Borneo Geol. Survey,* Mem. 13.

———, KEIJ, A.J. and PIMM, A.C. 1963 Preliminary report on the oceanographic cruise of HMS 'Dampier' in the South China Sea, 1963. *Borneo Reg., Malaysia, Geol. Survey,* Ann. Rpt.: 119–145.

HARRISON, T. 1950 The Chinese in Borneo. *Int. Affairs,* 26 (3): 354–362.

——— 1964 The Malays of southwest Sarawak before Malaysia. *Sarawak Museum J.,* 11 (23–24 in new series): 341–511.

HEPBURN, B.A.ST.J. 1949 *The handbook of Sarawak.* Malaya Pub. House, Singapore.

HOOVER, J. 1919 Cultivation of rice in the Rejang. *Sarawak Gazette,* 770.

HUNT, J. 1820 Sketch of Borneo. *Malayan Miscellanies,* 1 (8): 1–67.

JONES, L.W. 1962 *Sarawak: Report on a census of population taken on 15th June, 1960.* Government Printer, Kuching.

——— *1966 The population of Borneo: a study of the peoples of Sarawak, Sabah and Brunei.* London.

KAY, K.E.H. 1949 Pepper planting in Sarawak. *Sarawak Gazette,* 75 (1100): 292–293.

LAWRENCE, A.E. 1911 Stories of the first Brunei conquest of the Sarawak coast. *Sarawak Museum J.,* 1: 120–124.

Soil Resources Rpt. 32: 95–106.

LEYDEN, Dr. 1837 Sketch of Borneo. In MOOR, 1837: 93–109.

LIN, W.T. 1966 The first ten years of the New Foochow colony. *Sarawak Teacher,* 2 (2).

LOGAN, R. 1848 Notices of European intercourse with Borneo Proper prior to the establishment of Singapore in 1819. *J. Ind. Arch. and E. Asia,* 2 (9): 498–527.

LOW, R. 1848 *Sarawak, its inhabitants and productions.* London.

MARINE FISHERIES DEPARTMENT, SARAWAK 1972 *Annual Report.* Kuching.

MORRIS, J.H. 1953 *Report on a Melanau sago-producing community in Sarawak.* HMSO, London.

MORRIS, R.H. 1949 Our economic future. *Sarawak Gazette,* 1099: 259–260.

MUNDY, R. 1848 *Narrative of events in Borneo and Celebes, down to the occupation of Labuan: from the journals of James Brooke, Esq.* London.

NOAKES, J.L. 1949 The forgotten land. *Sarawak Gazette,* 1094: 99–102.

———— 1950 *A report on the 1947 population census, Sarawak and Brunei.* Government Printer, Kuching.

ONG, K.H. 1948 Sago production in Sarawak. *Sarawak Gazette,* 1088: 212–214.

———— 1949 The pepper industry in Sarawak. *Sarawak Gazette,* 1092: 53–55.

PARNELL, E. 1911 The tributes paid in former days to the Sultan of Brunei by the then dependent provinces of Sarawak. *Sarawak Museum J.,* 1: 125–130.

PAYNE, R. 1960 *The white rajahs of Sarawak.* London.

PORTER, A.F. 1968 *Land administration in Sarawak.* Government Printer, Kuching.

PRINGLE, R. 1970 *Rajahs and rebels; the Iban of Sarawak under Brooke rule (1841–1941).* London.

ROTH, H.L. 1896 *The natives of Sarawak and British North Borneo.* London.

RUNCIMAN, S. 1960 *The white rajahs: a history of Sarawak from 1841 to 1946.* Cambridge.

SANDFORD, R. 1952 Pepper in Sarawak. *Malayan Agric. J.,* 35: 208–214.

SANDIN, B. 1956 The westward migration of the Sea Dayaks. *Sarawak Museum J.,* 7 (7 in new series): 54–81.

———— 1957 The Sea Dayak migration to Niah River. *Sarawak Museum J.,* 8 (10 in new series): 133–135.

———— 1964 Descent of some Saribas Malays (and Ibans). *Sarawak Museum J.,* 11 (23–24 in new series): 512–515.

SARAWAK GOVERNMENT. 1960 *Sarawak census of agriculture, 1960.* Kuching (mimeo).

———— 1958 *The laws of Sarawak (revised edition).* Government Printer, Kuching.

SG (Sarawak Gazette) Anonymous contributions. Accredited articles are referenced under author.

SPURWAY, B.J.C. 1937 Shifting cultivation in Sarawak. *Malayan Forester,* 6: 124–128.

ST. JOHN, S. 1863 *Life in the forests of the Far East.* London.

STATISTICS DEPARTMENT. 1970 Crop estimation survey on padi in Sarawak, 1969–1970. Kuching (mimeo).

———— 1972 Extract from the 1970 population and housing census of Malaysia: Community Groups: Sarawak. Kuala Lumpur (mimeo).

SUTLIVE, V. H. 1972 From longhouse to pasar: urbanisation in Sarawak, East Malaysia. Ph. D. thesis, Univ. of Pittsburgh.

TREACHER, W.H. 1890 British Borneo: sketches of Brunei, Sarawak, Labuan and North Borneo (2nd part). *J. Roy. Asiatic Soc., (Straits Br.),* 20: 19–121).

TREMEER, R.E. 1964 The early history of rubber planting in Sarawak, 1880–1910. *Sarawak Gazette,* 1273: 50–52.

TREVENEN, N.P. 1891 *Notes on a visit to Sarawak and its trade.* G.B. Foreign Office, Misc. Series, 210.

T'IEN, J.K. and WARD, B.E. 1956 The early history of the Chinese in Sarawak. *L.S.E. Monographs in Social Anthropology,* 12 (App. 1.)

de WINDT, H. 1882 *On the Equator.* London.

de WAARD, P.W.F. 1964 Pepper cultivation in Sarawak. *World Crops,* 16 (3): 24–30.

APPENDIX III

METHODS OF ANALYSIS

The analyses provided by the Chemistry Division of the Research Branch, Sarawak Department of Agriculture, were undertaken using the following methods.

pH (H_2O and KCl): determined by Pye pH meter in a 1:2.5 Soil/Water suspension.

Organic carbon: determined by the Walkley and Black wet oxidation procedure (Metson, 1956: 63).

Nitrogen: determined by the semi-micro Kjeldahl method.

Cation exchange capacity: determined by leaching with N NH_4OAc (pH 7), (Metson, 1956: 104).

Exchangeable bases: K and Na determined by E.E.I. flame photometer, Ca and Mg by atomic absorption (Salt, 1967).

HCl-extractable P, Ca, Mg and K: determined as described by Bailey (1967).

HCl04-extractable P: determined by the method of Fogg and Wilkinson (1958: 406).

Morgan-extractable cations: Fe by the O-Phenanthroline method (Black, et al, 1965: 966); Al by the method of Jones and Thurman (1958); Mn, Zn and Cu by atomic absorption.

Available P: determined by the method of Bray and Kurtz (1945).

P retention: determined by the method of Kurtz (et al, 1946).

Na_2CO_3 extractable silicates: Si, Fe and Al determined by the method of Dobritskaya (1962); Ca, Mg and Mn by atomic absorption; Ti determined colorimetrically using H_2O_2.

6N HCl-extractable Fe_2O_3: determined by the O-Phenanthroline method (Black, et al, 1965: 966).

Analysis of peat ash extracts: determined following methods described by Sim (1965: 58).

Conductivity: measured by Mullard conductivity bridge using a 1:5 soil/water suspension.

Chloride: determined by the Mohr titration method (Metson, 1956: 146).

Sulphate: determined by the turbidity method (Massoumi and Cornfield, 1963: 321).

Granulometric analysis: determined by the international pipette method (Piper, 1950: 59–74), with revised fraction limits.

REFERENCES

BAILEY, J.M. 1967 Chemical changes in a Sarawak soil after fertilization and crop growth. *Plant and soil,* 27: 33–52.

BLACK, C.A. 1965 *Methods of soil analysis;* Part II: Chemical and Microbiological properties Amer. Soc. of Agron., Madison.

BRAY, R.H. and KURTZ, L.T. 1945 Determination of total, organic and available forms of phosphorus in soils. *Soil Sci.,* 59: 39–45.

DOBRITSKAYA, Yu. I. 1962 Quick method for a short total analysis of soils. *Soviet Soil Sci.,* 9: 965–972.

FOGG, D.N. and WILKINSON, N.T. 1958 The colorimetric determination of phosphorus. *Analyst,* 83: 406–414.

JONES, L.H. and THURMAN, D.A. 1958 The determination of aluminium in soil, ash and plant materials using Eriochrome Cyanine R.A. *Plant and Soil,* 9: 131–142.

KURTZ, T., de TURK, E.E. and BRAY, R.H. 1946 Phosphate absorption by Illinois soils. *Soil Sci.,* 61: 111–124.

MASSOUMI, A. and CORNFIELD, A.H. 1963 A rapid method of determining sulphate in water extracts of soils. *Analyst,* 88: 321–322.

METSON, A.J. 1956 Methods of chemical analysis for soil survey samples. *N.Z. Dept. of Sci. and Ind. Res., Soil Bur.,* Bull. 12.

PIPER, C.S. 1950 *Soil and plant analysis.* Adelaide.

SALT, P.D. 1967 Soil and plant analysis by flame emission spectrophotometry. *Spectrovision,* 18: 9–12.

SIM, E.S. 1965 *Methods of analysis for agricultural materials.* Sarawak Dept. of Agric. Kuching (mimeo).

APPENDIX IV

DATA ON SELECTED SOIL PROFILES

Forty-nine soil profiles are described. These do not cover all Families and Series present in the Area, but are chosen to indicate the range of profile forms encountered. They were sampled and analysed over an extended period and do not have a standardised set of supporting data. In general, those chosen for inclusion in this Appendix are profiles for which a broad range of data are available, although field descriptions without analytical data are included in two cases to illustrate extreme profile forms.

Profile number: The profiles are numbered consecutively (1-49). Some data from 26 other profiles from the Area are referred to in Chapters 10 and 11. These are designated by upper-case letters (A-Z) and are briefly listed in Appendix VI. Four further profiles from west Sarawak were incorporated in the numerical ordination study (Chapter 11 and Appendix VII) for purposes of comparison and are indicated by lower-case letters (a-d).

Location: Notations in parenthesis under this heading give, firstly, the 1:50,000 scale sheet number (Lands and Survey Department, Sarawak, Series T735) and, secondly, the approximate grid reference by the Netherlands East Indies (Equatorial Zone) Grid over-printed on that map series. Grid references are to the nearest 100 metres, 100,000-metres digits are omitted. The profiles are also located on Map 2.

Reference samples: Profile pit samples were given field numbers on collection. These were replaced by laboratory numbers if forwarded for analysis. Sample numbers quoted refer to the latter.

Field morphology: Field descriptions follow USDA terminology (USDA, 1951). The colour described is moist and is given in Munsell notation.

Micromorphology: Some profiles are supported by thin sections, for the preparation of which the writer is indebted to Dr. E.A. FitzPatrick, University of Aberdeen. General micromorphology descriptions are given for these profiles, at a level comparable to that for macromorphology. Terms used in field description are employed where applicable. Other features are described in the terminology of Brewer (1964) which, while not entirely accepted, has received wide circulation. Interpretative terms are avoided as far as possible, the significance of cutans and related features being discussed in Chapter 11. Classification of shape, and other features which may only reflect the section orientation, are also not stressed. Colour is described in Munsell terms without numerical notation, and refers to the colour in transmitted light through a blue substage filter.

For the confirmation of gibbsite in Profile 2 and the tentative identification of chlorite in Profile 12, the writer is indebted to Mr. Victor Hon, Geological Survey Department, Sarawak.

Analytical data: All granulometric and chemical analyses were undertaken by the Analytical Chemist, Department of Agriculture, Sarawak. Methods of analysis are listed in Appendix III. Most data are tabulated under the profile concerned. Some additional data are quoted in Chapter 11 and reference to that Chapter is made where this is the case.

Sand mineralogy: Heavy mineral separation and identification was undertaken by the writer for some profiles. In many upland soils the heavy fraction in the fine sand (the grade used for study) is very small and is dominantly opaques. The data are not tabulated in these cases. Facilities were not available for magnetic separation and opaques have been broadly classified on colour and form. Non-opaques are generally dominated by zircon, tourmaline and other resistant species. These have been subdivided on colour and degree of wear. The writer is indebted to the Royal Tropical Institute, Amsterdam, for the identification of paragonite and cristobalite in Profile 18.

Clay mineralogy: Selected clay fractions were analysed by x-ray diffraction and differential thermal analysis by the Royal Tropical Institute, Amsterdam. Statements under this heading are paraphrased from their reports.

Profile 1

Family: LALIS. *Series:* Lalis sandy clay.

Site: Middle slope of steeply rolling terrain; 23° slope. *Parent material:* Tertiary shale. *Location:* Near Tanjong Lalis, upper Kanowit River, Julau District; (1/111/4; 098.103). *Reference samples:* S2792/2798.

Field Morphology

A/B *0-2 cms:* Yellowish brown (10YR 5/4) clay. Moist. Massive. Friable. Abundant rootlets. Few pores. Many charcoal fragments. Distinct wavy boundary.

B2 *2-9 cms:* Reddish yellow (7.5YR 6/6) clay. Moist. Very weak coarse subangular blocky structure. Firm. Many rootlets. Few pores. Few charcoal fragments. Indistinct wavy boundary.

B3 *9-18 cms:* Reddish yellow (7.5YR 6/8) sandy clay, with many fine faint light yellowish brown mottles. Moist. Massive. Firm. Rare fine and medium angular quartz gravel and small fragments of weathered shale. Few rootlets. Few pores. Indistinct wavy boundary.

B/C *18-38 cms:* Strong brown (7.5YR 5/6) clay, with abundant coarse distinct patches of weak red weathered shale. Moist. Massive. Firm. Few rootlets. Few pores. Indistinct wavy boundary.

C1 *38-91 cms:* Abundant large fragments of weak red (7.5YR 4/4) weathered shale in a matrix of reddish yellow (7.5YR 6/6) clay. Moist. Massive. The matrix firm, the lithorelicts friable or powdery. Rare rootlets. Few pores. Indistinct wavy boundary.

C2 *91-150 cms:* Reddish yellow (7.5YR 6/8) and weak red (7.5YR 4/4) weathered shale. Powdery to moderately hard.

Comments

A common profile form on steep land under shifting cultivation and subject to accelerated soil creep. A similar profile on a gentler slope is illustrated in Colour Plate 1.

Table 54

Profile 1, analytical data for fine earth (<2mm)

Depth (cms)		*0* *2*	*2* *9*	*9* *18*	*18* *38*	*38* *91*	*91* *112*
Chemical analysis							
pH.	H_2O		4.6	4.6	4.8	5.1	5.3
pH	KC1		3.9	4.0			
C	%		1.46	0.50	0.35		
N	%	0.51	0.25	0.11	0.09	0.07	0.06
C/N			6	5	4		
CEC	me %	15.9	7.2	5.6	4.4		
Exch. Ca	me %		1.9	1.6	1.7		
Exch. Mg	me %		0.2	t	t		
Exch. K	me %	0.8	0.2	0.1	0.1		
Exch. Na	me %		0.1	0.1	0.1		
Base saturation	%		33	33	43		
Exch. A1	me %	4.2	4.6	4.3	3.5		
Extr. Ca (HC1)	ppm	810	80	10	20	30	110
Extr. Mg (HC1)	ppm	1380	1110	1190	1060	1100	920
Extr. K (HC1)	ppm	6800	7600	7300	8400	7800	8000
Extr. P (HC1)	ppm	520	290	290	320	370	
Avail. P	ppm	22	5	5	2	2	

Table 55

Profile 1, analytical data for fine earth (<2mm)

Depth (cms)	*0* *2*	*2* *9*	*9* *18*	*18* *38*	*38* *91*	*91* *150*
SiO_2	66.90	66.23	66.79	58.98	59.94	59.89
Fe_2O_3	8.32	8.75	10.12	12.03	12.06	11.18
$A1_2O_3$	21.21	21.37	19.69	25.58	24.32	24.49
TiO_2	0.79	0.71	0.76	0.75	0.74	0.77
CaO	0.98	0.21	0.20	0.25	0.34	0.22
MgO	0.26	0.30	0.31	0.51	0.44	0.40
Na_2O	0.19	0.19	0.15	0.21	0.19	0.29
K_2O	1.00	2.10	1.91	1.61	2.28	2.67
MnO	0.19	0.07	0.02	t	t	t
P_2O_5	0.15	0.07	0.05	0.08	0.10	0.10

Table 56

Profile 2, analytical data for fine earth (<2mm)

Depth (cms)		*0* *8*	*8* *30*	*30* *50*	*50* *74*	*74* *97*	*97* *120*
Granulometric analysis (%)							
2 – 1 mm	(vcs)	0.1	0.5	1.7	3.1		
1 – 0.5 mm	(cs)	3.7	4.9	5.2	4.9		
0.5 – 0.2 mm	(ms)	11.9	12.0	10.4	8.0		
0.2 – 0.1 mm	(fs)	11.8	12.0	11.3	8.2		
0.1 – 0.05 mm	(vfs)	18.6	20.0	21.4	15.1		
sand (2 – 0.05 mm)		46.2	49.4	50.1	39.2		
silt (0.05 – 0.002 mm)		16.5	17.1	14.0	15.1		
clay (<0.002 mm)		37.2	33.6	36.0	45.7		
% clay water-dispersable			80	33	2	1	<1
Chemical analysis							
pH	H_2O	3.6	3.8	3.6	3.7	4.0	4.1
pH	KCl	3.9	3.9	3.8	3.8	3.9	4.0
C	%	3.50	0.77	0.33	0.27	0.23	0.20
N	%	0.28	0.08	0.06	0.06	0.05	0.04
C/N		13	10	6	5	5	5
CEC	me %	13.4	4.8	4.2	3.6	2.9	3.4
Exch. Ca	me %	0.4	0.1	0.1	0.1	0.1	0.1
Exch. Mg	me %	0.4	t	t	t	t	t
Exch. K	me %	0.4	t	t	t	t	t
Exch. Na	me %	t	t	t	t	t	t
Base saturation	%	9	4	2	2	4	3
Exch. Al	me %				3.4	2.2	1.5
Extr. Ca (HCl)	ppm	210	220	110	220	110	220
Extr. Mg (HCl)	ppm	610	550	730	580	780	810
Extr. K (HCl)	ppm	1990	4120	3640	3060	3130	1180
Extr. P (HCl)	ppm	220	160	140	130	120	130
Extr. P ($HClO_4$)	ppm	230	160	100	140	70	120
Extr. Fe (Morgan)	ppm		26	20	t		
Extr. Al (Morgan)	ppm		390	340	310		

Profile 2

Family: MERIT. *Series:* Merit sandy clay loam.

Site: Upper slope of gently undulating terrain; 3° slope. *Parent material:* Tertiary shale. *Location:* Near mile 4, Selalang spur road, Sarikei District; (2/111/14; 206.537). *Cover:* Newly burnt for hill rice planting. *Reference samples:* MS1414/1419.

Field morphology

A1 *0-8 cms:* Brown to dark brown (10YR 4/3) sandy clay. Moist. Massive. Very friable. Abundant rootlets. Few pores. Indistinct wavy boundary.

A2 *8-30 cms:* Yellowish brown (10YR 5/8) sandy clay loam, with dark yellowish brown root channel infillings. Moist. Weak coarse subangular blocky structure. Friable. Many rootlets. Few pores. Diffuse wavy boundary.

B1 *30-50cms:* Yellowish brown (10YR 5/8) sandy clay. Moist. Coarse subangular blocky structure. Firm to very firm. Few rootlets. Few pores. Diffuse wavy boundary.

B2 *50-74 cms:* Yellowish brown (10YR 5/8) clay with scattered crushable fine quartz gravel. Otherwise as above. Indistinct wavy boundary.

B3 *74-120 cms:* Brownish to reddish yellow (10YR-7.5YR 6/8) clay with abundant platy fragments of red-iron enriched weathered shale and scattered crushable quartz fragments. Massive. Very rare rootlets. No pores seen.

Clay mineralogy

0-30 cms: Mainly poorly crystallised vermiculite and illite, with small amounts of poorly crystallised kaolinite. Some gibbsite, geothite and hydrated Al and Fe also present.

30-120 cms: Mainly poorly crystallised vermiculite and illite, with a greater amount of kaolinite (better crystallised than in higher horizons). Some gibbsite, probably mixed with geothite. Small amounts of hydrated Al and Fe.

Comments

See also Fig. 40. The mineralogy (Table 48) suggests that a variety of rock strata contribute to the profile and that there has been marked lateral movement. Some of the horizon contrasts in this Table may result, however, from the very low non-opaque heavy crop available for percentage estimation. The profile is included in the numerical ordination study.

Table 57

Profile 2, heavy minerals in 0.08–0.1 mm sand fraction

Depths (cms)		*0*	*8*	*30*	*50*	*74*
		8	*30*	*50*	*74*	*120*
% heavies		t	t	t	t	t
% opaques		75	84	72		79
% non-opaques		25	16	28		21
Opaques (%)						
Ilmenite, etc		23	16	22		3
Leocoxene, etc		75	80	73		67
Limonite, etc		2	4	5		30
Non-opaques (%)						
Zircon	clear, rolled	28	30	20		8
	clear, worn	5	11	6		—
	clear, euhedral	5	—	—		—
	pink, rolled	—	24	3		—
Tourmaline	brown	26	16	41		37
	green	39	—	9		29
	blue	—	3	2		12
Rutile	red	3	4	1		—
	yellow	—	—	1		—
Brookite	rough	8	12	1		6
	clean	2	—	—		—
Corundum	colourless	—	—	—		2
Alterites		5	—	13		—
Others		—	—	—		6

t = 0.002% or less

Profile 3

Family: MERIT. *Series:* Merit clay loam.

Site: Summit in moderately rolling terrain; slope 3°. *Parent meterial:* Tertiary shale. *Location:* Sebatu River, middle Mukah drainage basin; Mukah Subdistrict; (2/112/6; 787.563). *Cover:* Young regrowth following hill rice. *Reference samples:* S4857/4863.

Field morphology

A1 *0–3 cms:* Brown to dark brown (10YR 4/3) clay. Moist. Massive. Friable. Abundant rootlets. Few pores. Indistinct wavy boundary.

A2 *3–15 cms:* Yellowish brown (10YR 5/5) clay loam, with many, very coarse, prominent light brownish grey mottles. Moist. Massive. Friable. Many rootlets. Few pores. Indistinct wavy boundary.

B21 *15–28 cms:* Brownish yellow to strong brown (7.5–10YR 5.5/6) clay. Moist. Very weak, coarse subangular blocky structure. Few pressure coatings. Firm. Rare fine quartz fragments. Few rootlets. Few pores. Diffuse wavy boundary.

B22 *28–41 cms:* Strong brown (7.5YR 5/7) clay. Moist. Coarse angular blocky structure, breaking to medium. Many pressure coatings. Firm. Many small fragments of iron-enriched weathered shale and few iron-stained quartz fragments. Few rootlets. Rare pores. Diffuse wavy boundary.

B23 *41–58 cms:* Structure weak and rootlets rare; otherwise as above. Diffuse wavy boundary.

C *58–97 cms:* Thin inclined bands of alternating strong brown (7.5YR 5/7) clay and greyish brown to light yellowish brown (10YR 5.5/3) weathered clay shale.

Micromorphology

0–8 cms: Many fine subangular quartz sand grains in a finely variegated, very pale brown, mosepic matrix. Many large irregular channels with varied length and direction; no discrete structural peds. Few, fine, round and oblate voids, some with thin, diffuse, brownish yellow cutans. Few roots. Many large carbonised wood fragments. Few small, dark reddish brown ferric nodules.

8–18 cms: Abundant, very fine, subangular quartz sand grains in a yellowish brown, brownish yellow, and dark yellowish brown diffusely variegated, mosepic matrix. Many, large, irregular voids and short, narrow, irregular channels; no discrete structural peds. Few, small, round and oblate voids. Thin, brownish yellow cutans lining some small voids and intermittently present on some channels. Scattered medium to very fine, dark reddish brown, oblate or angular ferric nodules with intermittent, thin diffuse grain cutans. Few small papules. Rare roots. Few medium and small carbonised wood fragments.

28–34 cms: Many fine and very fine subangular quartz sand grains in a brownish yellow mosepic matrix. Many large irregular channels and short, narrow acicular voids and craze planes; no discrete structural peds. Few, medium and fine, oblate, round or irregular voids. Many, medium and small, tabular or oblate, ferric nodules comprising very fine subangular quartz grains in a dark reddish brown isotic matrix with some laminar rock structure. Rare thin diffuse cutans present, but confined to some oblate voids. Rare discrete tabular gibbsite crystals in larger channels, and fan structures of very fine gibbsite crystals in some channels and voids. Rare small carbonised wood fragments.

34–38 cms: As 28-34 cms, but many strong single or zoned domains in the matrix, discrete tabular gibbsite crystals absent, and gibbsite fan structures more frequent in larger voids.

Table 58
Profile 3, analytical data for fine earth (<2 mm)

Depths (cms)			*0*	*3*	*15*	*28*	*41*	*58*
			3	*15*	*28*	*41*	*58*	*97*
Granulometric analysis	(%)							
2 – 1 mm	(vcs)		0.1	0.2	0.2	2.5	7.0	
1 – 0.5 mm	(cs)		0.1	0.5	0.7	3.2	7.8	
0.5 – 0.2 mm	(ms)		0.6	0.8	0.6	1.8	3.8	
0.2 – 0.1 mm	(fs)		0.9	1.2	0.8	1.1	7.6	
0.1 – 0.05 mm	(vfs)		16.2	18.7	13.3	12.3	7.6	
sand (2 – 0.05 mm)			17.8	21.4	15.5	20.9	27.9	
silt (0.05 – 0.002 mm)			40.6	45.4	39.7	34.4	28.6	
clay (<0.002 mm)			41.6	33.2	44.8	44.8	43.5	
% clay water-dispersable								
Chemical analysis								
pH	H_2O			4.2	4.2	4.5	4.8	4.8
pH	KCl			3.7	3.8	3.8	3.9	3.9
C	%		4.29	2.01	0.73	0.41	0.45	0.42
N	%		0.31	0.14	0.07	0.06	0.06	0.08
C/N			14	14	11	7	8	5
CEC	me %		21.2	15.4	12.4	11.5	10.6	12.2
Exch. Ca	me %		0.3	0.2	0.3	0.1	0.1	0.2
Exch. Mg	me %		0.8	0.1	0.2	0.3	0.1	0.1
Exch. K	me %		0.3	0.2	0.1	0.1	0.1	0.1
Exch. Na	me %		0.1	0.1	0.1	0.1	0.1	0.1
Base saturation	%		7	4	5	4	4	4
Extr. Ca (HCl)	ppm		t	100	t	210	100	170
Extr. Mg (HCl)	ppm		1380	1300	1480	1610	2530	2400
Extr. K (HCl)	ppm		3660	3210	3300	2680	4510	6800
Extr. P (HCl)	ppm		200	140	120	120	100	110
Extr. Fe (Morgan)	ppm		85	105	39	14	3	1
Extr. Al (Morgan)	ppm		930	680	670	810	600	840
Extr. Mn (Morgan)	ppm		0	0	0	0	0	0
P retention	%		54.0	61.1	68.5	69.4	62.6	67.7

Table 59

Profile 3, total silicate analysis of fine earth (<2mm); adjusted percentages

Depth (cms)	*0* *3*	*3* *15*	*15* *28*	*28* *41*	*41* *58*	*58* *97*
SiO_2	79.60	79.23	70.18	61.32	58.84	64.32
Fe_2O_3	3.81	4.01	4.86	7.38	15.41	4.93
Al_2O_3	14.09	14.34	16.41	28.70	21.73	25.47
TiO_2	0.59	0.47	0.55	0.45	0.45	0.47
CaO	0.18	0.17	0.06	0.12	0.13	0.09
MgO	0.59	0.54	0.57	0.58	0.81	1.06
Na_2O	nd	nd	nd	nd	nd	nd
K_2O	1.28	1.21	1.37	2.31	2.33	3.48
MnO	t	t	t	t	t	t
P_2O_5	0.07	0.03	0.03	0.16	0.31	0.20

48–58 cms: Fine subangular quartz sand grains in a yellowish brown to brownish yellow insepic to omnisepic matrix. Many long, thin, acicular channels connecting medium and small oblate chambers; no discrete structural peds. Many fine oblate voids. Many medium and large lithorelicts comprising (a) few, fine and medium, angular quartz sand grains in a very pale brown masepic matrix, or (b) many quartz sand grains in a dark brown to dark reddish brown asepic matrix. Many narrow regular channels following, or inclined to, cleavage lines in lithorelicts, with intermittent, thick, well-defined, pale yellow, brownish yellow or red cutans. Cutans in matrix rare, thin, diffuse and intermittent, and confined to some oblate voids. Finely crystalline gibbsite fan structures common in larger channels, in both matrix and lithorelicts.

68–78 cms: (a) Large blocks and irregular fragments of brown to very pale brown weathered shale. Internal matrix insepic, with rare very fine quartz sand grains and dark brown isotic parallel zones or irregular random mottles. Many, narrow, irregular channels following or crossing cleavage planes, with few intermittent well-defined strong brown to yellowish brown cutans. Many channels with discrete, ovoid, microcrystalline gibbsite complexes; mesocrystalline fan structures not seen. Lithorelicts set in (b) pale brown to very pale brown insepic matrix with few fine angular quartz grains. Many fine oblate voids and narrow, random, unoriented channels. Thin diffuse cutans intermittently present in some fine voids and channels. Microcrystalline gibbsite structures very rarely present in some voids.

Comments

See also Tables 17 and 18, and Figs. 40 and 43. The field morphology illustrates a widespread profile form found in Merit Series (a more irregular colour horizonation is illustrated in Colour Plate 3), but the marked development of gibbsite crystal structures in subsoil cavities has not been noted in other profiles of the Series for which thin sections are available.

Profile 4

Family: MERIT. *Series:* Jakar silty clay (shallow phase).

Site: Upper slope of moderately rolling terrain; 4° slope; profile sampled from borrow pit face. *Parent material:* Tertiary siltstone. *Location:* Between Jakar and Selalang spur road junction; Sarikei District; (2/111/14; 241.637). *Cover:* Low regrowth at the site; most of the immediate vicinity under pepper. *Reference samples:* MS1398/1405.

Field morphology

A1 *0–5 cms:* Dark brown to dark reddish brown (7.5-10YR 4/4) silty clay. Moist. Weak medium subangular blocky structure, breaking to fine. Friable. Many roots and rootlets. Few pores. Diffuse smooth boundary.

A21 *5–13 cms:* Dark yellowish brown (10YR 4/4) silty clay, with many medium distinct brown and strong brown mottles. Moist. Weak coarse subangular blocky structure. Firm. Many rootlets. No pores seen. Indistinct wavy boundary.

A22 *13–18 cms:* Strong brown (7.5YR 5/6) silty clay, with many fine distinct light yellowish brown mottles and few coarse subangular blocky structure. Firm. Few rootlets. No pores seen. Diffuse wavy boundary.

B *18–25 cms:* Yellowish red (5YR 5/8) silty clay, with many fine distinct light yellowish brown and grey mottles, largely associated with root channels. Moist. Very weak coarse subangular blocky structure. Firm. Few rootlets. No pores seen. Indistinct wavy boundary.

B *25–33 cms:* As above, with many fine fragments of iron-enriched weathered siltstone; matrix texture is clay. Indistinct wavy boundary.

C1 *33–58/74 cms:* Red (2.5YR 5/8) and reddish yellow (7.5YR 6/6) coarsely mottled clay from weathered siltstone, showing relict rock structure lines. Moist. Firm. Rare rootlets. No pores seen. Diffuse irregular boundary.

Table 60

Profile 4, analytical data for fine earth (<2mm)

Depth (cms)			*0*	*5*	*13*	*18*	*25*	*33*	*58/74*
			5	*13*	*18*	*25*	*33*	*58/74*	*120*
Granulometric analysis (%)									
2 – 1 mm	(vcs)		0.5	1.6	1.4	1.4	5.4		
1 – 0.5 mm	(cs)		1.0	2.2	1.3	1.3	3.1		
0.5 – 0.2 mm	(ms)		2.4	2.2	1.9	1.4	1.6		
0.2 – 0.1 mm	(fs)		3.2	2.2	2.1	1.7	1.1		
0.1 – 0.05 mm	(vfs)		7.3	4.5	4.3	3.6	2.5		
sand (2 – 0.05 mm			14.5	12.8	11.1	9.3	13.7		
silt (0.05 – 0.002 mm)			43.0	44.3	45.6	41.0	34.8		
clay (0.002 mm)			42.5	42.9	43.3	49.7	51.5		
% clay water-dispersable			28	32	44	4	1	<1	<1
Chemical analysis									
pH		H_2O	4.8	4.7	4.7	4.8	4.9	5.1	5.2
pH		KCl	3.6	3.5	3.4	3.5	3.6	3.7	
C		%	2.38	1.39	0.68	0.59	0.53	0.35	0.20
N		%	0.24	0.15	0.10	0.09	0.17	0.08	0.07
C/N			10	9	7	6	3	5	3
CEC		me %	9.1	7.0	6.3	6.5	5.3	4.6	4.4
Exch. Ca		me %	0.2	0.1	0.1	0.1	t	0.1	0.1
Exch. Mg		me %	0.3	0.2	0.1	0.1	t	t	t
Exch. K		me %	0.2	0.1	0.1	0.1	0.1	0.1	t
Exch. Na		me %	0.1	0.1	t	t	t	t	t
Base saturation		%	8	8	6	4	3	3	4
Extr. Al		me %	4.4	4.2	4.9	5.2	4.5	3.9	3.7
Extr. Ca (HCl)		ppm	180	130	220	180	70	120	140
Extr. Mg (HCl)		ppm	1090	1100	1120	1220	1220	1550	1400
Extr. K (HCl)		ppm	4810	4590	5330	4390	7290	7680	9480
Extr. P (HCl)		ppm	190	170	130	140	170	130	140
Extr. P ($HClO_4$		ppm	180	140	120	140	120	130	130
Extr. Fe (Morgan)		ppm			23	18			
Extr. Al (Morgan)		ppm			420	450			
Avail. P		ppm	6	4	4	3	3	3	

C2 *58/74–120 cms:* Dusky red (2.5YR 3/2) hard, brittle weathered siltstone lithorelicts, interbanded with light greyish brown, light grey and very pale brown, firm silty clay. No roots seen. No pores seen.

Micromorphology

3–13 cms: Few, fine and coarse, subangular quartz sand grains in a brown insepic matrix. Many large irregular cavities and attenuated irregular channels; no discrete structural peds. Few, thin, diffuse, intermittent, reddish brown cutans on some channels margins. Rare coarse, dark brown to black, ferric nodules. Many cavities and channels occupied by live roots. Very rare small carbonised wood fragments.

21–31 cms: Few, fine and coarse, subangular quartz sand grains in a pale brown, brownish yellow and strong brown, coarsely variegated insepic matrix. Matrix patchily masepic and locally reworked in striotubules. Scattered highly irregular yellowish brown domains with varied but strong orientation, not associated with grains or voids. Few narrow acicular channels; few medium irregular voids; no discrete structural peds. Few thin, diffuse, intermittent cutans on some void margins; rare thin, well-defined, intermittent cutans on some channels walls. Rare, very coarse, ovoid or irregular, dark reddish brown ferric nodules. Rare small carbonised wood fragments.

40–50 cms: A complex of pale brown, yellowish brown and strong brown, coarsely variegated insepic to omnisepic matrix, with many partial striotubules. Many long, irregular to tabular channels, dominantly subvertical or subhorizontal, but rarely combining to define complete peds; many small, thin, acicular random craze planes. Few, small or medium, ovoid or irregular voids, commonly within striotubules. Thin, diffuse, intermittent cutans on some channel margins but absent from most voids. Many large, subtabular, dark brown to black shale lithorelicts with argillasepic unistrial fabric. One coarse block of irregular quartz intergrowths in a very dark brown weakly undulic matrix.

72–82 cms: Large shale fragments (a), in a fine matrix (b). (a): Dark red (macro). finely variegated light grey, and dark reddish brown (micro), subtabular to irregular shale fragments, largely in situ. Dominantly weakly unistrial argillaceous internal matrix (silty or clay shale) with some subvertical banding of very fine quartz grains in an asepic matrix (sandy shale). Scattered inclined cleavage separations. (b): Finely variegated light grey, pale brown and yellowish brown omnisepic fabric, partially reorganised in striotubules. Many short, acicular channels with random orientation or separating lithorelicts and matrix. Few medium equant voids. Many small, irregular, strongly oriented domains. Intermittent, thin, diffuse to well-defined cutans on some voids and channels and on lithorelict cleavage faces.

Clay mineralogy

0–120 cms: Mainly illite, with very small amounts of kaolinite and traces of gibbsite. Little differentiation between horizons.

Comments

Further data on Profile 3 are included in Tables 19, 20 and 21, and in Fig. 40. This profile is included in the numerical ordination study.

Profile 5

Family: MERIT *Series:* Jakar clay loam.

Site: Summit of low rise in gently undulating terrain; 1° slope. *Parent material:* Miocene shales (Balingian Formation). *Location:* Penipah headwaters, Mukah Subdistrict; (2/112/2; 163.557). *Cover:*4-year old regrowth, following hill rice. *Reference samples:* S5165/5175.

Field morphology

A1 *0–13 cms:* Brown to dark brown (10YR 4/2) clay loam. Moist. Weak fine angular blocky structure. Friable. Many rootlets. Few pores. Diffuse wavy boundary.

A21 *13–38 cms:* Strong brown (7.5YR 5/6) clay loam. Moist. Weak coarse angular blocky structure, breaking to fine. Slightly firm. Few rootlets. Few pores. Diffuse wavy boundary.

Table 61

Profile 5, analytical data for fine earth (<2mm)

Depth (cms)			*0* *13*	*13* *38*	*38* *58*	*58* *79*	*79* *91*	*91* *107*
Granulometric analysis (%)								
2 – 1 mm	(vcs)		0.1	0.2	0.1	0.4	5.1	0.3
1 – 0.5 mm	(cs)		0.7	0.4	0.3	0.5	4.1	0.4
0.5 – 0.2 mm	(ms)		1.8	1.7	1.3	1.4	2.4	0.9
0.2 – 0.1 mm	(fs)		15.7	9.4	8.7	8.3	5.8	4.5
0.1 – 0.05 mm	(vfs)		23.3	27.5	27.6	24.8	19.9	23.7
sand (2 – 0.05 mm			41.7	39.2	38.0	35.3	37.3	29.9
silt (0.05 – 0.002 mm)			31.2	25.0	22.8	19.1	19.9	24.9
clay (0.002 mm)			27.1	35.8	39.2	45.6	42.8	45.2
% clay water-dispersable			20	24	1	<1	<1	<1
Chemical analysis								
pH		H_2O	3.4	3.5	4.6	3.7	3.8	3.7
pH		KCl	3.5	3.5	4.0	3.6	4.1	3.6
C		%	2.76	0.82	0.49	0.42		
N		%	0.20	0.08	0.06	0.06		
C/N			14	10	8	7		
CEC		me %	10.4	10.2	10.5	13.3	12.7	16.5
Exch. Ca		me %	1.3	0.3	0.2	0.1	0.1	t
Exch. Mg		me %	0.8	0.3	0.1	0.1	0.2	0.3
Exch. K		me %	1.4	0.5	0.3	0.4	0.4	0.5
Exch. Na		me %	1.5	0.9	1.2	1.1	0.9	1.4
Base saturation		%	48	19	17	13	12	14
Extr. Ca (HCl)		ppm	320	110	110	210	320	210
Extr. Mg (HCl)		ppm	320	380	950	1270	2702	1290
Extr. K (HCl)		ppm	480	370	850	1150	2006	1730
Extr. P (HCl)		ppm	50	50	70	70	50	70
Extr. Fe (Morgan)		ppm	130	280	14	7	7	5
Extr. Al (Morgan)		ppm	500	740	720	860	800	1340
Extr. Mn (Morgan)		ppm	t	t	t	t	t	t
Extr. Zn (Morgan)		ppm	2	2		t		
Extr. Cu (Morgan)		ppm	t	t				
P retention		%	69	63	61	55	41	40

A22 *38–58 cms:* Strong brown to yellowish red (5-7.5YR 5/7) clay loam. Otherwise as above. Diffuse wavy boundary.

B21 *58–79 cms:* Strong brown to yellowish red (5YR 5.5/8) clay, reddish yellow (7.5YR 6/6) on some ped faces. Moist. Weak coarse angular blocky structure. Slightly friable. Few rootlets. Few pores. Rare small fragments of iron-enriched weathered shale. Indistinct wavy boundary.

B22 *79–91 cms:* Yellowish red (5YR 5/8) clay. Moist Massive. Slightly firm. Abundant platy or irregular fragments of iron-enriched weathered shale and root-pipe fragments. Few rootlets. No pores seen. Indistinct wavy boundary.

B3 *91–107 cms:* Red (2.5YR 4/8) and yellow (10YR 7/6) finely mottled clay. Moist. Massive. Slightly firm. Few rootlets. No pores seen.

Comments

See also Fig. 40. Mottled clay continues to a depth of 140 cms, at which level weathered shale is encountered. This profile is included in the numerical ordination study.

Profile 6

Family: BEKENU. *Series: Bekenu sandy clay loam.*

Site: Middle slope of moderately rolling terrain; 15° slope. *Parent material:* Tertiary shales and subordinate sandy shales or sandstones. *Location:* Near mile 3, Tanggi spur road; Sibu District; (2/112/9; 540.324). *Cover:* Shrubs and scattered trees; regrowth following hill rice 6 years previously. *Reference samples:* S7585/7590.

Field morphology

A1 *0–8 cms:* Dark yellowish brown (10YR 4/4) sandy clay loam. Moist. Massive. Very friable. Abundant rootlets. Few pores. Diffuse wavy boundary.

A2 *8–23 cms:* Yellowish brown (10YR 5/8) sandy clay loam, with few large distinct light grey and strong brown gley mottles. Moist. Very weak coarse subangular blocky structure. Friable. Many rootlets. Few pores. Dark greyish brown infilling in some old root channels. Indistinct wavy boundary.

A3 *23–43 cms:* Yellowish brown to brownish yellow (10YR 5.5/8) sandy clay loam, with many coarse faint reddish yellow mottles and few fine distinct light grey mottles. Moist. Very weak coarse angular blocky structure. Firm. Many rootlets. Few pores. Indistinct wavy boundary.

B21 *43–64 cms:* Red (2.5YR 5/8) and yellowish red (5YR 5/8) coarsely mottled sandy clay loam with many medium distinct light grey mottles. Moist. Massive. Very firm. Many rootlets. No pores seen. Distinct wavy boundary.

B22 *64–79 cms:* Angular hard fragments of iron-enriched weathered shale and fine quartz gravel in a matrix of coarsely mottled sandy clay loam as in overlying horizon. Moist. Massive. Very firm. Rare rootlets. No pores seen. Indistinct wavy boundary.

C *79–120 cms:* Red weathered shale and thin bands of secondary quartz in a matrix of pale yellow clay. Very rare rootlets. No pores seen.

Micromorphology

10–20 cms: Abundant medium and fine subangular quartz sand grains and few, very fine rolled zircons, tourmalines and rutiles in a brownish yellow to very pale brown asepic matrix. Many large irregular channels; no discrete structural peds. Many large and medium, equant and irregular, voids, commonly occupied by roots. No cutans on channels or other void faces.

30–40 cms: Abundant fine, and few medium, subangular quartz sand grians and scattered, very fine, rolled zircons and tourmalines in a pale brown asepic matrix with many coarse distinct irregular strong brown and reddish brown mottles, the matrix locally skelsepic in mottled areas. Many, medium and small, irregular channels and scattered, medium and fine, irregular or equant voids; no discrete structural peds. Few, very thin, intermittent, diffuse, pale brown cutans on some channels walls, but the majority clear. Thin, well-defined, brownish yellow cutans on some fine equant voids. Rare large, well-defined, finely variegated, dark brown and pale brown striotubules. Many small fecal pellets in voids and matrix. Few roots.

50–60 cms: Abundant small, and few medium and large, subangular quartz sand grains and very rare, very fine, zircons and tourmalines in a complex variegated matrix with three dominant components: (a) pale brown asepic material with few fine equant voids, some with thin, well-defined, brownish yellow cutans; (b) diffusely variegated yellowish brown, reddish yellow and dark reddish brown, omnisepic to skelsepic material with many short irregular channels and medium and fine irregular voids with thin, diffuse to well-defined, yellowish brown cutans; (c) medium and large striotubules of reworked (a) and (b) material. Matrix separations (a) and (b) are coarse, irregular and diffusely to abruptly separated. Rare long, narrow, irregular channels cross all matrix separations and lack cutans; no discrete structural peds. Scattered medium, irregular to ovoid, ferric nodules, comprising very fine quartz sand grains in a red to very dark reddish brown isotic matrix. Few roots.

Clay mineralogy

23–64 cms; 79–120 cms: Mainly illite and kaolinite in approximately the same amounts.

Table 62

Profile 6, analytical data for fine earth (<2mm)

Depth (cms)		*0* *8*	*8* *23*	*23* *43*	*43* *64*	*64* *79*	*79* *120*
Granulometric analysis (%)							
2 – 1 mm	(vcs)	t	0.1	0.2	0.6	13.4	
1 – 0.5 mm	(cs)	0.6	0.7	0.7	0.8	10.7	
0.5 – 0.2 mm	(ms)	1.4	1.5	1.2	1.0	4.4	
0.2 – 0.1 mm	(fs)	5.1	6.0	5.2	3.5	3.4	
0.1 – 0.05 mm	(vfs)	45.1	48.7	49.3	41.1	17.9	
sand (2 – 0.05 mm)		52.2	57.0	56.5	46.9	49.9	
silt (0.05 – 0.002 mm)		26.0	23.0	20.0	20.4	12.6	
clay (0.002 mm)		21.8	20.0	23.5	32.7	37.5	
% clay water-dispersable			60	81	5		
Chemical analysis							
pH	H_2O	4.6	5.1	4.9	4.9	5.2	5.2
pH	KCl	4.8	4.3	3.6	3.6		
C	%	6.54	1.67	0.34	0.24	0.26	0.15
N	%	0.42	0.14	0.04	0.03	0.05	0.03
C/N		16	12	9	8	5	5
CEC	me %	10.6	2.5	2.3	2.6	3.6	2.5
Exch. Ca	me %	1.0	t	0.1	0.1	t	0.2
Exch. Mg	me %	1.2	0.1	t	t	t	t
Exch. K	me %	0.3	0.1	0.1	0.1	0.1	0.1
Exch. Na	me %	0.1	t	t	t	t	t
Base saturation	%	25	10	11	9	4	12
Exch. Al	me %	7.2	4.6	3.7	4.3	4.1	2.6
Extr. Ca (HCl)	ppm	90	t	t	80		
Extr. Mg (HCl)	ppm	980	930	900	1440		
Extr. K (HCl)	ppm	1840	2280	2120	3960		
Extr. P (HCl)	ppm	180	80	70	90		
Extr. Fe (Morgan)	ppm	90	60	29	11		
Extr. Al (Morgan)	ppm	900	790	600	710		
Extr. Mn (Morgan)	ppm	7	2	2	2		
Extr. Zn (Morgan)	ppm	1	t	1	t		
Extr. Cu (Morgan)	ppm	t	t	t	t		
Extr. Fe_2O_3 (Na_2CO_3)	%	1.6	1.2	2.0	2.7	7.5	9.4
Extr. Al_2O_3 (Na_2CO_3)	%	8.2	11.5	12.2	18.8	26.7	23.8

Table 63

Profile 7, analytical data for fine earth (<2mm)

Depth (cms)		*0*	*3*	*8*	*23*	*36*	*53*	*70*
		3	*8*	*23*	*36*	*53*	*70*	*130*
Granulometric analysis (%)								
2 — 1 mm	(vcs)	0.4	0.3	0.2	0.1	0.4		
1 — 0.5 mm	(cs)	1.5	1.2	0.9	1.1	1.4		
0.5 – 0.2 mm	(ms)	4.0	4.1	1.7	2.8	1.5		
0.2 – 0.1 mm	(fs)	5.3	8.3	5.9	5.1	5.2		
0.1 – 0.05 mm	(vfs)	18.3	33.3	29.8	27.1	25.2		
sand (2 – 0.05 mm)		29.4	47.2	38.4	36.3	33.7		
silt (0.05 – 0.002 mm)		37.8	15.4	31.1	32.9	31.1		
clay (0.002 mm)		32.8	37.4	30.5	30.8	35.2		
% clay water-dispersable		15	14	42	46	6	<1	<1
Chemical analysis								
pH	H_2O		3.8	4.5	4.5	4.5	4.6	
pH	KCl		3.6	3.5	3.6	3.6	3.8	
C	%	3.14	1.41	0.47	0.34	0.28	0.19	0.23
N	%	0.21	0.10	0.06	0.06	0.06	0.05	0.06
C/N		15	14	9	6	5	4	4
CEC	me %	14.4	9.4	7.7	4.5	5.0	4.7	4.4
Exch. Ca	me %	0.4	0.1	0.1	t	t	t	t
Exch. Mg	me %	0.1	0.2	0.2	0.3	0.1	0.2	0.1
Exch. K	me %	0.3	1.2	0.4	0.2	0.1	0.2	0.3
Exch. Na	me %	1.3	1.3	1.1	1.2	0.8	1.0	0.6
Base saturation	%	15	30	23	36	21	29	23
Exch. Al	me %	6.9	6.3	7.7	6.0	4.4	3.8	4.0
Extr. Ca (HCl)	ppm	250	190	170	100	170	210	170
Extr. Mg (HCl)	ppm	950	760	1050	1080	1380	1320	1440
Extr. K (HCl)	ppm	3100	2950	4200	4550	5400	9000	9600
Extr. P (HCl)	ppm	180	130	110	120	120	140	120
Extr. Fe (Morgan)	ppm			43	31	13		
Extr. Al (Morgan)	ppm			1000	910	700		

Comments

Further data are included in Fig. 41. This is one of the few upland profiles in which apparently illuvial cutans are sufficiently common in thin section to meet the limits of the USDA argillic horizon. The profile is included in the numerical ordination study.

Profile 7

Family: BEKENU. *Series:* Sarikei clay loam.

Site: Upper slope of gently rolling terrain; 3° slope. *Parent material:* Tertiary shale. *Location:* Repok Road, Sarikei District; (2/111/15; 253.734). *Cover:* Low grass regrowth (including *Imperata cylindrica)* following hill rice. *Reference samples:* S2827/2835.

Field morphology

A11 *0–3 cms:* Brown to dark brown (10YR 4/3) clay loam. Moist. Structureless. Friable. Abundant rootlets. Distinct wavy boundary.

A12 *3–8 cms:* Brown (10YR 5/3) sandy clay, with many fine and medium distinct pale brown and reddish yellow mottles. Moist. Weak coarse subangular blocky structure. Firm. Many rootlets. Few pores. Few charcoal fragments. Distinct wavy boundary.

A2 *8–23 cms:* Reddish yellow (7.5YR 6/6) clay loam, with many medium distinct light yellowish brown mottles and few distinct fine red mottles. Moist. Weak coarse subangular blocky structure. Firm. Few rootlets. Few pores. Indistinct wavy boundary.

A3 *23–36 cms:* Strong brown (7.5YR 5/6) clay loam, with few fine faint light yellowish brown mottles and few medium distinct red mottles. Moist. Weak coarse angular blocky structure, breaking to fine blocky. Very firm. Few rootlets. Few pores. Diffuse wavy boundary.

B2 *36–53 cms:* Strong brown (7.5YR 5/8) clay loam, with abundant medium and coarse distinct red mottles. Moist. Structure as above. Very firm. Rare rootlets. Few pores. Diffuse wavy boundary.

B3 *53–70 cms:* Red (2.5YR 5/8) and yellowish red (5YR 5/8) coarsely mottled clay, with many fine distinct light yellowish brown mottles. Moist. Structure as above. Firm. Many medium and small hard angular fragments of red weathered shale. Frequent medium and coarse angular quartz gravel. Rare rootlets. Few pores. Diffuse wavy boundary.

C *70–130 cms:* Weak red (5R 5/3) and red (10R 4/8) large hard angular shale fragments in a matrix of yellowish red (5YR 5/8) clay, with many fine distinct light yellowish brown and white mottles and light yellow clay along the faces of some shale fragments. Moist. Massive. Firm. Very rare rootlets. No pores seen.

Clay mineralogy

23–53 cms; 70–94 cms: Mainly illite, with some moderately crystallised kaolinite.

Comments

See also Table 21 and Fig. 41. This profile is included in the numerical ordination study.

Profile 8

Family: NYALAU. *Series:* Nyalau sandy clay loam.

Site: Upper slope of strongly rolling terrain; 15° slope. *Parent material:* Miocene sandstone. *Location:* Bunyoh River, middle Arip valley, Balingian Subdistrict; (2/112/7; 022.964). *Cover:* Dipterocarp forest. *Reference samples:* S7793/7799.

Field morphology

A1 *0–5 cms:* Dark yellowish brown (10YR 4/4) sandy clay loam. Moist. Very weak fine subangular blocky structure. Friable. Abundant roots and rootlets. Few pores. Indistinct wavy boundary.

A2 *5–15/30 cms:* Brownish yellow (10YR 6/6) sandy clay loam, with prominent dark brown and reddish brown root-channel infillings. Moist. Very weak coarse subangular blocky structure. Very friable. Many roots and rootlets. Few pores. Diffuse irregular boundary.

B21 *15/30–48 cms:* Brownish yellow (10YR 6/6) sandy clay loam. Moist. Massive, except for narrow subvertical cracks. Friable. Many rootlets. Few large pores. Diffuse wavy boundary.

B22 *48–110 cms:* Brownish yellow (10YR 6/6) sandy clay loam. Moist. Massive, except for narrow subvertical cracks; crack surfaces intermittently polished, extensively and prominently so at depth (thin sections show no clay coatings). Friable. Rare small soft pale brown and yellowish brown lithorelicts. Few rootlets. Few large pores.

Micromorphology

33–43 cms: Abundant, medium and small, subangular quartz sand grains, and very rare small tourmalines and zircons, in a pale brown asepic to skelsepic matrix. Many, large and medium, irregular channels, commonly linking large irregular chambers; scattered, intermittent, very thin, diffuse to well-defined, pale brown cutans on some channel walls; no discrete structural peds. Scattered small, irregular and equant, voids with intermittent, very thin, diffuse, pale brown cutans. Rare, medium, very dark brown, ovoid or irregular, ferric nodules. Few live roots.

Table 64

Profile 8, analytical data for fine earth (<2mm)

Depth (cms)			*0* *5*	*5* *15/30*	*15/30* *48*	*48* *76*	*76* *110*
Granulometric analysis (%)							
2 – 1 mm	(vcs)		1.4	0	0	0	0
1 – 0.5 mm	(cs)		2.7	0.1	0.1	0.1	0.1
0.5 – 0.2 mm	(ms)		11.7	11.6	11.5	11.7	10.4
0.2 – 0.1 mm	(fs)		32.1	38.8	34.7	34.6	33.9
0.1 – 0.05 mm	(vfs)		13.1	16.2	12.4	15.8	16.0
sand (2 – 0.05 mm)			61.0	66.8	58.7	62.3	60.4
silt (0.05 – 0.002 mm)			12.1	13.3	13.7	11.7	12.6
clay (0.002 mm)			26.9	20.0	27.6	26.1	26.9
% clay water-dispersable				71	73	10	
Chemical analysis							
pH		H_2O	3.5	4.3	4.8	4.9	4.9
pH		KCl	2.2	3.6	3.9	3.7	3.6
C		%	8.87	0.83	0.56	0.09	0.12
N		%	0.43	0.07	0.06	0.03	0.03
C/N			21	12	10	4	5
CEC		me %	43.9	8.0	4.4	5.0	5.7
Exch. Ca		me %	0.3	0.4	0.3	0.3	0.3
Exch. Mg		me %	0.6	0.1	t	t	t
Exch. K		me %	0.5	0.1	0.1	0.1	0.1
Exch. Na		me %	0.2	0.1	0.1	0.1	0.1
Base saturation		%	4	8	11	8	7
Extr. Ca	(HCl)	ppm		t	t	t	
Extr. Mg	(HCl)	ppm		400	620	720	
Extr. K	(HCl)	ppm		1250	1680	2120	
Extr. P	(HCl)	ppm	160	190	320	60	160
Extr. Fe	(Morgan)	ppm		43	31	13	
Extr. Al	(Morgan)	ppm		1070	1030	770	
Extr. SiO_2	(Na_2CO_3)	%	44.8	42.3	41.1	41.8	43.3
Extr. Fe_2O_3	(Na_2CO_3)	%	2.4	5.0	5.1	6.1	5.0
Extr. Al_2O_3	(Na_2CO_3)	%	26.0	32.0	33.0	33.0	33.0

82-92 cms: Abundant, medium and small, subangular quartz sand grains, and very rare small tourmalines and zircons, in a pale brown to brownish yellow, skelsepic matrix. Many medium, irregular and acicular channels linking medium and very irregular chambers; no cutans; no discrete structural peds. Many, medium and fine, equant to irregular voids, clustered and commonly interconnected, some with medium to thin, diffuse, brownish yellow cutans. Rare, fine, ovoid and irregular, very dark brown ferric nodules.

Comments

See also Figs. 42 and 45. Variegated massive sandy clay loam underlies the profile described and, below 130 cms, thin inclined bands of iron-enriched weathered sandstone follow relict rock structure lines. This profile is included in the numerical ordination study.

Profile 9

Family: NYALAU. *Series:* Nyalau very fine sandy loam.

Site: Upper slope in steeply rolling terrain; slope 20° . *Parent material:* Tertiary sandstone, but the profile overlies material derived from weathered shale. *Location:* Near mile 3, Tanggi spur road; Sibu District; (2/112/9; 540.324). *Cover:* Broken primary forest. *Reference samples:* S7578/7584.

Table 65

Profile 8, heavy minerals in 0.08–0.1 mm sand fraction

Depth (cms)		*5* / *15/30*	*15/30* / *48*	*48* / *76*	*76* / *110*	*110* / *133*
% heavies		0.34	0.35	0.19	0.27	0.45
% opaques		73	73	71	70	76
% non-opaques		27	27	29	30	24
Opaques (%)						
Ilmenite, etc		5	6	5	7	4
Leocoxene, etc		94	93	92	86	95
Limonite, etc		1	1	3	7	1
Non-opaques (%)						
Zircon	clear, rolled	30	14	44	46	17
	clear, worn	15	17	25	22	25
	pink, rolled	6	2	2	8	–
	pink, worn	1	1	2	1	–
Tourmaline	brown	5	26	6	3	14
	green	14	25	5	6	23
	blue	4	1	2	2	7
Rutile	red	2	1	3	1	2
	yellow	6	3	4	8	1
Brookite		1	–	–	–	7
Anatase		13	11	6	2	1
Corundum		t	–	–	–	–
Unknown		3	1	–	1	–
Alterites		–	3	2	1	2

A1 *0–5 cms:* Brown to dark brown (10YR 4/3) very fine sandy loam. Moist. Massive. Loose. Abundant rootlets. Many pores. Diffuse wavy boundary.

A2 *5–30 cms:* Brownish yellow (10YR 6/8) very fine sandy loam, with few large faint grey mottles. Moist. Massive. Friable. Greyish brown staining associated with old root channels. Many rootlets; rare large roots. Few pores. Diffuse wavy boundary.

B1 *30–48 cms:* Brownish yellow (10YR 6/8) sandy clay loam. Moist. Massive. Friable. Scattered rare sandstone gravel and cobbles. Few rootlets. Rare pores. Diffuse wavy boundary.

B2 *48–79 cms:* Brownish to reddish yellow (7.5–10YR 6/8) sandy clay loam. Moist. Very weak coarse subangular blocky structure. Friable. Rare well-weathered sandstone cobbles. Rare rootlets. Rare pores. Diffuse wavy boundary.

B3 *79–112 cms:* Reddish yellow (7.5YR 6/8) very fine sandy loam, with abundant well-weathered brittle strong brown and red sandstone fragments and rare cobbles. Moist. Massive. Friable matrix. No roots or pores seen. Indistinct wavy boundary.

C *112–120 cms:* Red (2.5Y 5/6), light grey (2.5Y 7/2) and yellow (10YR 7/8) finely variegated clay loam, derived mainly from weathered shale. Moist. Massive. Slightly plastic. No roots or pores seen. A thin inclined layer of dark red weathered sandstone angles through this horizon.

Micromorphology

5–15 cms: Abundant medium and small quartz sand grains and very rare small rolled tourmalines and zircons in a brownish yellow skelsepic matrix. Many broad irregular anastomosing channels, isolating many small structural units but rarely bounding larger blocks. Few small and medium irregular voids. Thin diffuse brownish yellow cutans on some small voids; channel walls clear. Rare medium irregular ferric nodules comprising medium and small quartz grains in a dark brown isotic matrix. Scattered fine ovoid fecal pellets. Rare live roots.

18–28 cms: Abundant medium and small subangular quartz sand grains and very rare small rolled tourmalines and zircons in a brownish yellow skelsepic matrix. Many large subtabular

discrete channels and large and medium equant voids; no discrete structural peds. Rare diffuse thin brownish yellow cutans on some voids, rare and intermittent on some channel walls. Rare medium irregular ferric nodules comprising quartz grains in a dark brown to dark reddish brown isotic matrix.

38–48 cms: Abundant medium and small subangular quartz sand grains and very rare small rolled tourmalines in a brownish yellow skelsepic matrix. Few long narrow aciculaf channels, not combining to define discrete structural peds. Few fine equant voids with medium diffuse brownish yellow cutans, such voids commonly clustered; voids rare in much of matrix. No cutans seen on channel walls. Scattered large irregular ferric nodules as in section above.

Comments

The abrupt textural break at 112 cms, the scattered cobbles and the steep slope all indicate that the profile above this depth comprises material moving rapidly downslope.

Table 66

Profile 9, analytical data for fine earth (<2mm)

Depth (cms)			*0*	*5*	*30*	*48*	*79*	*112*
			5	*30*	*48*	*79*	*112*	*120*
Granulometric analysis (%)								
2 – 1 mm	(vcs)		0.8	0.1	0.2	0.2	0.1	0.1
1 – 0.5 mm	(cs)		1.5	0.8	1.2	0.8	1.5	0.5
0.5 – 0.2 mm	(ms)		10.1	9.9	9.0	8.7	6.3	3.3
0.2 – 0.1 mm	(fs)		30.1	32.6	31.6	30.2	31.3	15.6
0.1 – 0.05 mm	(vfs)		23.6	25.5	24.6	24.2	26.4	23.1
sand (2 – 0.05 mm)			66.1	68.9	66.6	64.1	65.6	42.6
silt (0.05 – 0.002 mm)			14.9	12.0	12.8	15.2	18.7	24.2
clay (0.002 mm)			19.1	19.2	20.7	20.7	15.7	33.3
% clay water-dispersable								
Chemical analysis								
pH		H_2O	4.1	4.8	5.1	5.2	5.0	4.9
pH		KCl	3.4	3.9	4.0	4.0	4.0	3.9
C		%	3.12	0.39	0.08	0.06	0.06	0.12
N		%	0.19	0.05	0.03	0.02	0.04	0.42
C/N			16	8	3	4	4	
CEC		me %	9.4	2.6	2.3	1.8	2.0	4.0
Exch. Ca		me %	0.3	0.1	t	0.1	0.1	0.1
Exch. Mg		me %	0.6	t	t	t	t	t
Exch. K		me %	0.2	0.1	0.1	t	t	0.1
Exch. Na		me %	0.1	t	t	t	t	t
Base saturation		%	13	7	4	10	8	6
Exch. Al		me %	7.7	4.2	3.6	3.6	2.9	6.2
Extr. Fe_2O_3	(Na_2CO_3)	%	1.7	1.8	2.5	2.3	3.4	2.3
Extr. Al_2O_3	(Na_2CO_3)	%	7.3	11.5	12.7	15.7	19.1	22.9

Table 67

Profile 9, heavy minerals in 0.08–0.1 mm sand fraction

Depths (cms)		*0* *5*	*5* *15*	*15* *30*	*30* *48*	*48* *120*
% heavies			0.20	0.12	0.19	
% opaques			85	83	74	
% non-opaques			15	17	26	
Opaques (%)						
Ilmenite, etc.			1	4	2	
Leocoxene, etc			96	95	86	
Limonite, etc			2	—	12	
Pyrite			1	1	—	
Non-opaques (%)						
Zircon	clear, rolled		14	20	24	
	clear, worn		20	28	37	
	clear, euhedral		2	—	1	
	pink, rolled		—	2	—	
	pink, worn		—	2	—	
Tourmaline	brown		6	14	21	
	green		44	18	7	
	blue		—	—	1	
Rutile	red		2	—	—	
	yellow		4	12	3	
Brookite	rough		—	—	4	
Alterites			6	3	—	
Others			2	1	1	

Profile 10

Family: NYALAU. *Series:* Nyalau sandy clay loam.

Site: Upper slope in moderately rolling terrain; profile sampled in road-cutting exposure; original slope approx. 5°. *Parent material:* Tertiary sandstone. *Location:* Mile 279, Oya Road; Sibu District; (2/111/12; 533.113). *Cover:* Regrowth; old rubber nearby. *Reference samples:* MS1512/1517

Field morphology

A1 *0–8 cms:* Very dark greyish brown (10YR 3/2) sandy clay loam. Moist. Very weak coarse granular structure. Loose. Abundant rootlets. Few pores. Indistinct wavy boundary.

B21 *8–23 cms:* Yellowish brown (10YR 5/8) sandy clay loam, with dark yellowish brown stains near root channels. Moist. Massive. Friable. Many roots and rootlets. Few pores. Diffuse wavy boundary.

B22 *23–46 cms:* Yellowish brown (10YR 5/8) sandy clay loam. Moist. Weak coarse subangular blocky structure. Few pressure coatings. Friable. Many roots and rootlets. Few pores. Diffuse wavy boundary.

B3 *46–66 cms:* Yellowish brown (10YR 5/8) sandy clay loam. Many pressure coatings. Few rootlets. Otherwise as above. Diffuse wavy boundary.

C *66–120 cms:* Yellowish brown (10YR 5/8) fine sandy loam. Few pressure coatings. Few rootlets. Otherwise as above.

Micromorphology

18–28 cms: Abundant medium and small quartz sand grains, rare very small rolled zircons, tourmalines and rutiles, and small ovoid, dark reddish brown ferric nodules, in a brownish yellow skelsepic matrix. Few long, irregular, narrow channels; rare large, equant to irregular, voids; many very small, short, discrete, acicular channels with random orientation; no discrete structural peds. Many small equant voids. Very rare, small, well-defined, brownish yellow cutan fragments locally present on few larger channel walls; cutans absent from other void surfaces. Few live roots. Many small carbonised wood fragments.

46–56 cms: Abundant, medium and small, subangular quartz sand grains, and rare, very small zircons, tourmalines and rutiles, in a brownish yellow skelsepic matrix. Scattered medium irregular channels; many, very small, short, discrete, acicular channels with random orientation or central between adjacent grain surfaces and roughly accordant with them; scattered medium irregular voids; no discrete structural peds. Fragments of thick, well-defined, poorly-orientated, brownish yellow cutans with included coarse silt grains on walls of some larger voids; cutans absent from other surfaces. Few live roots in larger channels.

Table 68

Profile 10, analytical data for fine earth (<2mm)

Depth (cms)			*0*	*8*	*23*	*46*	*66*
			8	*23*	*46*	*66*	*120*
Granulometric analysis (%)							
2 – 1 mm	(vcs)		0	0	0	0	t
1 – 0.5 mm	(cs)		0.6	2.1	1.8	1.8	1.7
0.5 – 0.2 mm	(ms)		15.8	22.1	20.5	20.8	19.8
0.2 – 0.1 mm	(fs)		22.6	21.5	21.8	21.8	21.6
0.1 – 0.05 mm	(vfs)		24.8	21.4	23.6	22.6	23.3
sand (2 – 0.05 mm)			63.7	67.0	67.6	67.1	66.5
silt (0.05 – 0.002 mm)			10.7	6.5	5.7	10.2	20.8
clay (0.002 mm)			25.6	26.5	26.7	22.7	12.8
% clay water-dispersable				77	8	4	
Chemical analysis							
pH		H_2O	3.5	4.3	4.3	4.3	4.4
pH		KCL	3.2	4.1	4.0	3.9	4.0
C		%	9.80	0.40	0.28	0.13	0.10
N		%	0.51	0.05	0.04	0.03	0.02
C/N			19	9	7	5	5
CEC		me %	22.5	2.4	2.5	2.1	2.0
Exch. Ca		me %	1.0	0.1	0.3	0.1	0.1
Exch. Mg		me %	0.6	0.1	0.1	0.3	0.4
Exch. K		me %	0.4	0.1	0.2	0.1	0.1
Exch. Na		me %	0.2	0.1	0.3	0.3	0.2
Base saturation		%	10	12	33	34	40
Extr. Ca	(HC1)	ppm	390	100	100	100	130
Extr. Mg	(HC1)	ppm	420	330	340	430	450
Extr. K	(HC1)	ppm	540	510	510	560	690
Extr. P	(HC1)	ppm	190	60	60	60	50
Extr. Fe_2O_3	(6NHC1)	%	2.8	2.0	2.9	2.4	2.6
Avail. P		ppm	14	3	7	3	4

Table 69

Profile 11, analytical data for fine earth (<2mm)

Depth (cms)			*0* *15*	*15* *33*	*33* *75*	*75* *120*
Granulometric analysis (%)						
sand (2 – 0.05 mm)			72.6	71.1	77.1	
silt (0.05 – 0.002 mm)			21.3	25.1	20.3	
clay (0.002 mm)			6.1	3.8	2.6	
Chemical analysis						
pH		H_2O	3.7	5.1	5.1	
pH		KCL	3.5	3.8	4.4	
C		%	0.89	0.49	0.24	
N		%	0.14	0.06	0.04	
C/N			16	12	15	
CEC		me %	9.2	4.6	2.4	
Exch. Ca		me %	0.4	0.3	0.1	
Exch. Mg		me %	0.2	0.2	0.2	
Exch. K		me %	0.1	0.1	0.3	
Exch. Na		me %	0.4	0.4	0.5	
Base saturation		%	12	20	44	
Extr. Ca	(HC1)	ppm	80	100	80	40
Extr. Mg	(HC1)	ppm	490	630	550	710
Extr. K	(HC1)	ppm	2550	3250	2700	3400
Extr. P	(HC1)	ppm	250	150	130	150

72–81 cms: Abundant, medium and small, subangular quartz sand grains, and rare very small rolled zircons, tourmalines and rutiles, in a brownish yellow skelsepic matrix. Many large irregular channels and large and medium irregular voids; very small acicular channels present as in other horizons studied but less frequent and randomly orientated; no discrete structural peds. Many small and medium irregular voids. No cutans seen.

Clay mineralogy

0–120 cms: Well-crystallised kaolinite with some vermiculite. Small amounts of gibbsite, becoming less with depth.

Comments

Below 66 cms the profile is developed in residual material from weathered sandstone. The higher clay content of horizons above this level suggests that nearby shale beds also contribute to the parent material and that some lateral mixing has taken place. This profile is included in the numerical ordination study.

Profile 11

Family: PENINJAU. *Series:* Sebaya sandy loam.

Site: Terrace flat abruptly bounded by steep cutoff slope; present floodplain 2½ metres below terrace elevation; no measurable slope. *Parent material:* Non-accreting riverine alluvium derived from Tertiary sedimentary rocks. *Location:* Tanjong Rantau Sebaya, Kanowit River, between Julau and Machan; Kanowit District; (2/111/16; 244.195). *Cover:* Old rubber in tapping. *Reference samples:* S3344/3348.

Field morphology

A11 *0–15 cms:* Very dark greyish brown (10YR 3/2) very fine sandy loam. Moist. Weak crumb structure. Loose. Few rootlets. Few pores. Indistinct smooth boundary.

A12 *15–33 cms:* Dark yellowish brown (10YR 4/4) sandy loam. Moist. Massive. Loose. Rare rootlets. Few pores. Diffuse smooth boundary.

A/C *33–75 cms:* Yellowish brown to dark yellowish brown (10YR 4.5/5) loamy sand. Moist. Single-grain structure. Loose. No roots seen. Diffuse smooth boundary.

C *75-120 cms:* Yellowish brown (10YR 5/6) loamy sand. Moist. Single-grain structure. Loose. No roots seen.

Comments

This profile is located in Sample Area F. Profile 32 is sited on the floodplain tract adjacent to this terrace.

Profile 12

Family: PENINJAU. *Series:* Peninjau loamy fine sand.

Site: Gravel pit exposure on upper slope of moderately undulating terrain; 5° slope. *Parent material:* Tertiary sandstone; abundant fresh secondary quartz crystals in spoil from excavated weathering zone. *Location:* Near Sungei Bankong school, Kelupu road; Binatang District; (2/111/15; 339.863). *Cover:* Old rubber and thick shrub growth. *Reference samples:* MS1490/1491; 1494/1495; 1660/1663.

Field morphology

A1 *0–8 cms:* Dark greyish brown (10YR 4/2) fine sandy loam. Moist. Massive. Friable. Porous. Abundant rootlets. Diffuse wavy boundary.

B(1) *8–28 cms:* Light olive brown (2.5Y 5/4) loamy fine sand. Moist. Single-grain structure. Loose. Few rootlets. Diffuse wavy boundary.

B(2) *28–50 cms:* Light olive brown (2.5Y 5/6) loamy sand. Moist. Single-grain structure. Loose. Rare rootlets. Diffuse wavy boundary.

C1 *50–70 cms:* Brownish yellow (10YR 6/6) fine gravelly loamy sand. Moist. Single-grain structure. Loose. Rare rootlets. Diffuse wavy boundary.

C2 *70–120 cms:* Brownish yellow (10YR 6/6) loamy sand with some fine and coarse gravel, becoming abundant at depth. Moist. Single-grain structure. Loose. Very rare rootlets.

Comments

This profile is included in the numerical ordination study.

Profile 13

Family: AJOH-MERIT intergrade. *Series:* Ajoh-Merit loam.

Site: Lower slope in very gently undulating terrain, 4° slope. *Parent material:* Tertiary shale. *Location:* Oya Road Forest Experimental Nursery; Sibu District; (2/111/12; 534.177). *Cover:* Poor regrowth; thick grass cover and scattered trees. *Reference samples:* S7563/7569.

Field morphology

A11 *0–5 cms:* Dark greyish brown (10YR 4/2) sandy loam. Moist. Weak medium subangular blocky structure. Friable. Many rootlets. Few charcoal fragments. Few pores. Diffuse wavy boundary.

A12 *5–15 cms:* Dark to very dark greyish brown (10YR 3.5/2) sandy loam. Moist. Weak medium subangular blocky structure. Friable. Many rootlets. Few charcoal fragments. Few pores. Diffuse wavy boundary.

A2 *15–30 cms:* Brownish yellow (10YR 6/6), strong brown (7.5YR 5/8) and very pale brown (10YR 7/4) coarsely variegated loam, with few medium distinct light grey mottles. Moist. Massive. Few rootlets. Few pores. Distinct wavy boundary.

B21 *30–46 cms:* Red (2.5YR 5/8) and very pale brown (10YR 7/3) coarsely variegated clay loam. Moist. Massive apart from sparse subvertical cracks (continuing to 63 cms). Firm. Rare rootlets. Few fine pores. Diffuse wavy boundary.

B22 *46–63 cms:* Yellowish red (5YR 4/8) and light grey (10YR 7/2) coarsely variegated clay. Moist. Structure as above, the crack surfaces pale brown (10YR 6/3). Firm. Few roots. No pores seen. Diffuse wavy boundary.

Table 70

Profile 12, analytical data for fine earth (<2mm)

Depth (cms)		*0* *8*	*8* *28*	*28* *38*	*38* *50*	*50* *61*	*61* *70*	*70* *120*
Granulometric analysis (%)								
2 – 1 mm	(vcs)	1.3	2.7	2.6	15.2	8.9	4.3	11.5
1 – 0.5 mm	(cs)	6.4	5.5	6.2	10.3	6.3	7.0	9.8
0.5 – 0.2 mm	(ms)	22.6	15.7	20.2	13.6	16.0	17.1	15.1
0.2 – 0.1 mm	(fs)	23.6	24.0	26.2	19.4	27.1	26.8	19.4
0.1 – 0.05 mm	(vfs)	24.3	33.2	25.9	19.9	21.6	25.7	24.5
sand (2 – 0.05 mm)		78.3	81.2	81.1	78.4	79.9	80.9	80.3
silt (0.05 – 0.002 mm)		6.9	8.2	16.1	19.6	17.0	17.1	17.4
clay (0.002 mm)		14.8	10.7	2.8	2.0	3.0	2.1	2.3
Chemical analysis								
pH	H_2O	4.4	4.6	4.4	4.3	5.0	5.0	4.5
pH	KCl	4.1	4.5	4.2	3.9	4.0	4.1	4.1
C	%	2.30	0.83	0.15	0.08	0.08	0.09	0.10
N	%	0.16	0.07	0.03	0.02	0.01	0.02	0.02
C/N		14	12	6	4	6	6	5
CEC	me %	5.4	9.5	0.4	0.8	2.0	2.2	0.8
Exch. Ca	me %	0.7	0.1	0.1	t	t	0.3	t
Exch. Mg	me %	0.2	0.1	0.1	t	0.1	0.2	t
Exch. K	me %	0.2	0.1	t	t	t	t	0.1
Exch. Na	me %	0.2	0.2	0.2	0.1	0.1	0.2	0.2
Base saturation	%	24	5	41	18	13	27	53
Extr. Ca (HCl)	ppm			100	120	120	100	
Extr. Mg (HCl)	ppm			250	350	270	370	
Extr. K (HCl)	ppm			360	710	410	360	
Extr. P (HCl)	ppm			30	20	20	20	
Extr. Fe (Morgan)	ppm			13	t	t		
Extr. Al (Morgan)	ppm			170	140	140		
Avail. P	ppm	6	5	1	1	1	t	3

C *63–120 cms:* White (10YR 8/2) clay, with profuse small and medium distinct red and brownish yellow mottles, becoming fewer with depth. Wet. Pastic. Sticky. Few rootlets. No pores seen. Below 90 cms weak red mottling is in inclined bands related to rock structure.

Micromorphology

5–18 cms: Few coarse and medium, and many fine and very fine, subangular quartz grains and rare small tourmalines and zircons in a light grey profusely mottled very fine dark yellowish brown humic isotic matrix. Many large irregular and few short acicular channels, not combining to define discrete structural peds; no cutans. Many fine equant voids without cutans. Many small fecal pellets. Scattered live roots, commonly in larger channels. Few small carbonised wood fragments.

18–25 cms: Quartz grains and rare zircons and tourmalines as above in a very pale brown diffusely mottled yellow, strong brown and reddish brown silasepic to argillasepic matrix, locally reorganised in many weakly defined striotubules. Rare subtabular channels and medium irregular chambers without cutans, commonly occupied by live roots; no discrete structural peds. Many

fine equant to irregular voids, some with thin distinct brownish yellow cutans. Many fine ovoid and few large ovoid or tabular ferric nodules.

33–43 cms: Very pale brown insepic material with diffuse irregular coarse mottles of yellow, dark yellowish brown to dark brown insepic to isotic material or in ellyptic masepic complexes with this material following resorting in striotubules; abundant fine and very fine subangular quartz grains and few medium and coarse quartz grains, the latter locally clustered without apparent reference to other matrix features. Many narrow short irregular to subtabular channels, crossing all matrix features or bordering subvertical or inclined medium and large striotubules; no discrete structural peds. Many fine and medium equant voids. Thin to medium distinct to diffuse brownish yellow to strong brown cutans on many fine pores and intermittently on smaller channels. Scattered small and medium abruptly-bound irregular to lenticular yellow, brownish yellow or strong brown plasma separations with weakly continuous fabric, commonly bordering striotubules. Rare fine irregular to ovoid dark reddish brown ferric nodules.

68–78 cms: Yellow to dark brown components more fragmented and sparser; matrix mainly pale to very pale brown. Abruptly-bound plasma separations with continuous fabric few. Otherwise as 33–43 cms.

Clay mineralogy

0–120 cms: Poorly-crystallised vermiculite and illite dominant throughout. Small amounts of poorly-crystallised kaolinite (increasing below 15 cms) and A1 and Fe oxides. Otherwise little contrast between horizons.

Comments

See also Tables 35 and 36. This profile is included in the numerical ordination study.

Table 71

Profile 13, analytical data for fine earth (<2mm)

Depth (cms)		*0* *5*	*5* *15*	*15* *30*	*30* *46*	*46* *63*	*63* *91*	*91* *120*
Granulometric analysis (%)								
2 – 1 mm	(vcs)	0	0.8	1.1	0.7	0	0.1	0.5
1 – 0.5 mm	(cs)	0.6	1.8	1.5	5.3	0.5	0.4	0.2
0.5 – 0.2 mm	(ms)	0.6	2.8	1.9	1.2	0.5	0.5	0.3
0.2 – 0.1 mm	(fs)	19.9	12.3	6.0	2.1	1.2	0.9	1.1
0.1 – 0.05 mm	(vfs)	31.9	36.5	37.0	23.4	18.5	14.4	11.3
sand (2 – 0.05 mm)		53.0	54.1	47.5	32.7	20.7	16.3	13.3
silt (0.05 – 0.002 mm)		34.0	33.9	32.8	32.8	34.5	35.1	37.8
clay (0.002 mm)		13.0	12.0	19.7	34.4	44.7	48.6	49.0
Chemical analysis								
pH	H_2O	4.3	4.5	4.6	4.8	5.0	4.9	5.0
pH	KCl	3.5	3.5	3.5	3.6	3.7	3.6	3.7
C	%	2.20	1.86	0.33	0.26	0.27	0.23	0.20
N	%	0.15	0.14	0.05	0.05	0.08	0.08	0.08
C/N		15	14	7	5	4	3	3
CEC	me %	3.2	2.6	2.0	2.9	3.5	4.1	4.3
Exch. Ca	me %	0.1	0.1	t	0.2	0.3	0.3	0.4
Exch. Mg	me %	0.2	0.2	0.1	0.1	t	0.2	0.3
Exch. K	me %	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Exch. Na	me %	0.1	0.1	t	t	t	t	0.1
Base saturation	%	17	17	9	12	10	15	18

Profile 14

Family: KERAIT. *Series:* Kerait loam.

Site: Upper slope of moderately undulating terrain; 3° slope. *Parent material:* Tertiary shale. *Location:* Near mile 3, Tanggi spur road; Sibu District; (2/112/9; 540.324). *Cover:* Regrowth (approximately 6 years old) of scattered trees and thick shrub cover, following hill rice. *Reference samples:* S7591/7595.

Field morphology

A1 *0–8 cms:* Dark grey (10YR 4/1) and greyish brown (10YR 5/2) loam. Moist. Very weak subangular blocky structure. Friable. Abundant roots and rootlets. Few pores. Indistinct wavy boundary.

A2 *8–23 cms:* Light grey (10YR 7/2) loam, with abundant medium distinct yellowish brown and strong brown mottles, scattered large dark grey patches of surface horizon material and grey coatings to main crack faces. Many rusty root channels. Moist. Very weak coarse angular blocky structure. Friable. Many rootlets. Few pores. Indistinct wavy boundary.

B2 *23–58 cms:* Light grey (2.5Y 7/2) clay loam, with many medium and coarse distinct yellowish brown mottles. Few rusty root channels. Moist. Weak very coarse angular blocky structure. Firm. Few rootlets. No pores seen. Indistinct wavy boundary.

B3 *58–120 cms:* Light grey (N7) clay with many fine and coarse distinct yellow and yellowish red mottles. Many rusty root channels. Moist. No structure seen apart from scattered subvertical cracks continuing from horizon above. Firm and slightly plastic. Rare rootlets. No pores seen.

Micromorphology

10–20 cms: Abundant very fine and fine subangular quartz grains and scattered medium and coarse quartz grains in a very pale brown insepic to weakly skelsepic matrix. Few very fine rolled zircons and tourmalines; rare rutiles. Few large irregular subvertical and subhorizontal channels linking medium irregular chambers and partially bounding incomplete coarse subangular blocks. Few medium and fine equant to irregular voids. No cutans on channels or voids. Scattered medium isotubules comprising fine quartz grains in a very pale brown, strong brown and black (humic) weakly insepic matrix. Scattered very fine fecal pellets.

28–38 cms: Abundant very fine and fine subangular quartz grains and scattered medium and coarse quartz grains in a very pale brown to light grey insepic matrix with diffuse fine to medium brown and brownish yellow mottles. Rare very fine zircons and tourmalines. Scattered long narrow irregular channels, bifurcating randomly and not combining to bound discrete structural peds. Very thin intermittent diffuse very pale brown cutans on some channel walls. Many fine and medium equant to irregular voids, with thin to medium well-ordered cutans, generally diffuse, some well-defined. Many very fine irregular humic fragments in matrix and intermittent humic coatings on some voids and quartz grains. Rare poorly-defined medium striotubules. Very rare live roots.

69–79 cms: Abundant very fine, many fine, and few medium subangular quartz grains and rare very fine rolled zircons in a light grey insepic to omnisepic matrix with scattered fine to coarse diffuse brownish yellow and brown mottles and many brownish yellow to yellow haloes round fine voids and channels. Many long thin irregular bifurcating channels partially bounding incomplete coarse and medium blocks. Few medium and fine equant voids. Few thin to medium diffuse light grey cutans on some voids; channel walls clear. Rare medium poorly-defined partial striotubules. Fecal pellet clusters in some channel cavities.

Clay mineralogy

8–97 cms: Mainly illite and kaolinite in approximately equal amounts. Little contrast between horizons.

Comments

See also Tables 30 and 31, and Fig. 46. This profile is included in the numerical ordination study.

Table 72

Profile 14, analytical data for fine earth (<2mm)

Depth (cms)		*0*	*8*	*23*	*58*	*97*
		8	*23*	*58*	*97*	*120*
Granulometric analysis (%)						
2 – 1 mm	(vcs)	0.2	0.1	0.6	t	0
1 – 0.5 mm	(cs)	0.6	0.3	0.3	0.1	0.1
0.5 – 0.2 mm	(ms)	1.1	0.9	0.7	t	0.1
0.2 – 0.1 mm	(fs)	4.0	3.4	2.6	1.3	t
0.1 – 0.05 mm	(vfs)	40.0	40.7	34.8	21.2	14.8
sand (2 – 0.05 mm)		45.9	45.3	39.0	22.9	15.2
silt (0.05 – 0.002 mm)		31.2	29.7	29.0	31.1	31.2
clay (0.002 mm)		23.0	25.0	32.0	46.0	53.5
% clay water-dispersable			62	42	8	
Chemical analysis						
pH	H_2O	4.4	4.4	4.7	4.7	4.5
pH	KCl	3.6	3.6	3.8	3.8	3.8
C	%	3.89	0.57	0.13	0.12	0.12
N	%	0.25	0.07	0.04	0.04	0.06
C/N		16	9	4	3	2
CEC	me %	8.8	4.4	3.4	3.3	4.7
Exch. Ca	me %	2.7	0.1	0.2	t	0.3
Exch. Mg	me %	0.1	t	t	t	t
Exch. K	me %	0.3	0.1	0.1	0.1	0.1
Exch. Na	me %	0.1	t	t	t	t
Base saturation	%	35	5	9	3	8
Exch. A1	me %	5.5	6.1	5.8	5.9	6.3
Extr. Ca (HCl)	ppm		t	t	t	
Extr. Mg (HCl)	ppm		870	1130	1640	
Extr. K (HCl)	ppm		2360	3610	6300	
Extr. P (HCl)	ppm	150	100	80	100	120
Extr. Fe (Morgan)	ppm	56	51	21	22	24
Extr. A1 (Morgan)	ppm	510	760	690	750	800

Profile 15

Family: AJOH. *Series:* Ajoh loam.

Site: Middle slope of gently undulating terrain; 3° slope. *Parent material:* Tertiary shale. *Location:* Northwestern boundary of Oya Road Forest Nursery; Sibu District; (2/111/12; 535.177). *Cover:* Sparse trees, area recently burnt through. *Reference samples:* MS1426/1432.

Field morphology

0–5 cms: Greyish brown (10YR 5/2) loam. Moist. Weak coarse granular structure. Friable. Many rootlets. Few charcoal fragments. Few pores. Diffuse smooth boundary.

5–13 cms: Greyish brown (10YR 5/2) loam, with few coarse distinct grey mottles and few rusty root channels. Moist. Weak medium subangular blocky structure. Friable. Many rootlets. Indistinct wavy boundary.

13–23 cms: Very pale brown to yellow (10YR 7/3) loam, with many fine distinct yellow mottles and rare medium distinct grey mottles. Moist. Weak medium coarse subangular blocky structure. Friable. Few small platy fragments of iron-enriched weathered shale. Few roots and rootlets. Few pores. Diffuse wavy boundary.

23–43 cms: Very pale brown (10YR 7/4), light grey (10YR 7/1) and reddish yellow (7.5YR 7/8) multicoloured clay. Moist. Weak coarse angular blocky structure. Firm. Plastic. Rare rootlets. No pores seen. Diffuse wavy boundary.

43–63 cms: Structure confined to pronounced subvertical cracks continuing to base of sampled profile, with well-defined pressure coatings on many crack faces. Otherwise as above. Diffuse wavy boundary.

63–120 cms: Light grey (10YR 7/1) clay, with abundant fine to coarse reddish yellow mottles, becoming few below 90 cms. Otherwise as above.

Comments

In addition to Table 79, data are included in Fig. 46.

Table 73

Profile 15, analytical data for fine earth (<2mm)

Depth (cms)		*0* *5*	*5* *13*	*13* *23*	*23* *43*	*43* *63*	*63* *89*	*89* *120*
Granulometric analysis (%)								
2 – 1 mm	(vcs)	0	0.5	1.3	0.7	0.1	0	0
1 – 0.5 mm	(cs)	0.3	1.5	2.2	1.3	0.5	0.2	0.2
0.5 – 0.2 mm	(ms)	3.3	3.0	3.6	1.7	0.6	1.0	0.5
0.2 – 0.1 mm	(fs)	6.5	3.9	3.7	1.8	0.7	2.9	0.5
0.1 – 0.05 mm	(vfs)	33.4	31.4	33.0	22.8	10.9	10.1	11.8
sand (2 – 0.05 mm)		43.4	40.3	43.8	28.3	12.8	14.2	13.0
silt (0.05 – 0.002 mm)		35.5	38.9	33.7	30.1	29.5	29.2	22.9
clay (0.002 mm)		21.0	20.8	22.5	41.6	57.7	56.6	53.0
Chemical analysis								
pH	H_2O	4.9	4.6	4.5	4.9	4.6	4.7	4.8
pH	KCl	3.7	3.6	3.7	3.7	3.7	3.7	3.7
C	%	2.19	1.44	0.47	0.25	0.24	0.17	0.13
N	%	0.15	0.14	0.07	0.04	0.09	0.09	0.10
C/N		15	11	7	6	3	2	1
CEC	me %	8.6	6.0	5.7	6.5	7.0	7.4	7.2
Exch. Ca	me %	1.1	0.2	0.6	0.1	0.1	0.1	0.1
Exch. Mg	me %	0.5	0.1	0.2	t	0.1	t	0.1
Exch. K	me %	0.4	0.1	0.1	t	0.1	0.1	0.1
Exch. Na	me %	0.1	0.1	t	0.1	t	0.1	0.2
Base saturation	%	24	8	16	3	4	4	7
Extr. Ca (HCl)	ppm			30	t			
Extr. Mg (HCl)	ppm			830	1320			
Extr. K (HCl)	ppm			2590	4200			
Extr. P (HCl)	ppm	140	140	80	80	80	60	180
Extr. Fe (Morgan)	ppm			43	30			
Extr. Al (Morgan)	ppm			360	530			
Extr. Fe (6NHC1)	%	0.8	0.8	1.1	2.2	3.2	4.3	4.2

Profile 16

Family: BANDANG. *Series:* Bandang loam.

Site: Upper slope of gently rolling terrain; 3° slope. *Parent material:* Tertiary shale or sandy shale. *Location:* Near Bukit Timang, north of Selalang; Sarikei District; (2/111/14; 249.483). *Cover: Imperata cylindrica,* presumably following hill rice. *Reference samples:* S4724/4728.

Field morphology

A 11 *0–5 cms:* Greyish brown (10YR 5/2) loam. Moist. Massive. Friable. Many rootlets. Few pores. Indistinct wavy boundary.

A 12 *5–10 cms:* Greyish brown (2.5Y 5/2) sandy loam. Moist. Massive. Friable. Many rootlets. Few pores. Many charcoal fragments. Indistinct wavy boundary.

Table 74

Profile 16, analytical data for fine earth (<2mm)

Depth (cms)		*0* *5*	*5* *10*	*10* *18*	*18* *41*	*41* *61*
Granulometric analysis (%)						
2 – 1 mm	(vcs)			0.5	0.6	0.1
1 – 0.5 mm	(cs)			0.9	0.7	0.4
0.5 – 0.2 mm	(ms)			2.6	2.2	1.8
0.2 – 0.1 mm	(fs)			11.9	10.0	6.6
0.1 – 0.05 mm	(vfs)			35.5	30.8	23.0
sand (2 – 0.05 mm)		50.7	52.2	51.4	44.2	31.9
silt (0.05 – 0.002 mm)		32.1	36.7	30.7	30.0	25.3
clay (0.002 mm)		17.2	11.1	17.9	25.8	42.8
Chemical analysis						
pH	H_2O	3.7	3.8	3.6	3.6	3.7
pH	KCl	3.4	3.5	3.5	3.5	3.5
C	%	2.30	1.60	0.67	0.42	0.34
N	%	0.17	0.12	0.04	0.06	0.06
C/N		7	8	17	7	6
CEC	me %	10.0	20.8	4.3	6.0	8.4
Exch. Ca	me %	0.3	0.1	0.6	0.4	0.6
Exch. Mg	me %	0.2	0.2	0.2	0.1	0.1
Exch. K	me %	0.1	0.1	t	0.1	0.1
Exch. Na	me %	0.4	0.3	0.1	0.1	0.1
Base saturation	%	9	3	22	12	11
Extr. Ca (HCl)	ppm			t	t	t
Extr. Mg (HCl)	ppm			690	1910	1910
Extr. K (HCl)	ppm			1570	4400	4400
Extr. P (HCl)	ppm	120	100	90	100	120
Extr. Fe (Morgan)	ppm			38	33	26
Extr. Al (Morgan)	ppm			590	880	1150
Extr. Fe (6NHCl)	%	0.2	0.4	0.3	1.0	2.0
Avail. P	ppm	15	9	3	2	1

Table 75

Profile 17, analytical data for fine earth (<2mm)

Depth (cms)		*0* *5*	*5* *30*	*30* *56*	*56* *110*
Granulometric analysis (%)					
2 – 1 mm	(vcs)	0.1	0.1	0.3	0.3
1 – 0.5 mm	(cs)	1.6	2.5	2.3	2.2
0.5 – 0.2 mm	(ms)	3.9	9.4	10.0	9.5
0.2 – 0.1 mm	(fs)	17.5	16.8	16.8	18.1
0.1 – 0.05 mm	(vfs)	43.2	37.2	37.0	36.5
sand (2 – 0.05 mm)		66.2	65.8	66.3	66.5
silt (0.05 – 0.002 mm)		16.9	16.5	14.0	14.3
clay (0.002 mm)		17.0	17.7	19.6	19.2
% clay water-dispersable				71	76
Chemical analysis					
pH	H_2O	3.4	3.9	4.1	3.9
pH	KCl	3.4	3.8	4.1	3.8
C	%	0.37	1.71	1.01	0.19
N	%	0.21	0.10	0.07	0.02
C/N		2	17	15	9
CEC	me %	8.8	4.6	3.3	1.9
Exch. Ca	me %	0.4	0.4	0.5	0.7
Exch. Mg	me %	0.1	t	t	t
Exch. K	me %	0.1	0.1	t	t
Exch. Na	me %	0.1	0.1	0.1	0.1
Base saturation	%	8	12	17	43
Exch. A1	me %		2.6	1.0	1.3
Extr. Ca (HCl)	ppm	t	t	t	80
Extr. Mg (HCl)	ppm	390	360	400	400
Extr. K (HCl)	ppm	1100	1200	1300	1200
Extr. P (HCl)	ppm	110	80	70	40
Extr. Fe (Morgan)	ppm			13	13
Extr. Al (Morgan)	ppm			810	390

A2 *10–18 cms:* Light brownish grey (2.5Y 6/2) loam, with many coarse distinct pale brown mottles and many rusty root channels. Moist. Massive. Very weak coarse subangular blocky structure. Friable. Rare rootlets. Few pores. Indistinct wavy boundary.

A3 *18–41 cms:* Light brownish grey to light grey (2.5Y 6.5/2) loam, with many medium distinct yellowish brown and pale brown mottles. Moist. Massive. Firm. Few rootlets. Few pores. Indistinct wavy boundary.

B *41–61 cms:* Light grey (2.5Y 7/2) clay, with many coarse distinct yellowish brown mottles. Moist. Massive. Firm. Slightly plastic. Few rootlets. No pores seen.

Comments

See also Fig. 46. The texture trend of this profile (Table 68) indicates that it may be partly colluvial in origin. It is included in the numerical ordination study.

Profile 17

Family: SARATOK. *Series:* Durin very fine sandy loam.

Site: Upper slope of moderately rolling terrain, fragmented by swamp tracts; 5° slope. *Parent material:* Tertiary sandstone and shale. *Location:* Approximately ½ mile west of Durin bazaar; Sibu District; (2/111/16; 361.177). *Cover:* Old rubber. *Reference samples:* S3329/3336.

Field morphology

A1 *0–5 cms:* Very dark greyish brown (10YR 3/2) very fine sandy loam. Moist. Massive. Firm. Many rootlets. Many pores. Indistinct smooth boundary.

A2 *5–30 cms:* Greyish brown (10YR 5/2) very fine sandy loam, with many very coarse dark grey gley mottles. Moist. Massive. Friable. Many rootlets. Many pores. Indistinct smooth boundary.

B2 *30–56 cms:* Light brownish grey (2.5Y 6/2) very fine sandy loam. Moist. Massive. Friable. Few rootlets. Few pores. Diffuse wavy boundary.

B3 *56–110 cms:* Pale yellow (2.5Y 7/4) very fine sandy loam. Moist. Very weak coarse subangular blocky structure. Firm. No roots seen. Few pores.

Table 76

Profile 18, analytical data for fine earth (<2mm)

Depth (cms)		*0* – *8*	*8* – *36*	*36* – *61*	*61* – *86*	*86* – *100*
Granulometric analysis (%)						
2 – 1 mm	(vcs)	0	0	0	0	0
1 – 0.5 mm	(cs)	0.1	0.3	0.3	0.3	0.3
0.5 – 0.2 mm	(ms)	3.2	6.0	6.3	6.4	5.8
0.2 – 0.1 mm	(fs)	37.7	38.6	39.0	41.1	31.6
0.1 – 0.05 mm	(vfs)	30.2	27.2	28.5	27.7	32.5
sand (2 – 0.05 mm)		71.2	72.1	74.1	75.5	70.2
silt (0.05 – 0.002 mm)		11.0	10.2	9.6	10.7	10.9
clay (0.002 mm)		17.8	17.6	16.3	13.8	18.9
% clay water-dispersable		35	47	51	53	
Chemical analysis						
pH	H_2O	4.2	4.8	5.0	5.5	5.6
pH	KCl	3.6	4.0	4.1	4.5	4.4
C	%	3.35	1.44	1.16	0.61	0.52
N	%	0.20	0.10	0.07	0.03	0.03
C/N		17	14	17	20	18
CEC	me %	9.2	5.9	4.3	2.3	
Exch. Ca	me %	0.1	t	t	t	
Exch. Mg	me %	0.3	0.1	0.1	t	
Exch. K	me %	0.1	0.1	0.1	t	
Exch. Na	me %	t	t	t	t	
Base saturation	%	6	4	4	1	
Extr. P (HCl)	ppm	90	60	50	50	40
Extr. Fe (6NHCl)	%	1.9	1.1	0.4	0.4	0.5
Avail. P	ppm	18	6	3	2	t

Comments

The profile remains pallid to a depth of more than 2 metres, becoming faintly mottled and slightly heavier in texture with depth. This profile is included in the numerical ordination study.

Table 77

Profile 19, analytical data for fine earth (<2mm)

Depth (cms)		*0* *10*	*10* *28*	*28* *41/61*	*41/61* *56/63*	*56/63* *86*	*86* *107*	*107* *120*
Granulometric analysis (%)								
2 – 1 mm	(vcs)	0	0	0	0	0	0	0
1 – 0.5 mm	(cs)	0	0.1	0.2	0.1	0.1	0.1	0.1
0.5 – 0.2 mm	(ms)	4.8	5.1	4.6	3.8	3.9	4.2	3.4
0.2 – 0.1 mm	(fs)	20.9	24.8	20.2	19.8	16.6	21.7	21.9
0.1 – 0.05 mm	(vfs)	38.8	48.6	39.2	39.0	33.8	22.5	25.9
sand (2 – 0.05 mm)		64.5	78.7	64.3	62.6	54.5	48.5	51.4
silt (0.05 – 0.002 mm)		25.1	9.2	24.5	25.2	27.0	22.4	19.5
clay (0.002 mm)		10.4	12.2	11.2	12.2	18.6	29.2	29.1
Chemical analysis								
pH	H_2O	3.9	4.4	4.0	4.6	4.5	4.4	4.3
pH	KCl	3.4	3.7	3.5	3.6	3.6	3.5	3.5
C	%	2.11	1.34	0.37	0.18	0.16	0.07	0.08
N	%	0.11	0.10	0.02	0.02	0.02	0.03	0.04
C/N		20	14	15	11	8	3	2
CEC	me %	5.3	11.6	3.4	2.3	3.1	9.8	10.8
Exch. Ca	me %	0.9	0.2	0.1	0.1	t	t	0.1
Exch. Mg	me %	0.3	t	0.2	0.1	0.1	0.3	0.3
Exch. K	me %	0.1	t	t	t	t	t	0.1
Exch. Na	me %	t	t	t	t	t	t	t
Base saturation	%	25	2	9	12	6	4	4
Extr. Ca (HCl)	ppm	200	200	200	304	100	40	170
Extr. Mg (HCl)	ppm	180	180	120	480	360	1030	340
Extr. K (HCl)	ppm	150	150	200	510	870	1620	1260
Extr. P (HCl)	ppm	30	20	10	20	20	20	20
Extr. Fe (Morgan)	ppm	89	61	38	20	7	4	7
Extr. Al (Morgan)	ppm	160	240	280	260	360	900	1230

Profile 18

Family: SARATOK *Series:* Saratok fine sandy loam.

Site: Upper slope of gently rolling terrain; fragmented by swamp tracts; 3° slope. *Parent material:* Tertiary sandstone. *Location:* 1½ miles northwest of Selalang; Sarikei District; (2/111/14; 236.446). *Cover:* Mature secondary forest. *Reference samples:* S4713/4717.

Field morphology

A11 *0-8 cms:* Very dark greyish brown (10YR 3/2) very fine sandy loam. Moist. Massive. Very friable. Many roots and rootlets. Few pores. Indistinct wavy boundary.

A12 *8-36 cms:* Dark greyish brown (10YR 4/2) fine sandy loam. Otherwise as above. Indistinct wavy boundary.

A21 *36-61 cms:* Greyish brown (10YR 5/2) fine sandy loam, dark greyish brown near root channels. Moist. Very weak fine subangular blocky structure. Very friable. Few rootlets. Few pores. Distinct wavy boundary.

A22 *61-86 cms:* Light brownish grey (2.5Y 6/2) fine sandy loam. Rare rootlets. Otherwise as above. Distinct wavy boundary.

B *86-100 cms:* Pale yellow (2.5Y 8/4) and light brownish grey (2.5Y 6/2) fine sandy loam, the grey colours in thin subvertical bands or elongated patches. Many rusty root channels. Moist. Massive. Firm. Rare rootlets. No pores seen.

Comments

Field appearance suggests that incipient humus accumulation is responsible for the grey patches in the basal horizon (although this is not reflected in carbon figures in Table 70). Were such weak humus staining continuous the profile would be considered a Saratok-Silantek intergrade in the proposed classification.

Profile 19

Family: PENIPAH *Series:* Penipah very fine sandy loam.

Site: Upper slope of very gently undulating terrain; slope less than 1°. *Parent material:* Miocene shale. *Location:* Penipah headwaters, Mukah Subdistrict; (2/112/2; 158.550). *Cover:* Old poor regrowth following hill rice. *Reference samples:* S5158/5164.

Field morphology

A1 *0-10 cms:* Very dark greyish brown (10YR 3/2) very fine sandy loam. Moist. Massive to very weakly granular. Friable. Abundant rootlets. No pores seen. Diffuse wavy boundary.

A21 *10-28 cms:* Yellowish brown. (10YR 5/4) and light brownish grey (2.5Y 6/2) variegated fine sandy loam, with rare medium distinct yellow mottles. Moist. Very weak fine subangular blocky structure. Friable. Many rootlets. Few pores. Indistinct wavy boundary.

A22 *28-41/61 cms:* Light grey (2.5Y 7/2) and brownish yellow (10YR 6/6) coarsely variegated very fine sandy loam. Moist. Massive. Friable. Few roots and rootlets. Few pores. Indistinct irregular boundary.

A3 *41/61-56/63 cms:* Strong brown (7.5YR 5/8) and light grey (2.5Y 7/2) coarsely variegated very fine sandy loam Otherwise as above. Distinct wavy boundary.

B1 *56/63-86 cms:* Strong brown (7.5YR 5/8) and light grey (2.5Y 7/2) very fine sandy loam, the strong brown colours in large irregular patches, the light grey in smaller irregular patches and following relict root channels. Moist. Very weak coarse angular blocky structure. Firm. Few rootlets. No pores seen. Diffuse wavy boundary.

B2 *86-120 cms:* Light grey (2.5Y 7/2) sandy clay loam, with many coarse distinct strong brown mottles, becoming fewer with depth, and many rusty root channels. Moist, Massive. Firm. Rare rootlets. No pores seen.

Comments

This profile is included in the numerical ordination study

Profile 20

Family: TIKA *Series:* Tika fine sandy loam.

Site: Summit of moderately rolling terrain; slope 2°. *Parent material:* Tertiary sandstone with subordinate shale. *Location:* Oya Road Agricultural Station, Sibu District; (2/112/9; 540.296). *Cover:* Tapioca, following hill rice. *Reference samples:* S2851/2857.

Field morphology

A *0-5 cms:* Greyish brown (10YR 5/2) loamy sand. Moist. Single-grain structure. Abundant roots and rootlets. Distinct smooth boundary.

A/B *5-15 cms:* Greyish brown (2.5Y 5/2) fine sandy loam, with many distinct medium grey mottles. Moist. Massive. Friable. Rare rootlets. No pores seen. Diffuse irregular boundary.

B *15-30 cms:* Mottles few and faint; otherwise as above. Diffuse irregular boundary.

IIC *50-100 cms:* Light brownish grey (2.5Y 6/2) loamy sand, with many faint coarse light grey mottles and few distinct fine reddish yellow mottles. Moist. Single-grain structure. Loose. Very rare fine quartz gravel. No roots seen.

Comments

The above profile is underlain by a pallid mottled sandy loam to a depth of least 230 cms, with scattered fragments of iron-enriched weathered shale present below 150 cms.

Profile 21

Family: TIKA. *Series:* Bintulu medium sand.

Site: Upper slope of gently undulating terrace remnant; 2° slope. *Parent material:* Probably fossil beach sand. *Location:* Near Bawang Assan school; Sibu District; (2/111/11; 543.869). *Cover:* Old rubber and thick regrowth. *Reference samples:* —

Field morphology

A11 *0–20 cms:* Dark brown (7.5YR 3.5/2) loamy medium sand. Moist. Single-grain structure. Loose. Many rootlets. Diffuse wavy boundary.

A12 *20–30 cms:* Dark brown to brown (7.5YR 4/2) medium sand. Moist. Single-grain structure. Loose. Few rootlets. Indistinct wavy boundary.

C1 *30–75 cms:* White (10YR 8/2) medium sand, with much small quartz gravel. Moist. Single-grain structure. Loose. No roots seen. Diffuse wavy boundary.

C2 *75–120 cms:* As above, with many small subrounded quartz stones.

Comments

The profile illustrates one extreme form of Regosol. Samples were not retained for analysis.

Profile 22

Family: AJOH. *Series:* Ajoh loam.

Site: Upper slope in very gently undulating terrain; 3° slope. *Parent material:* Tertiary shale. *Location:* Near northwest corner of Oya Road Forest Experimental Nursery; Sibu Subdistrict; (2/111/12; 534.177). *Cover:* Grasses and scattered trees, poor regrowth. *Reference samples:* S7570/7577.

Field morphology

A11 *0–5 cms:* Very dark greyish brown (10YR 3/2) loam. Very weak medium granular structure. Friable. Abundant rootlets. Rare pores. Diffuse wavy boundary.

A12 *5–15 cms:* Greyish brown (10YR 5/2) very fine sandy loam. Moist. Massive. Friable. Many rootlets. Scattered rusty root channels. Many pores. Diffuse wavy boundary.

A2 *15–25 cms:* Light grey (10YR 7/2) loam with many coarse and medium distinct brownish to reddish yellow mottles. Moist. Weak coarse angular blocky structure. Friable. Few rootlets. Many rusty root channels. Few pores. Indistinct wavy boundary.

B *25–33 cms.* A stoneline of angular quartz gravel in a clay loam matrix mottled as above horizon. Indistinct wavy boundary.

IIB21 *33–48 cms:* White (10YR 8/1), strong brown (7.5YR 5/8) and red (2.5Y 5/8) finely variegated clay. Moist. Weak coarse angular blocky structure. Firm. Scattered quartz gravel. Rare rootlets. No pores seen. Diffuse irregular boundary.

IIB22 *48–69 cms:* White (10YR 8/1) and brownish yellow (10YR 6/8) coarsely variegated clay. Moist. Massive. Plastic. Rare rusty root channels. No roots or pores seen. Diffuse wavy boundary.

IIB/C *69–120 cms:* White (10YR 8/1) clay with many coarse distinct brownish yellow mottles. Residual quartz stringers from prior shale structure angle through the horizon. Otherwise as above.

Table 78

Profile 20, analytical data for fine earth (<2mm)

Depth (cms)			*0*	*5*	*15*	*50*
			5	*15*	*50*	*100*
Granulometric analysis (%)						
2 – 1 mm	(vcs)		0.6	0.6	0.7	
1 – 0.5 mm	(cs)		8.2	7.6	5.7	
0.5 – 0.2 mm	(ms)		18.9	18.4	16.3	
0.2 – 0.1 mm	(fs)		30.9	30.7	31.3	
0.1 – 0.05 mm	(vfs)		21.3	22.0	24.0	
sand (2 – 0.05 mm)			79.8	79.4	78.0	78.4
silt (0.05 – 0.002 mm)			9.5	9.8	10.8	17.4
clay (0.002 mm)			10.7	10.7	11.3	4.2
Chemical analysis						
pH		H_2O	6.1	4.6	4.7	4.8
pH		KCl	5.6	3.7	4.0	4.1
C		%	11.52	0.75	0.44	0.14
N		%	0.22	0.08	0.04	
C/N			52	9	11	
CEC		me %	8.9	4.3	3.1	2.4
Exch. Ca		me %	6.7	0.1	0.3	0.7
Exch. Mg		me %	1.6	0.1	0.1	t
Exch. K		me %	0.1	0.2	0.1	t
Exch. Na		me %	0.3	0.3	0.3	0.3
Base saturation		%	100	17	25	43
Exch. A1		me %		2.6	1.6	0.8
Extr. Ca	(HC1)	ppm	2280	170	60	200
Extr. Mg	(HC1)	ppm	570	140	300	40
Extr. K	(HC1)	ppm	1200	1000	1400	1450
Extr. P	(HC1)	ppm	180	50	60	30

Micromorphology

0–10 cms: Abundant very fine and fine subangular quartz grains and few medium to very coarse angular quartz grains in a very pale brown weakly insepic matrix with abundant diffuse very fine brown and pale brown mottles. Rare very fine rolled zircons. Random medium irregular channels linking few medium chambers; No discrete structural peds. Many medium and fine equant to irregular voids. No cutans on channels or discrete voids. Many live roots. Many medium single and welded brown to pale brown fecal pellets. Scattered small carbonised plant fragments.

14–24 cms: Quartz grains as above in a very pale brown to pale brown insepic matrix, with many fine to coarse diffuse irregular yellowish brown to strong brown mottles and diffuse haloes around some fine voids and chambers. Few short irregular to subtabular channels, many medium and large irregular chambers and many fine equant voids; no discrete structural peds. Thin diffuse very pale brown cutans on some fine voids; other void surfaces clear. Scattered inclined very pale brown to light grey medium plasma separations with weak striated orientation and subparallel borders, some enclosing medium single and welded pale brown fecal pellets. Few live roots. Few small carbonised wood fragments.

43–53 cms: Material much modified by faunal activity, comprising (a) scattered patches of presumed initial fabric, in (b) a complex of striotubules. (a): Quartz grains as above in a very pale brown insepic to mosepic matrix with many diffuse fine and medium yellow and dark brown mottles; many fine and very fine equant to irregular voids with thin to medium diffuse

Table 79

Profile 22, analytical data for fine earth (<2mm)

Depth (cms)		*0*	*5*	*15*	*25*	*33*	*48*	*69*
		5	*15*	*25*	*33*	*48*	*69*	*120*
Granulometric analysis (%)								
2 – 1 mm	(vcs)	0.4	1.7	1.4	4.1	4.0	0.5	0.4
1 – 0.5 mm	(cs)	2.4	3.8	2.3	3.7	4.4	0.9	0.8
0.5 – 0.2 mm	(ms)	7.2	5.3	2.8	2.8	3.1	0.9	0.7
0.2 – 0.1 mm	(fs)	12.3	8.5	5.3	4.9	5.8	1.8	1.3
0.1 – 0.05 mm	(vfs)	29.8	39.0	34.1	25.4	16.1	13.7	13.1
sand (2 – 0.05 mm)		52.1	58.3	45.9	40.8	33.4	17.6	16.3
silt (0.05 – 0.002 mm)		35.3	31.4	33.5	27.2	23.6	31.1	39.8
clay (0.002 mm)		12.6	10.3	20.6	32.0	42.9	51.2	43.9
Chemical analysis								
pH	H_2O	4.2	4.3	4.3	4.5	4.6	4.5	4.6
pH	KC1	3.3	3.4	3.4	3.5	3.6	3.5	3.6
C	%	2.51	1.06	0.33	0.25	0.19	0.32	0.12
N	%	0.17	0.18	0.05	0.05	0.07	0.09	0.08
C/N		15	9	6	5	3	4	2
CEC	me %	7.3	2.5	3.9	4.3	4.1	4.7	5.4
Exch. Ca	me %	0.9	0.5	0.1	0.2	0.2	0.3	0.1
Exch. Mg	me %	0.2	t	t	t	t	0.2	0.1
Exch. K	me %	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Exch. Na	me %	0.1	0.1	0.1	t	0.1	0.1	0.1
Base saturation	%	19	25	6	8	10	8	4
Exch. Al	me %	2.6	2.7	4.8	5.3	5.4	6.3	5.9

well-ordered very pale brown cutans. (b): Quartz grains in a very pale brown omnisepic matrix with many fine to coarse diffuse to distinct yellow to dark brown mottles and ellypses reflecting striotubule structure; striotubules partial or complete, and unorientated; narrow, short irregular or curved acicular channels segment or bound tubule fragments; no discrete structural peds. Scattered fine equant to irregular voids with thin diffuse very pale brown or brownish yellow well-ordered cutans.

83–93 cms: Discontinuous thin to medium zones of vein quartz inclined through a very pale brown matrix with many diffuse very fine to coarse zoned plasma separations of continuous fabric aligned to the apparent rock structure and local thin distinct plasma separations of moderately continuous fabric in bifurcating interlinked zones of constant width with no apparent alignment. Few medium very diffuse striotubule fragments. Rare short thin acicular random channels with scattered thin intermittent diffuse very pale brown cutans; no discrete structural peds. Few fine equant voids, some with thin well-ordered diffuse very pale brown and pale brown cutans.

Clay mineralogy

15–25 cms, 33–48 cms and 69–100 cms: Mainly illite and moderately crystallised kaolinite.

Comments

Additional data are included in Fig. 46.

Profile 23

Family: GADING. *Series:* Changgan sandy clay loam.

Site: Upper slope of moderately rolling terrain; 5° slope. *Parent material:* Granite or granodiorite; probably including an admixture of colluvial wash from main ridge. *Location:* Foothills at western end of

Table 80

Profile 23, analytical data for fine earth (<2mm)

Depth (cms)		*0*	*4*	*13*	*36*	*56*	*81*
		4	*13*	*36*	*56*	*81*	*100*
Granulometric analysis (%)							
2– 1 mm	(vcs)	5.7	1.7	1.9	2.1	8.2	
1 – 0.5 mm	(cs)	13.0	12.5	11.7	10.8	14.4	
0.5 – 0.2 mm	(ms)	16.6	18.0	17.6	15.5	12.4	
0.2 – 0.1 mm	(fs)	20.9	20.2	20.4	16.9	11.2	
0.1 – 0.05 mm	(vfs)	12.4	16.2	16.1	13.8	8.2	
sand (2 – 0.05 mm)		68.7	68.6	67.7	59.1	54.4	
silt (0.05 – 0.002 mm)		8.1	4.0	5.0	8.6	7.6	
clay (0.002 mm)		23.3	27.5	27.3	32.3	37.9	
% clay water-dispersable				68	32	1	
Chemical analysis							
pH	H_2O	5.0	4.9	5.0	5.2	5.7	5.6
pH	KC1	3.4	3.9	4.0	4.1	4.5	4.8
C	%	3.28	1.33	0.85	0.64	0.40	0.29
N	%	0.28	0.12	0.08	0.06	0.04	0.03
C/N		12	11	11	12	9	9
CEC	me %	9.0	3.0	2.1	1.6	1.4	1.5
Exch. Ca	me %	0.6	0.3	0.4	0.3	0.3	0.3
Exch. Mg	me %	0.2	0.1	t	t	t	0.1
Exch. K	me %	0.2	0.1	0.1	0.1	t	0.1
Exch. Na	me %	0.3	0.1	0.1	0.1	0.1	0.1
Base saturation	%	14	16	27	29	29	34
Extr. Ca	(HCl) ppm			330	490	1230	
Extr. Mg	(HC1) ppm			50	80	t	
Extr. K	(HC1) ppm			380	390	160	
Extr. P	(HC1) ppm	280	360	400	200	380	340
Extr. Fe	(Morgan) ppm			18	13	8	
Extr. A1	(Morgan) ppm			240	230	220	
Avail. P	ppm	10	3	1	1	t	2

Bukit Piring, near Rumah Layang; Balingian Subdistrict; (2/112/7; 983.810). *Cover:* Rubber in tapping. *Reference samples:* S7762/7767.

Field morphology

A1 *0–4 cms:* Brown to dark brown (7.5YR 4/4) sandy clay loam. Moist. Weak coarse subangular blocky structure. Friable. Porous. Abundant rootlets. Diffuse wavy boundary.

A21 *4–13 cms:* Strong brown (7.5YR 5/6) sandy clay loam. Moist. Weak coarse subangular blocky structure. Friable. Slightly porous. Many rootlets. Diffuse wavy boundary.

A22 *13–56 cms:* Strong brown to yellowish brown (7.5–10YR 5/8) sandy clay loam. Moist. Weak coarse subangular blocky structure. Friable. Few rootlets. Diffuse wavy boundary.

B2 *56–81 cms:* Strong brown (7.5YR 5/6) sandy clay. Moist. Massive. Friable. Rare fragments of well-weathered granodiorite. Rare rootlets. Diffuse wavy boundary.

B3 *81–100 cms:* Many fragments of well-weathered granodiorite, becoming abundant at depth, in a matrix of strong brown (7.5YR 5/6) sandy clay. Moist. Massive. Friable. Very rare rootlets.

Micromorphology

15–25 cms and 43–53 cms: Abundant poorly-sorted coarse to very fine angular to subangular weathered quartz sand, few medium to fine subrounded fragments of hornfels and hornfels-quartz intergrowths, rare fine rolled zircons and many fine subangular black ferric nodules, in a strong brown weakly asepic matrix. Abundant highly irregular medium and fine anastomosing channels partially bounding incomplete very fine to medium angular and subangular blocks; no apparent macro-structure. No cutans. Few live roots.

Clay mineralogy

13–81 cms: Fairly well-crystallised kaolinite and some vermiculite. Gibbsite also present in small amounts.

Comments

See also Tables 28 and 29. This profile is included in the numerical ordination study. The fine sand has the highest heavy mineral concentrations of those soils examined (Table 81).

Profile 24

Family: ABOK. *Series:* Arip sandy clay loam.

Site: Broad footslope to high ridge; 10° slope. *Parent material:* rhyolite. *Location:* Sebatu headwaters, Arip valley; Balingian Subdistrict; (2/112/7; 954.032). *Cover:* Thin primary forest. *Reference samples:* S7789/7792.

Field morphology

A1 *0–5 cms:* Dark yellowish brown (10YR 4/4) sandy clay loam. Moist. Weak medium granular structure. Very friable. Abundant roots and rootlets. Few pores. Indistrict wavy boundary.

B *5–69/84 cms:* Strong brown to brownish yellow (7.5–10YR 5.5/7) sandy clay loam. Moist. Scattered subverticl cracks; otherwise massive. Friable. Many roots and rootlets. Few pores. At 43 cms rock fragments. Indistrict irregular boundary.

C *69/84–140 cms:* Strong brown (715YR 5/8) clay. Moist. Structure as above. Firm. Few roots. Few pores. Inclined bands of friable weathered rhyolite and hard iron-enriched rock fragments strike across the horizon.

Micromorphology

20–30 cms: Abundant fine and very fine angular and subangular sand grains and rare very fine zircons and tourmalines in a brownish yellow insepic to skelsepic matrix. Many random small and medium discrete voids (smoothed and mamillated orthovughs and metavughs, some vesicles), some with thin diffuse poorly-ordered brownish yellow cutans, few with thin well-ordered yellowish brown cutans. Few large very irregular voids without cutans. Rare large irregular channels occupied by roots. No discrete structural peds.

Table 81

Profile 23, heavy minerals in 0.08–0.1 mm sand fraction

Depth (cms)		*0*	*4*	*13*	*36*	*56*	*81*
		4	*13*	*36*	*56*	*81*	*100*
% heavies		22.2	22.8	21.9	21.3	20.0	19.6
Ilmenite, etc		97	94	97	95	98	96
Zircon	clear, euhedral and fractured	3	2	3	5	2	3
Anatase		t	3	t	—	—	1

Table 82

Profile 24, analytical data for fine earth (<2mm)

Depth (cms)			*0*	*5*	*43*	*69/84*
			5	*43*	*69/84*	*140*
Granulometric analysis (%)						
2 – 1mm		(vcs)	0.7	0.1	0	
1 – 0.5 mm		(cs)	1.2	0.1	0.2	
0.5 – 0.2 mm		(ms)	1.9	0.3	0.2	
0.2 – 0.1 mm		(fs)	8.2	4.9	4.7	
0.1 – 0.05 mm		(vfs)	46.7	44.4	42.6	
sand (2 – 0.05 mm)			58.7	49.8	47.7	
silt (0.05 – 0.002 mm)			20.3	18.6	18.9	
clay (0.002 mm)			20.9	31.6	33.4	
% clay water-dispersible				2	1	
Chemical analysis						
pH		H_2O	4.1	4.5	5.1	5.0
pH		KCl	3.2	3.5	3.6	3.6
C		%	3.82	0.31	0.17	0.18
N		%	0.22	0.05	0.03	0.05
C/N			17	6	5	4
CEC		%	14.4	12.3	8.1	8.0
Exch. Ca		me %	0.7	0.4	0.3	0.3
Exch. Mg		me %	0.5	t	0.1	0.1
Exch. K		me %	0.4	0.1	0.1	0.1
Exch. Na		me %	0.1	t	0.1	0.1
Base saturation		%	12	5	6	11
Extr. Ca	(HCl)	ppm		180	260	
Extr. Mg	(HCl)	ppm		1330	1810	
Extr. K	(HCl)	ppm		2480	3410	
Extr. P	(HCl)	ppm	150	110	70	120
Extr. Fe	(Morgan)	ppm		29	8	
Extr. A1	(Morgan)	ppm		1090	950	
Extr. SiO_2	(Na_2CO_3)	%	40.4	42.6	39.9	39.2
Extr. Fe_2O_3	(Na_2CO_3)	%	7.3	9.1	9.5	10.6
Extr. $A1_2O_3$	(Na_2CO_3)	%	28.0	30.2	30.2	29.9
Avail. P		ppm	14	2	1	2

53–63 cms: Sand grains as above in a yellowish brown insepic to skelsepic matrix. Few long narrow irregular anastomosing channels linking medium and large irregular voids and partially bounding incomplete coarse angular blocks; rare thin diffuse intermittent channel cutans but most channel walls clear. Discrete voids in matrix as in above horizon, commonly with thin diffuse poorly-ordered (rarely well-ordered) yellowish brown cutans. Few large to small irregular ferric nodules composed of fine quartz grains in a reddish brown isotic matrix.

97–107 cms: Three main components. (a) Material as in above horizon with brownish yellow to yellow matrix (and cutan) colour, many irregular anastomosing channels and craze planes; no discrete structural peds. (b) Many large irregular lithorelicts comprising fine quartz sand grains in a finely variegated brownish yellow, yellow and dark brown insepic to isotic matrix; relict cleavage zones and fine to medium irregular to equant internal voids coated or partially infilled by distinct thick brownish yellow poorly-ordered to well-ordered argillans. (c) Few medium and small irregular lithorelicts comprising fine and very fine quartz sand grains in a dominantly silty, partially insepic, matrix with many medium and fine irregular to equant voids with parallel to

Table 83

Profile 24, heavy minerals in 0.08–0.1 mm sand fraction

Depth (cms)		*0–5*	*5–43*	*43–69/84*	*69/84–140*
% heavies		0.05	0.06	0.05	0.07
Ilmenite, etc		6	6	15	9
Leucoxene, etc		66	67	74	75
Limonite, etc		1	t	4	1
Zircon	clear, rolled	1	3	2	—
	clear, worn	3	7	2	1
Tourmaline	brown	8	6	1	4
	green	7	4	2	3
	blue	2	1	—	—
Anatase		5	4	8	4
Rutile	yellow	1	—	—	—
Alterites		1	1	1	1

normal coatings of (?) chlorite crystals; some crystallaria are only partially enclosed by lithorelict material and the crystal layer abuts the matrix; rare thin intermittent well-ordered brownish yellow argillans locally overlie crystal layer.

Clay mineralogy

5–140 cms: Mainly vermiculite, with some poorly-crystallised kaolinite and traces of gibbsite. Little contrast between horizons.

Comments

This profile is included in the numerical ordination study.

Profile 25

Family: SERIN. *Series:* Piring clay.

Site: Upper slope of steeply sloping ridge; about 20° slope. *Parent material:* Believed to be largely quartz biotite hornfels. *Location:* South flank of Bukit Piring, north of Rumah Balong, Balingian Subdistrict; (2/112/7; 985.869). *Cover:* Broken primary forest. *Reference samples:* S7768/7773.

Field morphology

A1 *0–10 cms:* Dark brown (10YR 4/3) clay. Moist. Very weak coarse subangular blocky structure. Friable. Abundant roots and rootlets. Few pores. Indistinct wavy boundary.

A2 *10–38 cms:* Reddish yellow (7.5YR 6/8) clay. Moist. Very weak very coarse subangular blocky structure, breaking to medium and fine angular blocky. Friable Few rootlets. Few pores. Diffuse wavy boundary.

B21 *38–66 cms:* Reddish yellow (7.5YR 6/6) clay. Moist. Structure as above. Friable. Few pressure coatings. Few rootlets. Few pores. Diffuse wavy boundary.

B22 *66–89 cms:* Strong brown (7.5YR 5/8) clay. Moist. Coarse and medium angular blocky structure, breaking to fine angular blocky. Many pressure coatings. Friable. Few rootlets. Few pores. Indistinct wavy boundary.

B23 *89–97 cms:* A stoneline of iron-enriched weathered rock fragments in a matrix of the above material.

B3 *97–124 cms:* Yellowish red (5YR 5/8) clay with few fine and medium distinct yellowish brown mottles. Moist. Fine angular blocky structure. Slightly firm. Rare reddish brown soft lithorelicts. Few roots. Few pores.

Table 84

Profile 25, analytical data for fine earth (<2mm)

Depth (cms)		*0* *10*	*10* *38*	*38* *66*	*66* *89*	*97* *124*
Granulometric analysis (%)						
2 – 1 mm	(vcs)	1.3	t	0.1	0.2	
1 – 0.5 mm	(cs)	1.8	0.4	0.3	0.4	
0.5 – 0.2 mm	(ms)	2.3	1.0	1.0	1.0	
0.2 – 0.1 mm	(fs)	5.5	3.4	4.1	3.7	
0.1 – 0.05 mm	(vfs)	11.5	10.3	9.2	10.7	
sand (2 – 0.05 mm)		22.4	15.1	14.7	16.0	
silt (0.05 – 0.002 mm)		30.8	25.0	22.7	21.6	
clay (0.002 mm)		46.8	59.9	62.6	62.4	
% clay water-dispersable			<1	<1	<1	
Chemical analysis						
pH	H_2O	4.6	4.8	5.0	5.2	5.1
pH	KCl	3.4	3.7	3.6	3.7	3.7
C	%	5.10	0.85	0.30	0.27	0.23
N	%	0.36	0.07	0.03	0.03	0.02
C/N		14	12	12	8	12
CEC	me %	18.3	6.9	6.0	6.4	5.6
Exch. Ca	me %	0.5	0.2	0.3	0.4	0.2
Exch. Mg	me %	0.3	0.1	0.1	0.1	0.1
Exch. K	me %	0.2	0.1	t	t	t
Exch. Na	me %	0.2	0.1	0.1	0.1	0.1
Base saturation	%	6	7	8	11	8
Extr. Ca (HCl)	ppm		360	200	300	
Extr. Mg (HCl)	ppm		270	440	500	
Extr. K (HCl)	ppm		170	340	600	
Extr. P (HCl)	ppm	150	440	40	120	50
Extr. Fe (Morgan)	ppm		22	11	8	
Extr. Al (Morgan)	ppm		860	680	640	
Avail. P	ppm	6	4	2	1	1

Clay mineralogy

10–38 cms; 66–89 cms; and 97–124 cms: Mainly fairly well-crystallised kaolinite, with some vermiculite and traces of gibbsites. Little contrast between samples analysed.

Comments

This profile is included in the numerical ordination study.

Profile 26

Family: SERIN. *Series:* Nyaroh clay.

Site: Upper slope of moderately rolling terrain; 4° slope. *Parent material:* Uncertain; both rhyolite and carbonaceous shale outcrop nearby. *Location:* Near Selian River, Arip valley; Balingian Subdistrict; (2/112/7; 018.913). *Cover:* High shrub regrowth following hill rice. *Reference samples:* S7800/7806.

Table 85

Profile 25, heavy minerals in 0.08–0.1 mm sand fraction

Depth (cms)		*0* *10*	*10* *38*	*38* *66*	*66* *89*	*89* *124*	*124* *150*
% heavies		2.01	1.89	1.92	1.89	1.70	1.44
% opaques		63	55	62	61	55	55
% non-opaques		37	45	38	39	45	45
Opaques (%)							
Ilmenite, etc		3	3	4	4	8	5
Leucoxene, etc		91	94	95	96	91	95
Limonite, etc		6	6	1	—	1	—
Non-opaques (%)							
Zircon	clear, euhedral or worn	10	16	19	9	15	4
Tourmaline	brown	—	1	—	—	—	—
Rutile	yellow	—	—	1	—	—	—
Brookite		6	3	1	1	4	3
Anatase		76	78	78	90	81	93
Unknown		1	2	1	—	—	1
Alterites		1	2	1	—	—	1

Field morphology

A1 *0–8 cms:* Olive brown (2.5Y 4/4) clay. Moist. Weak medium to fine granular structure. Friable. Abundant roots and rootlets. Few pores. Indistinct wavy boundary.

A2 *8–28 cms:* Yellowish brown (10YR 5/6) clay. Moist. Weak medium angular blocky structure. Friable to slightly firm. Few pressure coatings. Few rootlets. Few pores. Diffuse wavy boundary.

B1 *28–66 cms:* As above, with structure coarse angular blocky, breaking to medium and fine angular blocky; many prominent pressure coatings. Indistinct wavy boundary.

B2 *66–124 cms:* Yellowish brown (10YR 5/6) clay, with few medium faint yellowish red mottles and rare fine distinct white mottles. Coarse angular blocky structure, breaking to medium and fine angular blocky. Firm. Few rootlets. Few pores.

Micromorphology

10–20 cms: Many medium to very fine subangular quartz sand grains, rare very fine zircons and tourmalines, very rare fine grains of (probable) thulite and scattered very fine angular ferric nodules in a brownish yellow to yellow insepic (weakly skelsepic) matrix. Many long narrow irregular channels linking large irregular voids, occupied by roots and partially bounding incomplete medium subangular blocks. Many small equant to irregular voids. No cutans on channels or larger voids, thin diffuse brownish yellow cutans on few small voids.

30–40 cms: Quartz, zircon, tourmaline grains (no thulite) and ferric nodules as above, in a yellowish brown to strong brown omnisepic matrix. Scattered narrow long irregular channels and many narrow short acicular channels; no discrete structural peds; no cutans. Few small equant and irregular voids, some with thin diffuse strong brown cutans.

99–109 cms: Sand grains and ferric nodules as above in a yellowish brown insepic to omnisepic matrix, with many coarse diffuse irregular reddish brown mottles and some reddish brown ellypses suggesting old striotubule structures. Otherwise as above.

140–150 cms: As above. Cutans confined to fine equant voids; medium to thick, moderately ordered and diffuse.

Sand mineralogy

Heavy mineral separates from the 0.08–0.1 mm sand fraction totalled only 0.11 – 0.16%, increasing with depth. The yield was insufficient for counting but mainly comprises opaques with some clear zircons (both euhedral and rolled) and few brown tourmalines.

Clay mineralogy

8–28 cms; 43–66 cms; and 91–124 cms: Mainly well-crystallised kaolinite and vermiculite, in approximately equal amounts; traces of gibbsite. Little contrast between samples.

Comments

See also Tables 24 and 25. Variegated yellowish brown clay with white mottles extends to at least 160 cms with no rock fragments or relict rock structure observed. This profile is included in the numerical ordination study.

Table 86

Profile 26, analytical data for fine earth (<2mm)

Depth (cms)			*0* *8*	*8* *28*	*28* *43*	*43* *66*	*66* *91*	*91* *124*
Granulometric analysis (%)								
2 – 1 mm	(vcs)		0.2	t	0	0	0	0
1 – 0.5 mm	(cs)		0.8	0.2	0.2	0.1	0.2	0.2
0.5 – 0.2 mm	(ms)		3.0	1.7	1.1	0.9	0.9	0.7
0.2 – 0.1 mm	(fs)		7.1	6.4	4.9	4.4	3.9	3.5
0.1 – 0.05 mm	(vfs)		12.1	12.5	13.4	11.4	10.2	7.1
sand (2 – 0.05 mm)			23.2	20.8	19.7	16.8	15.3	11.5
silt (0.05 – 0.002 mm)			27.0	23.2	23.6	20.7	19.9	23.5
clay (0.002 mm)			49.7	56.0	56.7	62.5	64.8	65.1
% clay water-dispersable				8	1	1	1	
Chemical analysis								
pH	H_2O		4.4	4.7	4.9	5.1	5.2	5.3
pH	KCl		3.4	3.6	3.7	3.8	3.8	3.9
C		%	4.17	0.95	0.64	0.52	0.47	0.37
N		%	0.30	0.09	0.08	0.06	0.05	0.04
C/N			14	10	9	9	10	10
CEC		me %	17.5	7.4	11.5	5.5	5.4	5.2
Exch. Ca		me %	0.8	0.3	0.4	0.3	0.4	0.3
Exch. Mg		me %	0.4	0.1	t	t	t	t
Exch. K		me %	0.3	0.1	0.1	0.1	0.1	t
Exch. Na		me %	0.2	t	0.2	t	t	t
Base saturation		%	9	7	6	7	10	7
Exch. Al		me %			4.4	2.8	2.6	1.9
Extr. Ca (HCl)		ppm		720	900	780	920	
Extr. Mg (HCl)		ppm		320	380	370	430	
Extr. K (HCl)		ppm		1070	1190	1380	1470	
Extr. P (HCl)		ppm	170	160	120	350	130	160
Extr. Fe (Morgan)		ppm		22	8	6	6	
Extr. Al (Morgan)		ppm		920	940	860	840	
Extr. SiO_2 (Na_2CO_3)		%	35.5	36.2	36.9	35.9	36.5	36.6
Extr. Fe_2O_3 (Na_2CO_3)		%	10.5	12.1	14.0	12.5	12.8	11.5
Extr. Al_2O_3 (Na_2CO_3)		%	30.0	31.3	30.8	32.0	30.9	32.5
Avail. P		ppm	7	2	1	2	1	2

Profile 27

Family: MIRI. *Series:* Miri fine sand.

Site: Very gently undulating terrace remnant, less than 1° slope. *Parent material:* Marine alluvium; fossil beach deposit. *Location:* Between Delta sawmill and Gunung Ayer, Tanjung Mani; Sarikei District; (2/111/14; 356.523). *Cover:* Poor regrowth at site (approximately 3 years old); thin heath forest on undisturbed sites nearby. *Reference samples:* MS1502/1506.

Field morphology

A11 *0–10 cms:* Dark reddish brown (5YR 2/2) fine sandy loam. Moist. Massive. Friable. Abundant roots and rootlets. Indistinct wavy boundary.

A12 *10–18 cms:* Dark brown (10YR 3/3) fine sand, with few large distinct greyish brown patches. Moist. Single-grain structure. Loose. Few rootlets. Indistinct wavy boundary.

A21 *18–28 cms:* Light grey (10YR 7/2) fine sand, with many fine distinct light brownish grey mottles, mainly associated with old root channels. Moist. Single-grain structure. Loose. Few rootlets. Diffuse wavy boundary.

Table 87

Profile 27: analytical data for fine earth (<2mm)

Depth (cms)			*0–10*	*10–18*	*18–28*	*28–53*	*53–120*
Granulometric analysis (%)							
2 – 1 mm	(vcs)		0	0	0	0	0
1 – 0.5 mm	(cs)		0	0.2	0	0	0
0.5 – 0.2 mm	(ms)		0.1	0.4	0.2	0.2	0.2
0.2 – 0.1 mm	(fs)		41.2	67.3	68.2	70.0	68.7
0.1 – 0.05 mm	(vfs)		14.4	20.5	25.2	24.4	15.6
sand (2 – 0.05 mm)			55.6	88.4	93.6	94.7	84.5
silt (0.05 – 0.002 mm)			8.5	5.6	3.8	3.1	3.4
clay (0.002 mm)			35.9	6.0	2.6	2.2	12.1
Chemical analysis							
pH	H_2O		3.3	4.0	4.2	6.3	3.2
pH	KCl		2.3	2.8	3.9	4.9	2.9
C		%	10.21	1.70	0.14	0.71	5.62
N		%	0.44	0.09	0.04	0.02	0.08
C/N			23	20	3	47	75
CEC		me %	33.7	3.6	0.2	0.1	25.4
Exch. Ca		me %	1.2	0.2	0.6	0.1	0.9
Exch. Mg		me %	2.0	0.1	0.1	t	0.3
Exch. K		me %	0.5	0.1	0.1	t	0.1
Exch. Na		me %	0.4	0.1	0.2	0.2	0.4
Base saturation		%	12	13	100	100	7
Extr. Ca (HCl)		ppm				t	50
Extr. Mg (HCl)		ppm				t	t
Extr. K (HCl)		ppm				t	190
Extr. P (HCl)		ppm	250	30	10	10	20
Extr. Fe (Morgan)		ppm				t	t
Extr. Al (Morgan)		ppm				20	270
Extr. Fe_2O_3 (6NHCl)		%	0.1	t	t	t	t

Table 88

Profile 27, heavy minerals in 0.05–0.2 mm sand fraction

Depth (cms)		*10–18*	*18–28*	*28–53*	*53–120*
% heavies		0.02	0.01	0.01	0.06
% opaques			75		73
% non-opaques			25		27
Opaques (%)					
Ilmenite, etc		2	t		—
Earthy hematite		1	t		25
Leocoxene, etc		96	96		74
Limonite, etc		1	3		t
Non-opaques (%)					
Zircon	clear, rolled	16	9		16
	clear, worn	15	t		11
	pink, rolled	2	1		—
Tourmaline	brown	16	35		25
	green	9	19		27
	blue	t	8		2
Rutile	red	2	1		2
	yellow	8	7		2
Brookite		2	t		6
Anatase		23	16		10
Sillimanite		t	t		—
Topaz		—	t		—
Paragonite		—	t		—
Cristobalite		—	t(?)		—

A22 *28–53 cms:* White (10YR 8/1) fine sand. Moist. Largely loose and single-grain but patchily very firm and compact. No roots seen. Distinct wavy boundary.

B2hc *53–120 cms:* Black (5YR 2/1) loamy fine sand. Strongly cemented by humus and can be fractured only with a pick. Distinct wavy boundary.

Bir/C *120 cms+:* Yellow sand grading rapidly to pale yellow sand. (Below the water-table and difficult to sample and describe satisfactorily.

Comments

This profile is included in the numerical ordination study. It is illustrated in Colour Plate 12.

Profile 28

Family: SILANTEK. *Series:* Buso fine sand.

Site: Summit of low fossil strand line in estuarine clay plain behind present coast; flat. *Parent material:* Subrecent beach sand. *Location:* Near Bidak River, Belawai; Sarikei District; (2/111/13; 439.348). *Cover:* Grassland. *Reference samples:* S7926/7929.

Field morphology

A1 *0–23 cms:* Grey (10YR 6/1) fine sand. Moist. Single-grain structure. Loose. Many roots and rootlets. Indistinct wavy boundary.

A2 *23–50 cms:* Light grey (10YR 7/2) fine sand. Moist. Single-grain structure. Loose. Rare rootlets. Distinct wavy boundary.

Table 89

Profile 28, analytical data for fine earth (<2mm)

Depth (cms)			*0*	*23*	*50*	*76*
			23	*50*	*76*	*110*
Granulometric analysis (%)						
2 – 1mm		(vcs)	0	0	0	0
1 – 0.5 mm		(cs)	0	0	0	0
0.5 – 0.2 mm		(ms)	1.9	1.3	0.6	1.9
0.2 – 0.1 mm		(fs)	89.2	90.9	93.3	92.4
0.1 – 0.05 mm		(vfs)	3.2	3.2	1.8	1.1
sand (2 – 0.05 mm)			94.3	95.3	95.7	95.5
silt (0.05 – 0.002 mm)			1.9	1.6	0.8	0.7
clay (0.002 mm)			3.8	3.1	3.5	3.8
Chemical analysis						
pH		H_2O	4.7	5.1	4.8	5.2
pH		KCl	3.8	4.0	3.9	4.6
C		%	0.49	0.13	1.62	0.85
N		%	0.03	0.01	0.06	0.04
C/N			16	11	30	23
CEC		me %	1.8	0.9	5.8	2.3
Exch. Ca		me %	0.6	0.3	t	0.3
Exch. Mg		me %	0.1	t	t	t
Exch. K		me %	t	t	t	t
Exch. Na		me %	t	t	t	t
Base saturation		%	41	38	1	14
Exch. Ca	(HCl)	ppm		t	t	
Extr. Mg	(HCl)	ppm		t	t	
Extr. K	(HCl)	ppm		160	340	
Extr. P	(HCl)	ppm	30	10	90	
Extr. Fe	(Morgan)	ppm		t	5	13
Extr. Al	(Morgan)	ppm		20	640	560
Extr. SiO_2	(Na_2CO_3)	%	98.9	98.4	94.1	95.2
Extr. Fe_2O_3	(Na_2CO_3)	%	0.1	0.1	0.3	0.6
Extr. Al_2O_3	(Na_2CO_3)	%	0.5	0.8	1.8	2.1

B21 *50–76 cms:* Very dark brown (10YR 2/2) fine sand. Moist. Single-grain structure. Loose. No roots seen. Indistinct wavy boundary.

B22h *76–110 cms:* Dark brown (10YR 3/3) fine sand. Wet. Single-grain structure. Loose. No roots seen.

Comments

This profile is included in the numerical ordination study.

Profile 29

Family: SILANTEK. *Series:* Silantek fine sandy loam.

Site: Middle slope of very gently rolling terrain; 1° slope. *Parent material:* Miocene sandstone. *Location:* Kenyana headwaters, Mukah Subdistrict; (2/112/6; 030.561). *Cover:* Poor heath forest. *Reference samples:* S5146/5157.

Field morphology

A1 *0–8/13 cms:* Brown (10YR 5/3) and pale brown (10YR 6/3) fine sandy loam, the colours diffusely variable, mixed in the surface 3 cms with dusky red raw litter fragments. Moist. Massive. Friable. Many rootlets. Diffuse wavy boundary.

A21 *8/13–30/41 cms:* Very pale brown (10YR 7/3) and light grey (2.5Y 7/2) fine sandy loam, the colours coarsely variable, with brown staining along root channels. Moist. Massive. Loose. Few rootlets. Diffuse irregular boundary, dipping near root channels.

A22 *30/41–51 cms:* White to light grey (5Y 7.5/1) loamy fine sand, with many coarse faint to distinct pale yellow and very pale brown mottles. Moist. Single-grain structure. Loose. Rare rootlets. Indistinct wavy boundary.

B2h *51–56/60 cms:* Dark brown (7.5YR 3/2) fine to very fine sandy loam, patchily mottled light yellowish brown, reddish brown and dark reddish brown. Moist. Massive. Firm. No roots seen. Indistinct very irregular boundary, dipping near root channels.

B2ir *56/60–69/84 cms:* Strong brown (7.5YR 5/6) and yellowish red (5YR 5/8) coarsely mottled fine to very fine sandy loam, as an irregular continuous zone breaking at depth to yellow fine to very fine sandy loam, with the stronger colours concentrated at residual rock structure planes. Moist. Only residual rock structure apparent. Friable. No roots seen. Indistinct irregular boundary.

Table 90

Profile 29, analytical data for fine earth (<2mm)

Depth (cms)			*0* *8/13*	*8/13* *21*	*21* *30/41*	*30/41* *51*	*51* *56/60*	*56/60* *69/84*	*69/84* *86*
Granulometric analysis (%)									
2 – 1mm		(vcs)	t	t	t	0.1	t	t	t
1 – 0.5 mm		(cs)	0.3	0.4	0.4	0.4	0.4	0.2	0.3
0.5 – 0.2 mm		(ms)	9.2	8.9	10.6	12.9	10.1	9.4	8.2
0.2 – 0.1 mm		(fs)	33.6	30.6	31.0	40.5	29.2	27.1	27.2
0.1 – 0.05 mm		(vfs)	25.3	25.9	28.0	20.3	24.2	23.4	24.2
sand (2 – 0.05 mm)			68.5	65.7	70.0	74.2	63.9	60.2	59.9
silt (0.05 – 0.002 mm)			25.7	29.3	27.4	23.0	26.0	26.8	25.4
clay (0.002 mm)			5.8	5.0	2.5	2.8	10.1	13.0	14.7
Chemical analysis									
pH		H_2O	3.2	3.6	4.2	5.2	5.1	4.4	4.3
pH		KCl	3.6	4.0	4.4	5.3		4.7	4.4
C		%	1.49	0.45	0.17	0.13	2.19	0.55	0.30
N		%	0.07	0.03	0.01	0.01	0.05	0.02	0.02
C/N			21	15	14	11	41	26	14
CEC		me %	0.4	1.4	2.5	0.9	13.4	2.0	1.1
Exch. Ca		me %	0.4	0.3	0.5	0.4	0.4	0.6	0.7
Exch. Mg		me %	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Exch. K		me %	t	t	t	t	t	t	0.1
Exch. Na		me %	0.1	0.1	0.1	0.1	0.1	0.2	0.1
Base saturation		%	100	32	27	78	5	46	86
Extr. Ca	(HCl)	ppm	110	200	200	150	40		
Extr. Mg	(HCl)	ppm	90	180	140	230	230		
Extr. K	(HCl)	ppm	630	360	910	170	530		
Extr. P	(HCl)	ppm	30	10	10	15	24		
Extr. Fe	(Morgan)	ppm	50	25	10	6	16		
Extr. Mn	(Morgan)	ppm	60	40	40	20	210		

Table 91

Profile 29, heavy minerals in 0.05–0.2 mm sand fraction

Depth (cms)		*8/13* *20*	*30/41* *44*	*51* *56/60*	*56/60* *69/84*	*86* *99*
% heavies						
% opaques		59	49	69	72	68
% non-opaques		41	51	31	28	32
Opaques %						
Ilmenite, etc		15	8	8	10	10
Leocoxene, etc		64	76	79	59	62
Limonite, etc		17	13	10	22	23
Earthy hematite		3	3	2	9	4
Non-opaques (%)						
Zircon	clear, rolled	37	41	49	47	49
	clear, worn	37	44	28	29	34
	pink, rolled	2	3	3	7	3
	pink, worn	–	1	–	3	–
Tourmaline	brown	4	4	9	3	3
	green	9	2	4	3	1
	blue	2	–	–	–	–
Rutile	red	1	1	–	2	1
	yellow	1	3	3	2	3
Anatase		4	2	1	4	6
Topaz		1	–	–	–	–
Alterites		1	–	1	–	–
Unknown		–	–	1	–	–

B3 *69/84–120 cms:* Pale yellow (2.5Y 7/4 and 5Y 8/3) fine to very fine sandy loam, with many medium and fine distinct yellowish red and brownish yellow mottles. Moist. Massive. Firm. Rare rootlets.

Comments

This profile is included in the numerical ordination study.

Profile 30

Family: SILANTEK. *Series:* Tunggal loamy sand.

Site: Summit of high ridge; 3° slope, falling quickly off to 40° on flank slopes within 10 metres. *Parent material:* Conglomerate, ascribed to the Liang Formation (Upper Pliocene). *Location:* Bukit Tunggal, Sarupai headwaters; Balingian Subdistrict; (2/112/3; 138.994). *Cover:* Thin primary forest. *Reference samples:* S7778/7782.

Field morphology

AO/A11 *0–8 cms:* Dusky red (2.5YR 3/2) litter in a sandy loam matrix, the litter raw but finely comminuted. Abundant rootlets. Distinct wavy boundary.

A12 *8–18 cms:* Brown (7.5YR 4.5/2) loamy sand. Moist. Single-grain structure. Very friable. Many roots. Diffuse wavy boundary.

A2 *18–45/48 cms:* White (7.5YR 8/0) loamy sand. Moist. Single-grain to massive. Consistence laterally variable from firm to compact, becoming generally very compact towards base of horizon. Rare rootlets. Diffuse wavy boundary.

Table 92

Profile 30, analytical data for fine earth (<2mm)

Depth (cms)			*0*	*8*	*18*	*45/48*	*56/63*
			8	*18*	*45/48*	*56/63*	*66*
Granulometric analysis (%)							
2 – 1mm	(vcs)			0.8	1.1	1.0	2.4
1 – 0.5 mm	(cs)			5.8	7.3	13.3	20.6
0.5 – 0.2 mm	(ms)			24.5	24.9	26.9	29.7
0.2 – 0.1 mm	(fs)			28.1	23.3	20.6	14.3
0.1 – 0.05 mm	(vfs)			22.3	22.4	17.7	12.9
sand (2 – 0.05 mm)				81.5	79.0	79.5	79.9
silt (0.05 – 0.002 mm)				11.5	17.9	12.9	10.4
clay (0.002 mm)				7.0	3.1	7.6	9.7
Chemical analysis							
pH		H_2O	3.5	4.6	5.7	4.2	4.7
pH		KCl	1.8	2.9	4.1	3.3	3.8
C		%	31.75	0.57	0.05	0.33	0.78
N		%	1.54	0.05	0.03	0.02	0.03
C/N			21	12	2	14	25
CEC		me %	102.0	1.1	1.5	1.9	5.0
Exch. Ca		me %	0.3	0.3	0.2	0.2	0.4
Exch. Mg		me %	1.3	0.4	t	t	t
Exch. K		me %	1.1	t	t	t	t
Exch. Na		me %	0.4	t	t	t	t
Base saturation		%	3	70	17	15	9
Extr. Ca	(HCl)	ppm			100	90	
Extr. Mg	(HCl)	ppm			t	140	
Extr. K	(HCl)	ppm			380	1000	
Extr. P	(HCl)	ppm	480	40	10	90	80
Extr. Fe	(Morgan)	ppm			8	8	
Extr. Al	(Morgan)	ppm			t	200	

B21h *45/48–56/63 cms:* Brown and dark brown (7.5YR 4/2 and 3/2) banded loamy sand in thin alternating bands approximately conformable with the horizon boundaries, the horizon angling through the profile and varying from 5 to 10 cms in thickness. Moist. Massive. Consistence friable to compact, varying laterally as horizon above and unrelated to colour banding. Rare rootlets, following friable zones. Distinct wavy boundary.

B22h/C *below 56/63 cms:* Very hard weathered conglomerate, dominantly yellow, but grey or light grey in fresher patches; cracks infilled with black, dark brown and strong brown coatings from (presumed) illuvial humus and sesquioxides.

Micromorphology

8–18 cms: Poorly-sorted angular and subangular coarse to very fine quartz sand grains and very rare angular zircons and tourmalines in a matrix of quartz silt and light grey isotic material with many distinct very fine light brown mottles. Scattered irregular packing voids. No cutans. Few roots.

47–57 cms: Poorly-sorted sand grains as above in a patchy finer matrix; matrix dark brown to brown omnisepic grading locally to very pale brown to light grey weakly insepic, the latter being in part apparently poorly-sorted silt and clay infill material. Few medium and small angular argillaceous lithorelicts. Scattered irregular medium and small packing voids and rare small equant voids in matrix. Rare irregular narrow channels; no discrete structural peds. Cutans on

many channels and other voids comprising (a) thick light grey to very pale brown, well-defined but poorly-sorted and unordered, silt clay and rare very fine sand in some larger channels; (b) medium to thin distinct well-ordered very pale brown to brown argillans on smaller voids. In some cases both types occur, a (b) cutan coating a void previously partially infilled by (a) cutan deposits.

Comments

This profile is included in the numerical ordination study.

Profile 31

Family: SILANTEK. *Series:* Silantek fine sand.

Site: Summit of isolated hill (c. 50 feet high), partly eroded by adjacent tidal creek. Profile sampled in landslip face; original slope probably slight. *Parent material:* Tertiary sandstone. *Location:* Near Nanga Bakau, Sukong, Sarikei District; (2/111/14; 312.529). *Cover:* Thick grasses and shrubs; regrowth after hill rice. *Reference samples:* MS1440/1447.

Field morphology

0 *30–0 cms:* Thick matt of grass roots with little mineral material, overlying:

A1 *0–8 cms:* Greyish brown (10YR 5/2) fine sand. Moist. Single-grain structure. Loose. Dark greyish brown staining near main root channels. Many rootlets. Indistinct wavy boundary.

A2 *8–20 cms:* Greyish brown to light brownish grey (10YR 5.5/2) fine sand. Moist. Single-grain structure. Loose. Rare rootlets. Indistinct wavy boundary.

B2h *20–25 cms:* Dark brown to dark reddish brown (5–7.5YR 3/2) fine sand. Moist. Massive. Friable. Rare rootlets. Indistinct wavy boundary.

B2ir *25–30 cms:* Brownish yellow (10YR 6/6) fine sand, with many fine to coarse distinct strong brown mottles and many rusty root channels. Moist. Massive, apart from subvertical cracks from residual rock structure, the main crack faces being coated dark reddish brown. Very firm. Rare rootlets. Few pores. Diffuse wavy boundary.

B3ir *30–53 cms:* Yellow (10YR–2.5Y 7/6) fine sandy loam. Otherwise as above. The subvertical cracks described above continue through this and the next horizon. Diffuse wavy boundary.

C *53–120 cms:* White (2.5Y 8/2) and yellow (10YR 7/6) coarsely mottled sandy clay loam, with many coarse distinct yellowish brown mottles, becoming few below 90 cms. Otherwise as above.

Micromorphology

10–20 cms: Abundant poorly-sorted coarse to very fine angular to subrounded quartz sand grains and very rare very fine zircons and tourmalines in a sparse finely variegated light grey and pale brown silasepic to isotic matrix. Few long narrow irregular channels, no discrete structural peds. Many fine and medium irregular packing voids. No cutans. Few roots.

20–23 cms: As above, but matrix dominantly comprises fine clusters of brown to dark brown humic particles; diffusely grading to:

23–26 cms: Continuous variegated yellowish brown to reddish brown isotic (humic) matrix. Few packing voids. Many roots. Otherwise as above.

26–30 cms: Sand grains as above in a very pale brown to pale yellow isotic to silasepic matrix. Rare narrow subvertical irregular channels; no discrete structural peds. Many fine and very fine irregular to equant voids. Channels and finer voids commonly coated with medium to thin generally intermittent yellow to strong brown cutans, locally well-ordered but dominantly isotic. Thin black isotic coatings common on sand grains. Rare roots. Local thick subvertical acicular zones have dominantly variegated brownish yellow and yellow isotic matrix and somewhat sparser sand grains, but are otherwise like surrounding material.

40–50 cms: Sand grains as above in a continuous light grey weakly silasepic to skelsepic matrix, locally diffusely mottled yellow. Rare thin irregular channels; no discrete structural peds. Many

Table 93

Profile 31, analytical data for fine earth (<2mm)

Depth (cms)		*0*	*8*	*20*	*25*	*30*	*53*	*86*
		8	*20*	*25*	*30*	*53*	*86*	*120*
Granulometric analysis (%)								
2 – 1 mm	(vcs)	0	0	0	0	0	0.3	0.5
1 – 0.5 mm	(cs)	0	0	0	0	2.1	1.1	1.2
0.5 – 0.2 mm	(ms)	33.0	1.0	2.2	0.6	25.2	13.4	11.5
0.2 – 0.1 mm	(fs)	36.1	50.6	50.5	49.9	23.7	20.9	20.1
0.1 – 0.05 mm	(vfs)	23.5	43.8	44.2	44.8	23.4	31.1	29.1
sand (2 – 0.05 mm)		92.6	95.4	96.9	95.3	74.4	66.8	62.3
silt (0.05 – 0.002 mm)		1.9	0.1	1.1	2.2	14.3	8.9	10.2
clay (0.002 mm)		5.4	4.5	2.0	2.5	11.3	24.2	27.5
Chemical analysis								
pH	H_2O	2.8	3.2	3.7	4.2	4.4	4.1	3.9
pH	KCl	3.3	3.7		4.0	4.2	3.8	3.7
C	%	2.92	0.53	1.96	1.58	0.33	0.01	t
N	%	0.11	0.03	0.02	0.04	0.01	0.01	0.01
C/N		27	16	120	44	25	1	
CEC	me %	7.4	1.0	8.6	7.4	1.4	2.0	2.6
Exch. Ca	me %	0.1	0.1	0.1	0.2	0.1	0.1	0.1
Exch. Mg	me %	0.1	t	0.1	t	0.1	0.1	0.1
Exch. K	me %	0.1	t	t	t	t	t	t
Exch. Na	me %	0.1	0.1	0.1	0.1	0.2	0.1	0.1
Base saturation	%	20	20	3	4	30	12	12
Extr. P (HC1)	ppm	50	20	60	50	30	70	50
Extr. Fe (Morgan)	ppm		t	t	29	38	t	
Extr. A1 (Morgan)	ppm		20	400	980	380	220	
Extr. Fe_2O_3 (6NHC1)	%	t	t	t	0.6	0.6	t	0.7
Avail. P	ppm	3	3	12	4	3	3	2

medium and fine dominantly irregular voids, the majority lacking cutans. Few voids have thin to thick very pale brown poorly-ordered weakly sepic cutans, in some instances overlying intermittent thin moderately well-ordered brownish yellow cutan fragments. No roots.

Clay mineralogy

3–8 cms: Mainly gibbsite with some geothite, illite and vermiculite.

8–20 cms: Mainly fairly well-crystallised illite with some kaolinite and mixtures of geothite and boehmite.

20–53 cms: Mainly fairly well-crystallised kaolinite with some vermiculite and gibbsitic A1 oxides. Hydrated A1 and Fe oxides or silicates are also present.

53–120 cms: Mainly fairly well-crystallised kaolinite with some vermiculite and gibbsitic A1 oxides.

Comments

This profile is illustrated in Colour Plate 10. It is included in the numerical ordination study.

Table 94

Profile 31, heavy minerals in 0.08–0.1 mm sand fraction

Depth (cms)		*20–25*	*25–30*	*30–120*
% heavies		0.01		0.08
% opaques		47	47	65
% non-opaques		53	53	35
Opaques (%)				
Ilmenite, etc		17	21	10
Leocoxene, etc		79	78	86
Limonite, etc		4	1	3
Earthy hematite		—	1	1
Non-opaques (%)				
Zircon	clear, rolled	38	23	27
	clear, worn	27	19	33
	clear, euhedral	2	—	33
	pink, rolled	31	2	1
	pink, worn	1	—	1
Tourmaline	brown	9	25	11
	green	1	13	10
	blue	—	4	3
Anatase		11	10	9
Rutile	red	—	2	1
	yellow	5	3	2
Brookite		1	—	t

Profile 32

Family: SEDUAU. *Series:* Seduau silty clay.

Site: Riverine bottomland; almost flat. *Parent material:* Accreting riverine alluvium derived from sedimentary rocks. *Location:* Kanowit River floodplain; Tanjung Rantau Sebaya, between Julau and Machan; Kanowit District; (2/111/16; 243.193). *Cover:* Old rubber in tapping. *Reference samples:* S3349/3355.

Field morphology

A11 *0–4 cms:* Brown to dark brown (10YR 4/3) silty clay. Moist. Weak medium and coarse subangular blocky structure. Friable. Many rootlets. Few pores. Indistinct wavy boundary.

A12 *4–10 cms:* Dark yellowish brown (10YR 4/4) clay. Moist. Weak medium subangular blocky structure. Friable. No roots seen. Few pores. Diffuse smooth boundary.

A/B *10–41 cms:* Dark yellowish brown to yellowish brown (10YR 4.5/4) silty clay. Otherwise as above. Diffuse smooth boundary.

B *41–74 cms:* Yellowish brown (10YR 5/8) clay. Otherwise as above. Boundary arbitrary.

B *74–99 cms:* Clay loam. Otherwise as above. Diffuse smooth boundary.

B *99–117 cms:* Yellowish brown (10YR 5/8) loam. Moist. Weak medium subangular blocky structure. Friable. No roots seen. Few pores.

Comments

The basal unmottled yellowish brown loam horizon extends to a depth of at least 150 cms. The profile is within 100 metres of Profile 42, on the terrace tract which fringes the bottomland in this locality. While developed in accreting alluvium, the carbon levels at depth are below those required for a Fluvent classification. Correlations with the USDA taxonomy are given in Appendix V.

Table 95

Profile 32, analytical data for fine earth (<2mm)

Depth (cms)		*0* *4*	*4* *10*	*10* *41*	*41* *74*	*74* *99*	*99* *117*
Granulometric analysis (%)							
sand (2 – 0.05 mm)		10.9	16.9	17.1	16.8	39.7	51.5
silt (0.05 – 0.002 mm)		45.4	37.6	40.8	39.8	26.5	30.3
clay (0.002 mm)		43.7	45.5	42.1	43.4	33.8	18.2
Chemical analysis							
pH	H_2O	4.1	4.0	4.1	4.4	4.3	4.2
pH	KCl	3.9	3.6	3.6	3.6	3.8	3.8
C	%	3.33	1.26	0.57	0.37	0.23	0.19
N	%	0.36	0.17	0.10	0.08	0.05	0.04
C/N		11	13	18	22	5	5
CEC	me %	15.0	10.2	6.6	5.6	4.4	3.6
Exch. Ca	me %	0.7	0.6	0.7	1.0	0.9	1.0
Exch. Mg	me %	1.9	0.4	0.3	0.3	0.4	0.3
Exch. K	me %	0.2	0.1	0.2	0.1	0.1	0.2
Exch. Na	me %	0.4	0.4	0.4	0.4	0.4	0.4
Base saturation	%	21	15	24	32	40	50
Exch. A1	me %	3.1	4.4	3.4			
Extr. Ca (HC1)	ppm	540	430	430	320	220	320
Extr. Mg (HC1)	ppm	2960	2550	2720	2490	2220	1920
Extr. K (HC1)	ppm	9800	8950	8750	7800	7650	6250
Extr. P (HC1)	ppm	530	440	350	290	300	280
Extr. Fe (Morgan)	ppm	83	38	19	16	7	
Extr. A1 (Morgan)	ppm	350	430	360	420	240	
Extr. Mn (Morgan)	ppm	420	90	40	30	20	
Extr. Zn (Morgan)	ppm	7	2	1	1	1	
Extr. Cu (Morgan)	ppm	1	t	1	t	t	

Profile 33

Family: SEDUAU. *Series:* Malang silty clay.

Site: Narrow bottomland drained by minor stream; 1° slope. *Parent material:* Accreting riverine alluvium derived from Tertiary sedimentary rocks. *Location:* Jikang River floodplain, near Durin; Sibu District; (2/111/16; 254.120). *Cover:* Thin secondary forest; old regrowth presumably following hill rice. *Reference samples:* S2809/2816.

Field morphology

A1 *0–8 cms:* Brown to dark brown (10YR 4/3) silty clay. Moist. Very weak fine crumb structure. Friable. Many roots and rootlets. Few pores. Distinct smooth boundary.

A2 *8–15 cms:* Yellowish brown (10YR 5/6) silty clay. Moist. Weak medium to fine subangular blocky structure. Firm. Many rootlets. Few pores. Indistinct wavy boundary.

A3 *15–30 cms:* Brownish yellow (10YR 6/6) silty clay, with many faint light grey and yellow mottles. Moist. Weak coarse subangular blocky structure. Very firm. Porous. Few rootlets. Indistinct wavy boundary.

B *30–76 cms:* Reddish yellow (7.5YR 6/8) clay, with abundant fine and medium faint brownish yellow mottles. Moist. Weak coarse subangular blocky structure. Very firm. Rare rootlets. Few pores.

Comments

Reddish yellow mottled silty clay extends to 137 cms, and is underlain by moist brownish yellow mottled silty clay to a depth of at least 190 cms. This profile is included in the numerical ordination study.

Table 96

Profile 33, analytical data for fine earth (<2mm)

Depth (cms)			*0* *8*	*8* *15*	*15* *30*	*30* *76*	*76* *109*
Granulometric analysis (%)							
2 – 1 mm	(vcs)				0	0	0
1 – 0.5 mm	(cs)				0	0	0
0.5 – 0.2 mm	(ms)				0	0.2	0.4
0.2 – 0.1 mm	(fs)				0.2	0.4	0.5
0.1 – 0.05 mm	(vfs)				1.1	0.4	1.1
sand (2 – 0.05 mm)			0.9	1.1	1.3	1.0	2.0
silt (0.05 – 0.002 mm)			40.0	50.6	45.2	36.7	41.7
clay (0.002 mm)			59.1	48.4	53.6	62.4	56.3
Chemical analysis							
pH		H_2O	3.7	3.9	4.0	4.0	4.3
pH		KCl	3.6	3.4	3.4	3.6	3.7
C		%	10.98	1.66	0.75	0.41	0.28
N		%	0.08	0.20	0.12	0.09	0.08
C/N			137	8	6	5	4
CEC		me %	23.1	10.2	10.7	7.7	5.8
Exch. Ca		me %	2.6	0.4	1.0	0.7	0.7
Exch. Mg		me %	1.5	0.5	0.2	0.2	0.5
Exch. K		me %	0.5	0.2	0.1	0.1	0.1
Exch. Na		me %	0.3	0.3	0.1	0.1	0.1
Base saturation		%	22	14	13	14	23
Exch. A1		me %				5.0	3.2
Extr. Ca (HC1)		ppm	580	210	230	100	90
Extr. Mg (HC1)		ppm	2090	2700	2160	1750	2100
Extr. K (HC1)		ppm	1650	7100	6250	9150	8100
Extr. P (HC1)		ppm	650	220	160	150	140
Extr. Fe (Morgan)		ppm			31	8	5
Extr. A1 (Morgan)		ppm			960	790	580

Profile 34

Family: BEMANG. *Series:* Bemang sandy clay loam.

Site: Riverine bottomland 20 metres back from low levee; almost flat. *Parent material:* Accreting riverine alluvial deposits derived from Tertiary sedimentary rocks. *Location:* Pasai River floodplain; Oya Road Agricultural Station, Sibu District; (2/112/9; 540.295).

Field morphology

A11 *0–18 cms:* Dark yellowish brown (10YR 4/4) sandy clay loam. Moist. Very weak medium subangular blocky and coarse granular structure. Friable. Abundant rootlets. Few pores. Diffuse wavy boundary.

A12 *18–43 cms:* Clay loam; structure weak. Otherwise as above. Indistinct wavy boundary.

Table 97

Profile 34, analytical data for fine earth (<2mm)

Depth (cms)		*0*	*5*	*18*	*43*	*71*	*89*
		5	*18*	*43*	*71*	*89*	*110*
Granulometric analysis (%)							
2 – 1 mm	(vcs)	0	0	0	0	0	0
1 – 0.5 mm	(cs)	0.2	0.1	0.1	0	t	0.2
0.5 – 0.2 mm	(ms)	1.0	0.5	0.3	0.3	2.9	8.2
0.2 – 0.1 mm	(fs)	4.9	8.3	6.1	4.2	16.3	28.4
0.1 – 0.05 mm	(vfs)	28.0	38.1	36.6	32.8	34.9	34.1
sand (2 – 0.05 mm)		34.1	46.9	43.1	37.4	54.1	70.9
silt (0.05 – 0.002 mm)		34.2	26.0	28.3	29.3	22.2	13.5
clay (0.002 mm)		31.6	27.2	28.6	33.3	23.7	15.6
Chemical analysis							
pH	H_2O	4.2	4.2	4.2	4.5	4.7	4.9
pH	KCl	3.7	3.7	3.7	3.8	3.8	4.0
C	%	2.33	1.65	1.06	0.76	0.43	0.43
N	%	0.24	0.18	0.13	0.13	0.08	0.08
C/N		10	9	8	6	5	5
CEC	me %	9.9	6.8	6.7	7.1	3.9	2.5
Exch. Ca	me %	1.6	0.6	0.2	0.1	0.1	0.1
Exch. Mg	me %	0.7	0.3	0.1	0.1	t	0.4
Exch. K	me %	0.2	0.2	0.1	0.1	0.1	0.1
Exch. Na	me %	0.1	0.1	0.1	0.2	0.2	0.2
Base saturation	%	26	18	8	6	11	29
Extr. P (HCl)	ppm	310	310	310	1270	290	170
Extr. Fe_2O_3 (6NHCl)	%	3.5	2.7	3.8	4.0	3.2	1.2

A/B *43–71 cms:* Dark yellowish brown to yellowish brown (10YR 4.5/4) clay loam, with few fine distinct pale brown mottles. Moist. Weak coarse subangular blocky structure. Friable. Many rootlets. Few pores. Indistinct wavy boundary.

B *71–89 cms:* Yellowish brown (10YR 5/4) sandy clay loam, with abundant fine distinct pale brown mottles and few fine distinct strong brown mottles. Otherwise as above. Instinct wavy boundary.

Cg or IICg *89-110 cms:* Light brownish grey (2.5 YR 6/2) very fine sandy loam, with many fine and medium distinct yellowish brown and strong brown mottles. Moist. Very weak coarse subangular blocky structure. Friable. Rare rootlets. No pores seen.

Comments

This profile is illustrated in Colour Plate 14.

Profile 35

Family: BEMANG. *Series:* Semilajau loamy fine sand.

Site: Low narrow levee on bank of minor river channel; less than 1° slope. *Parent material:* Accreting riverine alluvium derived from Tertiary sedimentary rocks. *Location:* Bank of Pasai River, Oya Road Agricultural Station, Sibu District; (2/112/9; 540.295). *Cover:* Secondary riverain forest with scattered fruit trees. *Reference samples:* S2896/2902.

Table 98

Profile 35, analytical data for fine earth (<2mm)

Depth (cms)		*0* *8*	*8* *33*	*33* *58*	*58* *86*
Granulometric analysis (%)					
2 – 1 mm	(vcs)	0	0	0	0
1 – 0.5 mm	(cs)	0	0	0	0
0.5 – 0.2 mm	(ms)	2.7	2.0	2.3	6.4
0.2 – 0.1 mm	(fs)	48.7	40.5	34.2	36.5
0.1 – 0.05 mm	(vfs)	26.7	33.0	31.6	25.6
sand (2 – 0.05 mm)		78.1	75.4	68.1	68.5
silt (0.05 – 0.002 mm)		8.9	21.1	26.8	25.3
clay (0.002 mm)		13.0	3.4	5.1	6.2
Chemical analysis					
pH	H_2O	3.7	4.6	4.8	4.8
pH	KCl	3.6	3.6	3.6	3.6
C	%	1.27	0.94	0.17	0.19
N	%	0.05	0.06	0.04	0.04
C/N		25	5	4	5
CEC	me %	4.6	2.7	3.7	3.6
Exch. Ca	me %	0.3	0.3	0.3	0.3
Exch. Mg	me %	0.2	0.2	0.2	0.2
Exch. K	me %	0.1	0.1	0.1	0.1
Exch. Na	me %	0.3	0.4	0.4	0.3
Base saturation	%	17	30	23	21
Extr. Ca (HCl)	ppm	40	120	120	360
Extr. Mg (HCl)	ppm	950	330	510	400
Extr. K (HCl)	ppm	4090	1900	1850	3250
Extr. P (HCl)	ppm	210	90	80	120

Field morphology

A/C *0–8 cms:* Strong brown (7.5YR 5/6) fine sandy loam. Moist. Massive. Very friable. Many rootlets. Few pores. Indistinct wavy boundary.

C1 *8–33 cms:* Yellowish brown. (10YR 5/6) loamy fine sand. Moist. Massive. Very friable. Few rootlets. Few pores. Boundary arbitrary.

C2 *33–58 cms:* Very fine sandy loam. Otherwise as above. Boundary arbitrary.

C3 *58–114 cms:* Fine sandy loam. Otherwise as above.

Comments

Between 114 cms and 145 cms the profile is wet and faintly mottled, with a matrix colour of 10YR 5/8.

Profile 36

Family: KABONG. *Series:* Kabong fine sand.

Site: Top of low sand ridge in fossil strand line and swale complex behind present coast; no measurable slope. *Parent material:* Subrecent marine alluvium. *Location:* Near Belawai, Sarikei District; (2/111/13; 437.333). *Cover:* Poor secondary growth of grasses and shrubs. *Reference samples:* S7917/7921.

Field morphology

A11 *0–15 cms:* Dark greyish brown (10YR 4/2) fine sand. Moist. Single-grain structure. Loose. Many fine and medium roots. Indistinct wavy boundary.

Table 99

Profile 36, analytical data for fine earth (<2mm)

Depth (cms)		*0–15*	*15–28*	*28–61*	*61–102*	*102–120*
Granulometric analysis (%)						
2 – 1 mm	(vcs)	0	0	0	0	0
1 – 0.5 mm	(cs)	0	0	0	0	0
0.5 – 0.2 mm	(ms)	3.6	2.8	4.3	4.7	1.9
0.2 – 0.1 mm	(fs)	88.2	88.1	91.1	91.9	94.6
0.1 – 0.05 mm	(vfs)	2.3	2.3	0.9	0.3	0.8
sand (2 – 0.05 mm)		94.0	93.2	96.3	96.9	97.3
silt (0.05 – 0.002 mm)		1.7	2.1	0.3	0.6	0.2
clay (0.002 mm)		4.3	4.7	3.4	2.5	2.5
Chemical analysis						
pH	H_2O	5.5	5.5	5.7	5.8	6.0
pH	KCl	4.7	4.6	4.8	4.9	4.8
C	%	0.08	0.62	0.19	0.06	0.04
N	%	0.05	0.03	0.02	0.01	0.01
C/N		2	18	11	6	3
CEC	me %	0.7	1.2	0.4	0.9	0.6
Exch. Ca	me %	0.2	0.2	0.2	0.3	0.2
Exch. Mg	me %	t	0.1	t	t	t
Exch. K	me %	0.1	t	t	t	t
Exch. Na	me %	t	t	t	t	t
Base saturation	%	50	27	51	33	34
Extr. Ca (HCl)	ppm	t	t	t	t	
Extr. Mg (HCl)	ppm	t	t	t	t	
Extr. K (HCl)	ppm	350	460	630	500	
Extr. P (HCl)	ppm	120	110	100	80	
Extr. Fe (Morgan)	ppm			8	8	
Extr. Al (Morgan)	ppm			100	50	
Extr. SiO_2 (Na_2CO_3)	%	93.0	94.2	92.6	96.7	98.2
Extr. Fe_2O_3 (Na_2CO_3)	%	1.2	1.4	1.5	1.2	1.0
Extr. Al_2O_3 (Na_2CO_3)	%	1.5	1.8	1.9	1.8	2.1
Conductivity (mmhos/cm/25°C)		16	10	6	4	5
Cl	ppm	25	21	21	21	21
SO_4 (Water-soluble)	%	t	t	t	t	t

A12 *15–28 cms:* Dark yellowish brown (10YR 4/4) fine sand. Moist. Single-grain structure. Loose. Few roots. Diffuse wavy boundary.

C1 *28–61 cms:* Brownish yellow (10YR 6/6) fine sand. Moist. Single-grain structure. Loose. Rare rootlets. Diffuse wavy boundary.

C2g *61–120 cms:* Pale brown (10YR 6/3) fine sand, with few medium distinct strong brown mottles. Wet. Single-grain structure. Loose. No roots seen.

Comments

This profile is included in the numerical ordination study.

Table 100

Profile 37, analytical data for fine earth (<2mm)

Depth (cms)		*0*	*25*	*46*	*61*
		25	*46*	*61*	*75*
Granulometric analysis (%)					
2 – 1 mm	(vcs)	0	0	0	0
1 – 0.5 mm	(cs)	0	0	0	0
0.5 – 0.2 mm	(ms)	0.5	1.9	1.5	0.8
0.2 – 0.1 mm	(fs)	79.5	85.0	84.1	92.4
0.1 – 0.05 mm	(vfs)	8.6	3.3	6.2	2.6
sand (2 – 0.05 mm)		88.5	90.2	91.7	95.8
silt (0.05 – 0.002 mm)		3.2	2.3	1.9	0.7
clay (0.002 mm)		8.3	7.5	6.4	3.5
Chemical analysis					
pH	H_2O	4.9	5.3	5.2	5.4
pH	KCl	4.1	4.7	4.7	4.6
C	%	0.10	0.29	0.20	0.09
N	%	0.06	0.02	0.02	0.01
C/N		60	16	11	7
CEC	me %	1.9	0.4	0.4	0.3
Exch. Ca	me %	0.3	0.2	0.3	0.2
Exch. Mg	me %	0.1	t	t	t
Exch. K	me %	0.1	0.1	0.1	0.1
Exch. Na	me %	0.1	0.1	t	0.1
Base saturation	%	29	89	92	100
Extr. Ca (HCl)	ppm	40	240	100	t
Extr. Mg (HCl)	ppm	t	t	t	t
Extr. K (HCl)	ppm	350	440	630	500
Extr. P (HCl)	ppm	100	100	140	80
Extr. Fe (Morgan)	ppm		13	18	5
Extr. Al (Morgan)	ppm		100	160	110
Extr. SiO_2 (Na_2CO_3)	%	93.4	94.3	92.8	95.3
Extr. Fe_2O_3 (Na_2CO_3)	%	1.2	3.1	2.6	0.8
Extr. Al_2O_3 (Na_2CO_3)	%	2.0	2.0	2.2	
Conductivity (mmhos/cm/25°C)		12	8	10	5
Cl	ppm	21	28	25	28
SO_4 (Water-soluble)	%	t	t	t	t

Profile 37

Family: KABONG. *Series:* Belawai fine sand.

Site: Top of low sand ridge in fossil strand line and swale complex behind present coast; no measurable slope. *Parent material:* Subrecent marine alluvium. *Location:* Near Berawan Kechil River, Jerijeh, Sarikei District; (2/111/13; 395.323). *Cover:* Grasses and scattered Casuarina. *Reference samples:* S7913/7916.

Field morphology

A1 *0–25 cms:* Dark greyish brown (10YR 4/2) fine sand. Moist. Single-grain structure. Very loose. Many fine and medium roots. Distinct wavy boundary.

B *25–46 cms:* Strong brown (7.5YR 5/7) fine sand; with many medium distinct weak red (2.5YR 5/2) mottles, largely associated with small root channels. Moist. Single-grain structure. Very loose. Few live roots. Distinct wavy boundary.

C1 *46–61 cms:* Yellow (10YR 7/6) fine sand, mottled weak red as horizon above. Moist. Single-grain structure. Very loose. Rare rootlets. Indistinct wavy boundary.

C2g *61–75 cms:* Pale brown (10YR 6/3) fine sand. Wet. Single-grain structure. Very loose. No roots seen.

Comments

This profile is included in the numerical ordination study.

Profile 38

Family: SEDUAU-BIJAT Intergrade. *Series:* Malang-Bijat clay loam.

Site: Top of low broad levee bounding major river channel; profile sampled from face of river cutting. *Parent material:* Accreting riverine alluvium, largely derived from sedimentary rocks. *Location:* North bank of Rajang River; immediately upstream of Durin ferry slip; Sibu District; (2/112/13; 381.230). *Cover:* Grass regrowth on edge of pepper garden. *Reference samples:* MS1470/1475.

Field morphology

A1 *0–8 cms:* Brown to dark brown (7.5YR 4/4) silty clay. Moist. Weak coarse subangular blocky structure. Friable. Many rootlets. Few pores. Diffuse wavy boundary.

B1 *8–30 cms:* Reddish yellow (7.5YR 6/6) clay loam, with many fine distinct light yellowish brown mottles and few coarse distinct red mottles. Moist. Weak coarse angular blocky structure. Friable. Few rootlets. No pores seen. Diffuse wavy boundary.

B2 *30–46 cms:* Reddish yellow (7.5YR 6/6) and strong brown (7.5YR 5/6) coarsely mottled clay, with many fine distinct light yellowish brown mottles and many coarse distinct red mottles. Moist. Weak coarse angular blocky structure. Friable. Rare rootlets. No pores seen. Diffuse wavy boundary.

C1g *46–64/75 cms:* Light grey (10YR 6/1) silty clay, with profuse fine and medium distinct yellowish brown and reddish yellow mottles. Moist. Very coarse angular blocky structure with prominent subvertical cracks; crack faces light yellowish brown. Firm. Rare rootlets. No pores seen. Diffuse irregular boundary

C2g *64/75–120 cms:* Light grey (10YR 7/2) silty clay, with few fine distinct yellowish brown mottles. Moist. No apparent structure apart from subvertical cracks continuing from horizon above. Firm. Very rare rootlets. No pores seen.

Micromorphology

8–18 cms: Few fine subangular quartz sand grains in a profusely variegated brownish yellow, strong brown and reddish brown insepic to omnisepic matrix mainly comprising overlapping medium and large well-defined to diffuse striotubules with random orientation. Long narrow irregular channels partially bounding incomplete coarse angular blocks. Many small narrow acicular discrete channels; abundant medium to fine equant to irregular voids. Thin diffuse poorly-ordered yellowish brown cutans on some voids and intermittently on channel walls; most void surfaces clear.

30–40 cms: Few medium and fine subangular quartz sand grains in a diffusely variegated light grey and very pale brown insepic matrix with many coarse distinct irregular reddish yellow and

Table 101

Profile 38, analytical data for fine earth (<2mm)

Depth (cms)		*0* *8*	*8* *30*	*30* *46*	*46* *64/75*	*64/75* *76/97*	*76/97* *120*
Granulometric analysis (%)							
sand (2 – 0.05 mm)		19.1	20.4	26.4	12.1	4.7	6.8
silt (0.05 – 0.002 mm)		40.3	39.6	24.3	43.0	43.1	43.5
clay (0.002 mm)		40.6	40.0	49.4	44.9	52.3	49.6
Chemical analysis							
pH	H_2O	5.0	5.1	5.2	5.2	5.2	4.3
pH	KCl	3.9	3.9	3.9	3.9	3.7	3.7
C	%	0.52	0.43	0.32	0.15	0.25	0.19
N	%	0.15	0.09	0.09	0.08	0.09	0.07
C/N		4	5	4	2	3	3
CEC	me %	8.6	8.5	8.3	7.8	9.2	8.0
Exch. Ca	me %	1.2	0.2	0.2	0.8	0.1	1.1
Exch. Mg	me %	0.8	0.2	t	0.3	0.7	1.6
Exch. K	me %	0.3	0.1	0.1	0.1	0.1	0.1
Exch. Na	me %	0.2	0.1	0.2	0.2	0.4	0.3
Base saturation	%	28	7	5	18	15	38
Extr. Ca (HCl)	ppm	310	120	t	100	100	420
Extr. Mg (HCl)	ppm	2630	2760	2130	2450	4090	3280
Extr. K (HCl)	ppm	6880	7580	6900	7050	7700	6940
Extr. P (HCl)	ppm	280	190	330	240	150	120
Extr. Fe (Morgan)	ppm		5	5	8		
Extr. Al (Morgan)	ppm		1000	900	1090		
Extr. Fe_2O_3 (Na_2CO_3)	%	4.9	6.1	7.5	4.8	1.8	1.6

dark brown mottles; this material partially resorted in medium distinct striotubules. Many medium irregular channels commonly linking large irregular voids; no discrete structural peds. Many medium to fine equant to irregular voids, some with thin diffuse poorly-ordered brownish yellow cutans. Thin cutans also intermittently present on channel walls. Many small fecal pellets.

61–71 cms: Abundant poorly-sorted medium to fine angular and subangular quartz sand grains in a very pale brown insepic matrix with many distinct fine to coarse irregular yellowish brown to reddish brown mottles; this material locally resorted in striotubules. Many medium and small discrete acicular channels, many medium irregular voids and few fine equant voids; no discrete structural peds. Thin to thick distinct well-ordered brownish yellow cutans on some fine voids and intermittently on some channel walls. Many small fecal pellets in larger voids.

101–111 cms: Quartz grains as above in a very pale brown to light grey insepic to omnisepic matrix with many diffuse coarse yellow to dark brown mottles and as haloes round larger voids. Few medium and short irregular acicular channels; few medium and fine equant to irregular voids; no discrete structural peds. Many medium to thin diffuse poorly-ordered yellowish brown and yellow cutans on larger voids and channels; some well-ordered cutans on fine voids. Some voids partially infilled with fecal material. Scattered large irregular separations of very pale brown strongly orientated clay within matrix.

Clay mineralogy

0–120 cms: Poorly-crystallised illite and kaolinite, with some gibbsitic oxides. Little contrast between horizons.

Comments

This profile is included in the numerical ordination study.

Profile 39

Family: BEMANG-PAKAN intergrade. *Series:* Bemang-Pakan intergrade.

Site: Edge of narrow riverine floodplain; very gently undulating; 3° slope. *Parent material:* Accreting riverine alluvium, (with possibly some colluvial admixture from adjacent hills) derived from Tertiary sedimentary rocks. *Location:* About 0.8 km southeast of Genting, Binatang District; (2/111/15; 323.900). *Cover:* Grass and shrub regrowth following rice 3 years previously. *Reference samples:* S4176/4183.

Field morphology

0–13 cms: Brown to dark brown (10YR 4/3) loam. Wet. Slightly sticky and plastic. Few roots and rootlets. Distinct wavy boundary.

13–23 cms: Yellowish brown (10YR 5/4) loam, with few fine faint light yellowish brown mottles. Wet. Slightly sticky and plastic. Few rootlets. Indistinct wavy boundary.

Table 102

Profile 39, analytical data for fine earth (<2mm)

Depth (cms)		*0* *13*	*13* *23*	*23* *33*	*33* *48*	*48* *74*	*74* *90*
Granulometric analysis (%)							
2 – 1 mm	(vcs)		3.0	1.7	2.8	2.5	
1 – 0.5 mm	(cs)		5.8	4.8	4.8	4.6	
0.5 – 0.2 mm	(ms)		5.1	4.9	4.8	4.4	
0.2 – 0.1 mm	(fs)		5.9	5.9	5.1	4.4	
0.1 – 0.05 mm	(vfs)		23.6	23.7	18.8	16.6	
sand (2 – 0.05 mm)		39.5	43.3	41.0	36.3	32.5	
silt (0.05 – 0.002 mm)		47.3	34.4	33.7	32.9	31.3	
clay (0.002 mm)		13.2	22.4	25.2	30.8	36.2	
Chemical analysis							
pH	H_2O	4.3	4.1	3.5	3.5	3.6	3.4
pH	KCl	4.2	3.8	3.6	3.4	3.5	3.5
C	%	1.62	1.73	1.56	0.89	0.42	0.33
N	%	0.15	0.14	0.12	0.06	0.05	0.05
C/N		9	8	13	15	8	6
CEC	me %	6.8	7.4	6.4	5.4	3.9	8.8
Exch. Ca	me %	1.5	0.7	1.0	0.4	0.4	0.6
Exch. Mg	me %	0.9	0.5	0.4	0.2	0.2	0.2
Exch. K	me %	0.2	0.1	0.5	t	t	t
Exch. Na	me %	0.3	0.3	0.1	0.1	0.1	0.1
Base saturation	%	43	20	31	13	18	10
Extr. Ca (HCl)	ppm	210	170	280	220	280	280
Extr. Mg (HCl)	ppm	860	710	780	950	1100	1360
Extr. K (HCl)	ppm	2870	1800	2100	2780	4900	8300
Extr. P (HCl)	ppm	140	150	120	110	90	90
Extr. Fe (Morgan)	ppm		126	38	25	13	
Extr. Al (Morgan)	ppm		480	450	470	430	

23–33 cms: Brownish yellow (10YR 6/8), light grey (10YR 7/2) and very pale brown (10YR 7/4) mottled loam. Moist. Very weak coarse subangular blocky structure. Firm. Rare rootlets. Few pores. Rare charcoal fragments. Indistinct wavy boundary.

33–48 cms: Pale brown (10YR 6/3) and strong brown (7.5YR 5/8) clay loam. Moist. Very weak coarse subangular blocky structure. Slightly firm. Many coarse angular quartz gravel fragments. Rare rootlets. Few pores. Diffuse wavy boundary.

48–90 cms: Reddish yellow (7.5YR 6/8), light grey (2.5Y 7/2) strong brown (7.5YR 5/8) and very pale brown (10YR 7/3) variegated clay loam. Moist. Massive. Slightly firm. Few medium and coarse angular quartz fragments. Rare rootlets. Indistinct wavy boundary.

Comments

This profile is included in the numerical ordination study.

Profile 40

Family: PAKAN. *Series:* Pakan sandy clay loam.

Site: Lower slope of very gently undulating terrain; 2° slope. *Parent material:* Accreting riverine alluvium derived from Tertiary sedimentary rocks. *Location:* Raya River headwaters near mile 240, Sarikei-Durin Road, Binatang District; (2/111/15; 273.935). *Cover:* Regrowth following wet rice 4 years previously. *Reference samples:* S3571/3577.

Field morphology

0–23 cms: Greyish brown (10YR 5/2) very fine sandy loam. Moist. Very weak coarse crumb structure. Very friable. Many rootlets. Few pores. Distinct wavy boundary.

23–46 cms: Light grey (7.5YR 7/0) sandy clay loam, with many medium and coarse distinct brownish yellow mottles. Moist. Structureless. Firm. Slightly porous. Few rootlets. Few pores. Indistinct wavy boundary.

46–94 cms: Light grey (7.5YR 7/0) clay loam, with profuse medium and coarse distinct brownish yellow and red mottles. Moist. Massive. Firm. Rare small angular quartz stones. Rare rootlets. No pores seen. Indistinct wavy boundary.

94–117 cms: White (7.5YR 8/1) and reddish yellow (7.5YR 6/8) coarsely mottled clay. Moist. Massive. Firm. Rare small fragments of weathered shale. No roots seen. No pores.

Clay mineralogy

23–94 cms: Mainly illite and moderately crystallised kaolinite.

Comments

The profile is illustrated in Colour Plate 15, and is included in the numerical ordination study. White clay from shale weathered in situ occur below 117 cms and is mottled brownish yellow or pale brown to a depth of at least 218 cms. See also Table 37.

Profile 41

Family: SIRIK. *Series:* Sirik clay loam.

Site: Coastal alluvial plain; flat. *Parent material:* Estuarine or marine alluvium. *Location:* Near Kampong Bruit, Daro Subdistrict; (2/112/6; 992.520). *Cover:* Low regrowth following wet rice. *Reference samples:* S7435/7439.

Field morphology

0–13 cms: Brown to dark brown (7.5YR 4/2) silty clay loam, with many large distinct dark grey and strong brown mottles. Moist. Massive. Firm and slightly plastic. Few rootlets. No pores seen. Distinct wavy boundary.

13–51 cms: Grey (10YR 5/1) clay loam, with many coarse distinct strong brown mottles. Otherwise as above. Indistinct wavy boundary.

Table 103

Profile 40, analyticai data for fine earth (<2mm)

Depth (cms)		*0* *23*	*23* *46*	*46* *94*	*94* *117*
Granulometric analysis (%)					
2 – 1 mm	(vcs)	0	0.3	0.4	0
1 – 0.5 mm	(cs)	0.3	0.6	0.8	0.5
0.5 – 0.2 mm	(ms)	3.1	3.0	2.8	1.4
0.2 – 0.1 mm	(fs)	16.4	12.9	9.8	4.8
0.1 – 0.05 mm	(vfs)	44.1	40.6	30.2	16.5
sand (2 – 0.05 mm)		63.9	57.4	44.1	23.2
silt (0.05 – 0.002 mm)		22.3	22.5	25.0	31.0
clay (0.002 mm)		13.9	20.2	31.0	45.9
Chemical analysis					
pH	H_2O	4.2	4.4	4.4	4.6
pH	KCl	3.5	3.4	3.5	3.6
C	%	0.98	0.18	0.13	0.12
N	%	0.10	0.04	0.04	0.06
C/N		10	23	33	46
CEC	me %	3.9	4.0	3.2	3.9
Exch. Ca	me %	t	t	t	t
Exch. Mg	me %	0.1	t	t	t
Exch. K	me %	0.1	t	t	t
Exch. Na	me %	t	t	0.1	t
Base saturation	%	6	1	4	1
Extr. Ca (HCl)	ppm	300	160	200	300
Extr. Mg (HCl)	ppm	300	730	791	890
Extr. K (HCl)	ppm	2300	3680	5800	9350
Extr. P (HCl)	ppm	70	70	50	70
Extr. Fe (Morgan)	ppm	86	18	5	8
Extr. Al (Morgan)	ppm	270	370	280	300
Extr. Mn (Morgan)	ppm	3	1	1	1
Extr. Zn (Morgan)	ppm	1	1	t	1
Extr. Cu (Morgan)	ppm	t	t	t	t
Cl	ppm	35	35	28	39
SO_4 (Water-soluble)	%	t	0.1	t	t

Table 104

Profile 40, total silicate analysis of fine earth (<2mm); adjusted percentages.

Depth (cms)	*0–23*	*23–46*	*46–94*	*94–117*	*117–168*
SiO_2	94.62	91.20	83.78	74.03	69.55
Fe_2O_3	0.86	1.28	3.39	4.76	5.16
Al_2O_3	**3.20**	**6.07**	**10.44**	**17.36**	**18.47**
TiO_2	0.81	0.56	0.72	0.73	0.75
CaO	t	t	t	t	t
MgO	0.06	0.09	0.13	0.18	0.29
Na_2O	–	–	–	–	–
K_2O	0.45	0.80	1.54	2.93	3.56
MnO	t	t	t	t	t
P_2O_5	t	t	t	t	t

Field morphology (cont.)

51–76 cms: Dark grey (10YR 4/1) clay loam, with many coarse distinct strong brown mottles. Wet. Massive. Nonsticky. Plastic. No roots seen. Indistinct wavy boundary.

76–100 cms: Dark grey (10YR 4/1) clay loam, with few medium distinct yellowish brown mottles. Wet. Massive. Nonsticky. Plastic. No roots seen.

Comments

This profile is included in the numerical ordination study.

Profile 42

Family: TATAU. *Series:* Tatau medium sand.

Site: 30 metres back from beach in very gently undulating ridge and swale terrain; flat. *Parent material:* Subrecent beach sand. *Location:* Near Oya-Mukah coast road, at Patian Bahru river; Mukah Subdistrict;(2/112/1; 191.220). *Cover:* Casuarina and grassland. *Reference samples:* 4958/4961.

Field morphology

0–28 cms: Dark greyish brown (10YR 4/2) loamy sand, with many fine indistinct brownish yellow mottles. Moist. Single-grain structure. Loose. Abundant rootlets. Indistinct wavy boundary.

28–76 cms: Light grey (10YR 7/1) medium sand, with many coarse distinct brownish yellow mottles. Moist. Single-grain structures. Loose. Few rootlets. Indistinct wavy boundary.

76–100 cms: Dark greenish grey (5BG 4/1) medium sand, with few medium distinct yellow mottles. Wet. Single-grain structure. Loose. Rare rootlets.

Comments

No analytical data are available for this profile.

Table 105
Profile 41, analytical data for fine earth (<2mm)

Depth (cms)			*0*	*13*	*51*	*76*
			13	*51*	*76*	*100*
Granulometric analysis (%)						
2 – 1 mm	(vcs)		0	0	0	0
1 – 0.5 mm	(cs)		0.1	0	0	0
0.5 – 0.2 mm	(ms)		1.4	2.7	5.3	4.2
0.2 – 0.1 mm	(fs)		11.6	25.3	30.5	30.0
0.1 – 0.05 mm	(vfs)		5.0	4.2	5.0	5.6
sand (2 – 0.05 mm)			18.0	32.2	40.8	39.7
silt (0.05 – 0.002 mm)			43.7	32.3	26.7	29.7
clay (0.002 mm)			38.3	35.5	32.5	30.6
Chemical analysis						
pH		H_2O	7.0	5.9	6.8	6.5
pH		KCl	5.2	5.0	4.2	3.6
C		%	0.69	0.25	0.18	0.19
N		%	0.27	0.16	0.13	0.13
C/N			3	2	1	1
CEC		me %	16.6	11.0	9.6	10.8
Exch. Ca		me %	1.5	1.9	0.1	2.3
Exch. Mg		me %	7.0	2.4	3.5	2.2
Exch. K		me %	0.1	0.7	1.1	0.1
Exch. Na		me %	1.6	2.0	0.6	2.0
Base saturation		%	61	63	55	61
Extr. Ca (HCl)		ppm	520	330	390	360
Extr. Mg (HCl)		ppm	4670	4530	3940	3900
Extr. K (HCl)		ppm	5700	5500	5470	5790
Extr. P (HCl)		ppm	540	330	290	290
Extr. Fe (Morgan)		ppm	88	33	85	160
Extr. Al (Morgan)		ppm	66	75	100	230
Conductivity (mmhos/cm/25°C)			390	650	810	1050
Cl		ppm	0.2	0.2	0.3	0.3
SO_4 (water-soluble)		%	t	0.1	0.1	t

Profile 43

Family: TATAU. *Series:* Matu fine sand.

Site: Coastal swamp plain, 0.8 km inland from present beach; flat. *Parent material:* Surface peat overlying fossil marine alluvium. *Location:* Near Kampong Bruit, Daro Subdistrict;(2/112/6; 989.515). *Cover:* Grasses and scattered trees; old regrowth following clearance for wet rice. *Reference samples:* S7440/7443.

Field morphology

0–10 cms: Very dark brown (10YR 2/2) hemic peat. Wet. Spongy. Distinct smooth boundary.

10–38 cms: Brown (10YR 5/3) fine sand. Wet. Loose. Few rootlets. Indistinct smooth boundary.

38–90 cms: Greyish brown (2.5Y 5/2) fine sand. Wet. Single-grain structure. Loose. No roots seen.

Comments

Despite field characteristics the surface peat horizon lacks sufficient carbon to qualify for a histic epipedon. Correlations in the USDA classification are given in Appendix V.

Table 106

Profile 43, analytical data for fine earth (<2mm)

Depth (cms)			*0* *10*	*10* *38*	*38* *61*	*61* *90*
Granulometric analysis (%)						
2 – 1 mm	(vcs)			0	0	0
1 – 0.5 mm	(cs)			0	0	0
0.5 – 0.2 mm	(ms)			0.5	1.0	0.5
0.2 – 0.1 mm	(fs)			86.2	86.7	91.6
0.1 – 0.05 mm	(vfs)			6.1	6.9	3.5
sand (2 – 0.05 mm)				92.7	94.6	95.6
silt (0.05 – 0.002 mm)				1.5	1.3	1.0
clay (0.002 mm)				5.7	4.1	3.4
Chemical analysis						
pH		H_2O	3.8	4.3	4.4	4.3
pH		KCl	3.9	4.1	4.1	4.3
C		%	7.47	0.71	0.57	
N		%	1.05			
C/N			7			
Conductivity (mmhos/cm/25°C)			430	70	50	100
Cl		ppm	t	t	t	t
SO_4 (water-soluble)		%	t	t	t	t

Profile 44

Family: RAJANG. *Series:* Rajang clay loam.

Site: Coastal alluvial plain, flat with scattered mud-lobster mounds. *Parent material:* Estuarine or marine alluvium. *Location:* Near Kampong Belawai, Sarikei Distirct; (2/111/13; 372.333). *Cover:* Mangrove *(Avicennia sp.)*, partly extracted. *Reference samples:* S8016/8018.

Field morphology

0–23 cms: Greyish brown (10YR 5/2) clay loam, with many medium and coarse distinct strong brown mottles. Moist. Massive. Very firm. Few roots. No pores seen. Indistinct smooth boundary.

23–61 cms: Grey (5Y 5/1) clay. Wet. Massive. Sticky and plastic. Few roots. Indistinct smooth boundary.

61–120 cms: Dark grey (5Y 4/1) clay loam. Wet. Massive. Sticky and plastic. Few roots.

Comments

This profile is included in the numerical ordination study.

Table 107

Profiles 44 and 45, analytical data for fine earth (<2mm)

		Profile 44			Profile 45	
Depth (cms)		*0* 23	*23* 61	*61* 120	*0* 20	*20* 50
Granulometric analysis (%)						
2 – 1 mm	(vcs)	0	0	0	0	t
1 – 0.5 mm	(cs)	0.1	0.2	0.1	0	0.5
0.5 – 0.2 mm	(ms)	0.9	0.4	0.5	0	0.3
0.2 – 0.1 mm	(fs)	19.7	2.3	17.1	1.1	0.6
0.1 – 0.05 mm	(vfs)	13.8	18.4	24.5	8.9	7.5
sand (2 – 0.05 mm)		34.5	21.3	42.2	10.0	9.2
silt (0.05 – 0.002 mm)		32.5	37.8	25.8	41.4	40.3
clay (0.002 mm)		33.1	40.9	32.0	48.6	50.4
Chemical analysis						
pH	H_2O	4.1	2.7	3.0	4.5	3.4
pH	KCl	3.5	2.6	2.9	5.7	3.5
C	%	0.34	0.59	0.33	2.75	3.06
N	%	0.15	0.16	0.11	0.21	0.20
C/N		2	4	3	13	15
CEC	me %	6.0	14.2	13.8	23.5	26.3
Exch. Ca	me %	0.4	3.9	3.4	5.8	5.5
Exch. Mg	me %	3.8	1.5	2.0	10.1	15.3
Exch. K	me %	0.3	0.1	t	1.2	0.8
Exch. Na	me %	1.4	0.7	0.9	4.3	1.8
Base saturation	%	99	43	45	91	89
Extr. Ca (HCl)	ppm	660	980	610		
Extr. Mg (HCl)	ppm	3120	2280	1840		
Extr. K (HCl)	ppm	6320	6620	5250		
Extr. P (HCl)	ppm	260	110	130		
Extr. Fe (Morgan)	ppm		1590	800		
Extr. Al (Morgan)	ppm		310	510		
Cl	%	1.0	1.1	0.8	2.0	2.0
SO_4 (water-soluble)	ppm	5000	17000	10000	t	t

Profile 45

Family: RAJANG *Series:* Rajang silty clay.

Site: Top of slip-off slope bounding tidal creek; flooded by some hightides; flat. *Parent material:* Estuarine alluvium. *Location:* Bank of Sukong River, opposite mouth of Aloh River; Sarikei Distirct; (2/111/14; 312.512). *Cover:* Mangrove forest (*Rhysophora sp.*). *Reference samples:* S7641/7642.

Field morphology

0–20 cms: Dark greyish brown (10YR 4/2) silty clay, with many fine and coarse distinct reddish brown mottles. Moist. Very weak coarse subangular blocky structure. Friable. Slightly sticky. Many mangrove roots. Few pores. Diffuse wavy boundary.

20–50 cms: Grey (5Y 5/1) silty clay with many fine and medium distinct yellowish red and reddish brown mottles. Otherwise an above.

Micromorphlogy

5–15 cms: Scattered fine quartz sand grains, rare very fine hypersthene grains and abundant wisps of plant remains in a finely variegated brown and pale brown omnisepic matrix with scattered coarse distinct irregular dark yellowish brown, reddish brown and black mottles, the mottles mainly associated with long irregular channels and medium irregular or subtabular voids. Scattered fine prolate or equant voids. Most channels and smaller voids occupied by roots. No apparent macrostructure. No cutans.

36–46 cms: Rare cryptocrystalline pyrite (?) grains associated with some plant fragments. Otherwise as above.

Profile 46

Family: MUKAH *Series:* Patok peat.

Site: Flat coastal swamp plain; roughly 700 metres behind present beach. *Parent material:* Peat deposits overlying estuarine clay. *Location:* Near Kampong Bruit, Daro Subdistrict; (2/112/6; 000.506). *Cover:* Swamp palms. *Reference samples:* S7417/7419.

Table 108
Profile 46, analytical data for fine earth (<2mm)

Depth (cms)		*0* 13	*13* 50	*50* 120
Granulometric analysis (%)				
sand (2 – 0.05 mm)				21.6
silt (0.05 – 0.002 mm)				40.0
clay (0.002 mm)				38.5
loss on ignition			27.4	
Chemical analysis				
pH	H_2O	4.2	4.4	5.2
pH	KCl	4.1	4.2	3.0
C	%	24.71	12.20	3.42
N	%	1.86	0.94	0.27
C/N		13	13	13
CEC	me %			25.3
Exch. Ca	me %			2.5
Exch. Mg	me %			9.6
Exch. K	me %			0.4
Exch. Na	me %			2.6
Base saturation	%			60
Conductivity (mmhos/cm/25°C)		880	590	2000
Cl	%	580	290	530
Analysis following ashing: (HCl extraction):				
P	%	0.11	0.08	
K	%	0.31	0.53	
Ca	%	0.17	0.10	
Mg	%	0.28	0.33	
Fe	ppm	11782	9697	
Cu	ppm	8	8	
Zn	ppm	102	65	
Mn	ppm	389	121	

Field morphology

0–50 cms: Dark brown (10YR 3/3) raw fibrous peat. Wet. Distinct smooth boundary.

50–120 cms: Dark Grey (5Y 4/1) and grey (5Y 5/1) coarsely variegated clay loam. Wet. Sticky. Plastic. Rare roots.

Profile 47

Family: IGAN. *Series:* Igan peat.

Site: Flat coastal swamp plain; about 1500 metres behind present beach. *Parent material:* Peat deposits overlying marine clay. *Location:* Near Kampong Bruit, Daro Subdistrict; (2/112/6; 007.501). *Cover:* *Nipa fruticans*. *Reference samples:* S7413/7416.

Field morphology

0–75 cms: Very dark brown (10YR 2/2) raw peat. Wet. Few large roots. Distinct smooth boundary.

75–100 cms: Greyish brown to dark greyish brown (2.5Y 4.5/2) loamy fine sand. Wet. Single-grain structure. Loose. Rare roots.

Table 109

Profile 47, analytical data for peat and fine earth (<2mm)

Depth (cms)		*0* *13*	*13* *50*	*50* *75*	*75* *100*
Granulometric analysis (%)					
sand (2 – 0.05 mm)					83.5
silt (0.05 – 0.002 mm)					7.0
clay (0.002 mm)					9.5
Chemical analysis					
pH	H_2O	5.5	5.2	5.3	5.5
pH	KCl	3.6	3.5	3.2	
C	%	26.71	21.63	9.06	0.98
N	%	0.48	0.40	0.64	
C/N		56	54	14	

Profile 48

Family: ANDERSON. *Series:* Anderson peat (very deep phase).

Site: Interior of basin peat swamp; flat. *Parent material:* Peat deposits from swamp forest dominated by *Shorea albida*. *Location:* North of Bukit Tunggal, Balingian Subdistrict; (2/112/3; 137.978). *Cover:* *Shorea albida* forest. *Reference samples:* S7774/7777.

Field morphology

0–100 cms: Very dark brown (10YR 2/2) hemic peat (fibric in patches) containing abundant fragments of tree branches and roots. No apparent distinction between surface layer and subsurface deposits. Wet, with water-table within a few cms of the soil surface.

Table 110

Profile 48, analytical data for <2mm fraction

Depth (cms)		*0* *25*	*25* *50*	*50* *75*	*75* *100*
Loss on ignition	(%)	99.2	99.4		
Chemical analysis					
pH	H_2O	3.0	3.2	3.3	3.3
pH	KCl	1.9	1.9	2.0	2.0
C	%	37.98	31.43	38.78	37.22
N	%	1.15	1.14	1.22	1.14
C/N		33	28	32	33
Analysis following ashing (HCl extraction):					
P	%	0.03	0.02	0.02	0.02
K	%	t	t	t	t
Ca	%	0.03	0.16	0.03	0.08
Mg	%	0.15	0.10	0.13	0.08
Fe	ppm	225	285	149	249
Cu	ppm	10	25	8	3
Zn	ppm	20	21	16	9
Mn	ppm	10	5	50	10

Comments

No underlying mineral horizons are present within 3 metres of the surface. Data from other areas suggests that the peat profile is here underlain by old marine or lagoonal clays at a depth of 5 – 8 metres.

Profile 49

Family: ANDERSON. *Series:* Luk peat (moderately deep phase).

Site: Shore of estuary, behind storm beach built of same organic material as profile described (Plate 18); very gently undulating; slope less than 1°. *Parent material:* Estuarine organic alluvium, presumably derived from riverine erosion of peat, with possible contribution of upstream sawmill waste.

Location: About 1500 metres north of Kampong Bruit, Daro Subdistrict; (2/112/6; 005.526). *Cover:* Sparse grassland. *Reference samples:* MS1732/1737.

Field morphology

0–10 cms: Dark brown (10YR 3/3) finely divided small raw wood fragments. Dry. Loose. Few grass roots. Arbitrary boundary.

10–64 cms: Rare scattered medium fragments of rotting wood, partly water-worn, present. Moist. Otherwise as above.

64–112 cms: Wet. Otherwise as above. Abrupt smooth boundary.

112–145 cms: Dark grey (5Y 4/1) silty clay loam. Wet. Massive. Sticky and plastic. No roots.

Comments

This profile is illustrated in Colour Plate 16.

Table 111

Profile 49, analytical data for <2mm fraction of organic layers and for fine earth (<2mm) of mineral stratum

Depth (cms)		*0* *10*	*10* *36*	*36* *64*	*64* *89*	*89* *112*	*112* *145*
Granulometric analysis (%)							
sand (2 – 0.05 mm)							9.8
silt (0.05 – 0.002 mm)							57.0
clay (0.002 mm)							33.2
loss on ignition		75.2	71.4	74.1	72.0	65.6	34.0
Chemical analysis							
pH	H_2O	5.6	5.5	6.0	4.8	6.2	6.5
pH	KCl	5.7	5.6	6.0	4.9	6.3	6.6
C	%	21.68	19.89	21.67	19.17	17.66	3.81
N	%	1.26	1.32	1.30	1.10	0.93	
C/N		17	15	17	17	19	
CEC	me %	72.1	130.3	134.6	129.7	212.8	39.2
Exch. Ca	me %	13.9	15.5	19.3	28.1	12.3	9.6
Exch. Mg	me %	28.7	53.3	46.0	66.5	54.5	24.2
Exch. K	me %	1.0	2.3	0.8	2.5	1.7	2.2
Exch. Na	me %	17.1	65.4	20.2	7.1	30.0	23.6
Base saturation	%	84	105	67	80	81	152
Avail. P	ppm	9	8	8	6	5	5
Conductivity	(mmhos/cm/ 25°C)	3219	6599	1610	2414	3219	4346
Cl	ppm	8900	39000	6100	3200	13900	14800
Analysis following ashing (HCl extraction):							
P	%	0.10	0.10	0.11	0.10	0.19	0.08
K	%	0.13	0.16	0.13	0.13	0.24	0.68
Ca	%	1.00	0.82	1.00	0.91	1.71	0.30
Mg	%	0.85	0.82	0.79	0.81	1.05	0.81
Fe	ppm	38041	60146	47880	45108	36413	37153
Cu	ppm	51	6	62	48	54	20
Zn	ppm	36	39	37	39	42	91
Mn	ppm	2696	2728	2604	2304	2268	1141

REFERENCES

BREWER, R. 1964 *Fabric and mineral analysis of soils.* Wiley, New York.

USDA (United States Dept of Agriculture) 1951 *Soil survey manual.* USDA Agric. Handbook 18.

APPENDIX V

CORRELATION OF REFERENCE PROFILES IN THE USDA TAXONOMY AND WITH THE FAO/UNESCO WORLD SOIL MAP LEGEND

The forty-nine profiles described in Appendix IV are correlated with the USDA (1975) and FAO (1974) systems below. Many of the correlations are tentative, due to lack of data or difficulties in interpretation. These problems are discussed in Chapter 11.

Profile	*Series*	*USDA (1975)*	*FAO (1974)*	*Notes*
1	Merit	Oxic Dystropept	Ferralic Cambisol	1, 2
2	Merit	Typic Dystropept	Dystric Cambisol	2, 3
3	Jakar	Oxic Dystropept	Ferralic Cambisol	1, 2
4	Jakar	Typic Dystropept	Dystric Cambisol	
5	Bekenu	Oxic Dystropept	Ferralic Cambisol	1, 2
6	Sarikei	Oxic Dystropept	Ferralic Cambisol	
7	Nyalau	Oxic Dystropept	Ferralic Cambisol	1
8	Nyalau	Quartzipsammentic Haplorthox	Xanthic Ferralsol	5
9	Nyalau	Oxic Dystropept	Ferralic Cambisol	
10	Piring	Typic Haplorthox	Xanthic Ferralsol	
11	Nyaroh	Typic Haplorthox	Xanthic Ferralsol	
12	Arip	Typic Dystropept	Dystric Cambisol	6
13	Changgan	Oxic Dystropept	Ferralic Cambisol	7
14	Kerait	Oxic Dystropept	Ferralic Cambisol	8
15	Bandang	Oxic Dystropept	Ferralic Cambisol	5, 8
16	Saratok	Oxic Dystropept	Ferralic Cambisol	9
17	Saratok	Oxic Dystropept	Ferralic Cambisol	9
18	Miri	Typic Tropaquod	Gleyic Podzol	10
19	Silantek	Aeric Tropaquod	Gleyic Podzol	10
20	Silantek	Typic Tropohumod	Humic Podzol	9, 10
21	Tunggal	Entic Tropohumod	Humic Podzol	9, 10
22	Buso	Aeric Tropaquod	Gleyic Podzol	9, 10
23	Ajoh	Typic Tropaquept or Aquic Oxic Dystropept	Gleyic Cambisol	5, 8
24	Ajoh	Typic Tropaquept	Dystric Planosol(?)	5, 8
25	Ajoh–Merit	Aquic Oxic Dystropept	Gleyic Cambisol	5, 8
26	Penipah	Aquic Oxic Dystropept	Gleyic Cambisol	5, 8
27	Pakan	Typic Tropaquept	Dystric Gleysol	
28	Tatau	Tropaquent	Dystric Fluvisol or Dystric Gleysol	11
29	Matu	Tropaquent	Humic Gleysol	
30	Rajang	Tropic Sulfic Fluvaquent	Thionic Fluvisol	12
31	Rajang	Tropic Sulfic Fluvaquent	Thionic Fluvisol	12
32	Sirik	Tropaquent	Eutric Gleysol	
33	Seduau	Oxic Dystropept	Ferralic Cambisol	4
34	Malang	Aquic Oxic Fluventic Dystropept	Gleyic Cambisol	5
35	Bemang	Oxic Fluventic Dystropept	Ferralic Cambisol	5
36	Semilajau	Typic Troporthent (Tropofluvent)	Dystric Regosol (Dystric Fluvisol)	4

37	Kabong	Aquic Quartzipsamment	Dystric Regosol	13
38	Belawai	Aquic Oxic Quartzipsamment	Eutric Regosol	13
39	Malang–Bijat	Aquic Oxic Dystropept	Gleyic Cambisol	
40	Bemang–Pakan	Aquic Oxic Fluventic Dystropept	Dystric Fluvisol	5
41	Peninjau	Typic Quartzipsamment	Dystric Regosol	
42	Sebaya	Typic Quartzipsamment	Dystric Regosol	
43	Tika	Typic Troporthent	Albic Arenosol	
44	Bintulu	Typic Quartzipsamment	Albic Arenosol	
45	Lalis	Typic Troporthent	Dystric Regosol	
46	Patok	Histic Fluvaquent	Humic Gleysol	14
47	Igan	Terric Tropofibrist	Dystric Histosol	14
48	Anderson	Typic or Hemic Tropofibrist	Dystric Histosol	14
49	Luk	Terric Tropofibrist	Eutric Histosol	14

Notes

1. CEC is low and recognition of a cambic horizon assumes the presence of weatherable minerals.
2. Clay increase is adequate for an argillic horizon and a Udult/Acrisol correlation is possible.
3. The subsoil carbon trend indicates a Fluventic subgroup. The soil is residual and this is ignored.
4. The profile is Fluventic but this is not reflected in the carbon trend.
5. Profile data does not extend to the depth required to confirm the correlation and assumptions have been made.
6. Recognition of a cambic horizon rests on the doubtful evidence for a 'colour B' horizon.
7. Data suggests an oxic horizon but water–dispersable clay is very high.
8. Problems regarding these soils are discussed in the text (11.20).
9. The subsoil is pallid and unmottled; assumption regarding the drainage regime are necessary for correlation.
10. Data to characterise the spodic horizon are inadequate.
11. Laboratory data are lacking and the correlation is assumed.
12. Data on total sulphur are lacking and the correlation is assumed.
13. Heavy mineral studies from coastal sands suggest that weatherable minerals in these soils may be sufficiently high to give a Tropopsamment.
14. Data are not available to confirm subdivisions of histic materials.

REFERENCES

FAO (United Nations Food and Agriculture Organisation) 1974 *FAO–UNESCO Soil Map of the World*, Vol. 11. Unesco, Paris.

USDA (United States Department of Agriculture) 1975 *Soil taxonomy*. USDA Agric. Handbook 436.

APPENDIX VI

SUPPLEMENTARY SOIL PROFILES

In addition to the 49 numbered profiles described in App. IV, data from a further 26 profiles are used for text discussion. These profiles are designated by upper-case letters A–Z. Brief details regarding them are given below.

Profile	*District*	*Reference samples*	*Family*	*Series*
A	Julau	S4140/4148	Merit	Merit clay loam
B	Sibu	S2881/2887	Merit	Jakar clay loam
C	Sibu	M4158/4165	Nyalau	Nyalau sandy loam
D	Sibu	M4182/4187	Nyalau	Nyalau sandy clay loam
E	Sibu	M4150/4157	Nyalau	Nyalau sandy loam
F	Mukah	S4838/4845	Nyalau	Nyalau sandy clay loam
G	Sarikei	S4734/4740	Nyalau	Nyalau sandy clay loam
H	Sarikei	S4718/4723	Nyalau	Nyalau sandy clay loam
I	Sarikei	S4149/4157	Merit	Merit clay loam
J	Julau	S4131/4138	Nyalau	Nyalau sandy loam
K	Sarikei	S3564/3570	Bekenu	Bekenu sandy clay loam
L	Sarikei	S3557/3563	Bekenu	Bekenu silty clay loam
M	Sarikei	S3527/3539	Nyalau	Nyalau sandy loam
N	Sibu	S3320/3328	Bekenu	Bekenu sandy clay loam
O	Sibu	S2888/2894	Nyalau	Nyalau sandy loam
P	Binatang	S7907/7912	Kerait	Kerait very fine sandy loam
Q	Sibu	S2858/2865	Saratok	Durin sandy loam
R	Binatang	S2799/2804	Saratok	Saratok sandy loam
S	Binatang	S3365/3374	Saratok	Saratok sandy loam
T	Mukah	S7975/7979	Miri	Miri fine sand
U	Sarikei	S7922/7925	Kabong	Belawai sand
V	Sarikei	S4729/4733	Kabong	Kabong sand
W	Sibu	S2926/2929	Seduau	Seduau clay
X	Sarikei	S7643/7644	Rajang	Rajang silty clay
Y	Matu/Daro	S7432/7434	Sirik	Sirik clay loam
Z	Matu/Daro	S7420/7423	Rajang	Rajang silty clay

The following four profiles were included for purposes of comparison in the numerical ordination study and are located in west Sarawak. Family and series designations follow Andriesse (1972) and are based on the 1966 system (Sarawak Soil Survey Staff, 1966).

Profile	*District*	*Reference samples*	*Family*	*Series*
a	Kuching	S7687/7691	Merit	Semongok
b	Lundu	S7509/7512	Abok	Gading
c	Kuching	MS1253/1258	Triboh	—
d	Kuching	S7681/7686	Tarat	Tarat

REFERENCES

ANDRIESSE, J.P. 1972 Soils of West Sarawak (East Malaysia). *Sarawak Dept. of Agric.*, Res. Br. Mem. 1, Kuching.

SARAWAK SOIL SURVEY STAFF, 1966 A classification of Sarawak soils. *Sarawak Dept. of Agric.*, Res. Br. Tech. Paper 2. Kuching.

APPENDIX VII

NUMERICAL ORDINATION STUDY: METHODS

A numerical ordination study of 42 profiles was undertaken. The results are discussed in Chapter 11 and the ordinations shown by phenograms in Fig. 49. The methods used are detailed here.

The profile was characterised by data from two subsoil horizons, chosen to be representative of the upper and lower subsoil respectively. Horizons within 25 cms of the surface were excluded from consideration, as were B/C and C horizons and the stoneline zone, if one were present.

Twenty-eight characters were used for each horizon (and are listed in Table 112). The soils were therefore defined by 56 variables. No between-horizon rations were used. Non-numerical characters (mottle frequency, mottle size, structure, consistence, roots) were coded to arbitrary scales (cf. Cipra et al, 1970). Hue was scaled following Rayner (1966: 83). Numerical characters were entered directly in the initial matrix (Table 112), exchangeable Ca, Mg, K and Na being expressed as percentage of total bases, dispersable clay as percentage of total clay, and the remaining chemical variables on a fine earth basis.

Character data in the initial matrix were then reduced to a common 0–100 coding (Hole and Hironaka, 1960). Scaling the characters to zero mean and unit variance has been used (Russell and Moore, 1967; Cipra et al, 1970) and may have been preferable but the need for manual input of all data for both character correlation and similarity analysis made a simple coding essential with the computing equipment available. A coded character matrix (Table 113) was then prepared, the coded values being expressed to the nearest integer.

Product-moment correlation of characters was computed from this matrix, both for all soils (Table 114) and also for five subgroups comprising soils which were considered to have many common characteristics. High between-horizon correlation could be foreseen for many characters and this was accepted. Other high total correlations (greater than 0.80) were referred to the subgroup correlations. In the few cases where this occurred inspection of the subgroups showed that in most of them the high correlation reflected uniformly low levels for the characters concerned. In the one, or rarely two, subgroups where values were higher than the rest the between-character correlation for the subgroup alone was relatively low. The high total correlation in these cases was not, therefore grounds for deletion of one character. All 56 characters were therefore accepted for inclusion in the similarity analysis.

There is no general agreement on the appropriate similarity index for use in soil taxonomy and a number of indices have been applied to this type of data. Some early studies (Hole and Hironaka, 1960; Bidwell and Hole, 1964) employed the Bray and Curtis (1957) index. More recently, product-moment correlation and measures of distance such as Euclidean distance and mean character distance have been used. Russell and Moore (1967: 51) noted that product-moment correlation emphasises the difference in pattern or 'shape' of characters while distance measures emphasise the differences in magnitude or 'size'. For their study they considered pattern more important and used product-moment correlation as a similarity index. Sarkar (1965, quoted by Grigal and Arneman, 1969: 435) found, on the other hand, that Euclidean distance as a measure of similarity in soil studies was superior both to product-moment correlation and to association coefficients. In vegetation studies, also, Euclidean distance produced a more efficient ordination than the Bray and Curtis method (Austin and Orlocci, 1966; Bannister, 1968); it may, however, either under-estimate or accentuate differences between vegetation stands in certain cases (Bannister, 1968: 33). Webster and Burrough (1972, quoting Moore and Russell, 1967; Cuanalo and Webster, 1970) also note, with reference to soil studies, that Euclidean distance is very sensitive to single aberrant character values, which may be an undesirable feature for a general-purpose classification.

In the present study the strategy of Webster and Burrough (1972) was largely followed. Three distance measures were computed: Euclidean distance, mean character distance, and the index of Lance and Williams (1967) styled the 'Canberra metric'. The Canberra metric was computed as its complement, giving similarities between 0 and 1, where 1 is identity, Euclidean distance and mean character distance was transformed to also give similarities on a 0–1 scale. Values between the extremes on the three scales are not comparable but these transformations made subsequent grouping computations by a desk calculator simpler. Indices were computed to three decimal places. The three similarity matrices (Tables 115–117) were used as the bases for phenograms (Fig. 49) which were constructed using the unweighted pair-group method (Sokal and Sneath, 1963) and arithmetic averages.

Coding of Field Characters

Initial coding of non-numerical characters used the following arbitrary scales:

Hue	2.5YR	– 1	5YR	– 2
	7.5YR	– 3	10YR	– 4
	2.5Y	– 5	5Y	– 6

Value and Chroma were scaled using the Munsell notation figures.

Mottles	None	– 0	Rare	– 1
	Few	– 2	Many	– 3
	Abundant	– 4		

Further mottling characters (size, contrasts, type, colour) were not introduced in order to avoid having too many characters based on colour.

Consistence	Very loose	– 0
	Loose	– 1
	Friable	– 2
	Firm, slightly hard	– 3
	Very firm, hard, very hard, plastic	– 4
Structure	Structureless, massive	– 0
	Very weak	– 1
	Weak	– 2
	Moderate	– 3

Where structure was observed it was, in almost all cases, moderate or coarse subangular blocky. No further distinction was therefore made on structure type.

Roots	None	– 0	Rare	– 1
	Few	– 2	Many	– 3
	Abundant	– 4		

Similarity indices

The similarity indices used are, in their basic forms before transformation, as follows:

$$\text{Euclidean Distance} = \sqrt{\sum (Xij - Xkj)^2/p}$$

$$\text{Canberra Metric} = \sum \frac{(Xij - Xkj)}{(Xij + Xkj)} /p$$

$$\text{Mean character distance} = \sum (Xij - Xkj) /p$$

where:

Xjl, Xkj = the scores for property j in soil profiles i and k respectively;

p = the number of properties measured (56).

References

AUSTIN, M.P. and ORLOCCI, L. 1966 Geometric models in ecology, II: An evaluation of some ordination techniques. *J. Ecol.*, 54: 217–227.

BANNISTER, P. 1968 An evaluation of some procedures used in simple ordinations. *J. Ecol.*, 56: 27–34.

BIDWELL, O.W. and HOLE, F.D. 1964 An experiment in the numerical classification of some Kansas soils. *Proc. Soil Sei. Soc. Amer.* 28: 263–268

BRAY, J.R. and CURTIS, J.T. 1957 An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monographs*, 27: 325–349.

CIPRA, J.E., BIDWELL, O.W. and ROHLF, F.J. 1970 Numerical taxonomy of soils from nine Orders by cluster and centroid-component analysis. *Proc. Soil Sci. Soc. Amer.*, 34: 281–287.

Quality/Horizon	*	No.	6	7	4	5	a	1	2	13	10	G	J	8	38	33	39	25	26	24	23	b	17	14	19	15	16	8	c	41	40	2	Y	44	28	29	31	27	T	30	12	d	37	36
Hue(A)		1	10YR	7.5YR	7.5YR	7.5YR	10YR	10YR	10YR	10YR	10YR	10YR	10YR	10YR	7.5YR	10YR	10YR	7.5YR	10YR	10YR	8.75YR	8.75YR	10YR	2.5Y	10YR	2.5Y	10YR	2.5YR	5YR	10YR	10YR	7.5YR	2.5YR	2.5YR	5YR	10YR	5YR	10YR	10YR	7.5YR	10YR	2.5Y	2.5YR	7.5YR	10YR
Value(A)		2	5	6	5	5	7	5	5	6	5	5	6	6	6	6	8	8	6	7	8	8	2	2	2	5	2	1	2	1	0	1	1	1	2	1	2	1	2	0	6	8	7	6
Chroma(A)		3	8	6	6	6	8	8	8	6	8	6	5	6	6	6	6	6	5	5.5	5	5	6	7	7	7	6	6	5	5	1	2	3	3	5	7	7.5	5.5	8	8	8	5	5	6	6
Hue(B)		4	3.75YR	7.5YR	5YR	5YR	10YR	7.5YR	10YR	5YR	10YR	7.5YR	10YR	10YR	7.5YR	5YR	7.5YR	7.5YR	10YR	8.75YR	8.75YR	7.5YR	2.5Y	N	2.5Y	10YR	2.5YR	5YR	10YR	10YR	7.5YR	2.5YR	2.5YR	5YR	10YR	7.5YR	3.75YR	5YR	7.5YR	10YR	2.5YR	10YR	10YR	10YR	10YR
Value(B)		5	5	5	5	5.5	7	6	5	4	5	5	7	6	5	6	6	5	5	5.5	5	6	7	7	7	7	7	6	7	4	7	3	3	4	2	3	3	2	2	3.5	6	4	6	6
Chroma(B)		6	8	8	8	8	6	6	8	8	8	8	6	6	6	8	8	8	6	7	8	6	4	0	2	1	2	3	2	1	0	1	2	1	2	2	2	1	2	0	6	8	3	3
Structure(A)	a	7	vw	w	w	w	m	w	w	vw	vw	vw	a	a-vw	w	w	vw	vw	w	a	w	a	a	vw	a	w	vw	a	vw	a	a	a	a	a	a	a	a	a	a	a	w-m	a	a	a
Consistence(A)	a	8	f-fm	fm	fm	f-fm	f-fm	f-fm	f	f-fm	f	f	rf-f	vf-f	f	vfm	fm	f	vfm	f	f	f	rf-f	f-fm	f	f	f	f	f	f	f	f	f	f	f	f	r	f	n	f	r	f-m	f	f
Roots(A)	a	9	m	f	f	f	f	f	m	f	m	f	f	m	f	f	r-f	f	f	m	f	r	f	m	f	f	f	f	f	f	f	n-r	m	f	a	a	a	a	a	a	a	a	w-m	a	a
Structure(B)	a	10	a	w-m	vw	w	m	a	w	vw	w	w	a	a	w	w	a	w	w	a	w	a-w	vw	vw	vw	w	a	a	w	a	a	a	a	vf	fm	f	xfm	vfm	xfm	f	f	1	vf
Consistence(B)	a	11	vfm	vfm	fm	f-fm	fm	fm	fm-vfm	fm	f	vf-f	rf-f	f	f	vfm	f-fm	f	vfm	f	f	f-fm	rf-f	fm	f-fm	fm	fm	fm	fm	fm	fm	fm	fm	fm	vf	fm	f	xfm	vfm	xfm	f	f	1	vf
Roots(B)	a	12	m	r	f	f	r-f	f	f	m	f	f	f	m	m	m	a	n	n	n	n	n	n	a	a	m	m	n	n	m	m	a	a	n	n	m	n	n	n	n	n	m	n
Mottle Frequency(A)	a	13	m	m	m	n	m	n	n	a	n	a	f	m	m	m	a	n	n	n	n	n	n	a	a	m	m	n	n	m	m	a	a	n	n	m	n	n	n	n	n	m	n
Mottle Size(A)	a	14	c	m	f	n	m	n	n	c	n	n	f	vc	f	f	f	c	n	n	n	n	n	m	a	a	m	m	n	f	a	a	n	n	a	n	n	n	n	n	n	n	m	f
Mottle Frequency(B)	a	15	a	a	m	f	a	f	n	a	n	n	m	n	m	a	a	n	f-m	n	n	n	n	m	c	vc	c	f	n	m	m-c	c	n	n	vc	n	n	n	n	n	n	n	m	n
Mottle Size(B)	a	16	m	m-c	f	f	c	m	n	c	n	n	m	n	m	f	c	n	m	n	n	n	n	m	c	vc	c	f	n	m	m-c	c	n	n	vc	n	n	n	n	n	n	n	m	n
pH(A)		17	5.1	4.5	4.7	4.5	4.4	3.5	3.8	4.6	4.3	4.3	3.6	4.3	5.1	4.0	3.5	4.8	4.7	4.5	5.0	5.5	4.1	4.4	4.0	4.5	3.6	4.2	4.8	5.9	4.4	6.7	7.1	2.7	5.1	5.4	3.2	6.3	5.1	5.7	4.4	4.3	5.3	5.7
pH(B)		18	4.9	4.5	4.8	5.0	4.5	3.7	3.7	5.0	4.3	3.8	3.7	4.9	5.2	4.3	3.4	5.2	5.1	5.1	5.2	5.5	3.9	4.7	4.6	4.9	3.7	4.3	4.8	6.5	4.4	6.8	7.1	3.0	4.8	5.1	3.7	3.2	3.6	4.2	5.0	4.6	5.4	5.8
C(A)	b	19	1.67	0.47	0.68	0.82	0.48	0.68	0.77	0.33	0.40	1.18	0.18	0.83	0.43	0.75	0.89	0.85	0.95	0.31	0.85	0.72	1.01	0.57	0.37	0.47	0.69	0.38	0.54	0.25	0.18	0.69	0.28	0.59	0.13	0.10	0.53	0.71	0.01	0.02	0.15	1.27	0.29	0.19
C(B)	b	20	0.24	0.28	0.59	0.42	0.47	0.28	0.27	0.27	0.28	0.33	0.09	0.09	0.32	0.28	0.33	0.27	0.52	0.17	0.64	0.54	0.07	0.12	0.16	0.25	0.34	0.18	0.21	0.19	0.13	0.37	0.21	0.16	1.62	2.19	1.96	5.62	1.82	0.33	0.08	0.04	0.09	0.06
C/N(A)		21	12.1	8.5	6.7	10.0	4.8	9.7	9.6	6.9	8.5	19.7	8.9	12.2	4.7	6.2	14.9	11.6	10.1	6.2	11.3	12.5	15.4	8.6	15.4	7.2	17.0	15.4	9.8	1.5	4.3	1.8	1.4	3.7	10.8	8.3	15.6	47.3	1.1	0.7	6.0	10.67	16.3	10.6
C/N(B)		22	8.0	5.1	6.4	7.4	5.4	5.4	4.9	3.6	6.8	10.6	4.5	3.6	3.6	3.5	6.2	8.4	8.7	5.3	11.6	20.6	5.0	2.7	8.4	6.3	5.7	8.1	9.5	1.4	3.0	1.9	1.6	3.1	29.5	40.6	122.5	74.9	29.8	13.8	6.2	0.78	7.4	6.1
BS(A)	d	23	10.3	23.0	6.0	19.1	9.5	12.5	3.6	8.9	11.9	20.1	56.8	8.2	6.6	13.1	13.3	6.5	6.9	4.5	27.3	2.5	17.3	5.2	9.3	15.5	21.6	16.2	9.5	63.1	0.0	44.3	51.3	42.9	38.3	68.8	20.0	100.0	100.0	17.0	40.5	23.7	89.2	51.4
BS(B)	d	24	9.2	21.2	3.5	12.6	4.5	16.3	1.7	10.1	33.3	24.6	44.6	8.2	5.4	23.4	10.1	10.7	7.0	5.8	28.7	3.0	38.6	2.7	5.5	3.2	10.8	29.6	5.2	60.7	3.5	42.1	63.2	45.1	1.4	5.1	2.8	6.7	14.5	15.1	13.3	15.1	100.0	33.0
Extractable Ca(A)	e	25	0	170	222	105	323	230	220	0	103	77	259	0	115	230	281	356	718	183	333	127	0	0	201	25	0	216	0	333	158	1206	860	982	0	99	200	0	0	100	102	1032	238	0
Extractable Mg(A)	e	26	926	1054	1119	376	3750	985	553	608	332	436	804	396	2755	2162	778	274	318	1334	51	25	404	867	121	832	693	363	163	3533	731	5830	6249	2276	0	299	0	0	0	0	245	729	0	0
Extractable K(A)	e	27	2278	4200	5328	370	3763	2050	4118	1488	513	384	2450	1245	7577	6250	2100	171	1071	2484	384	254	1300	2359	203	2586	1574	1850	344	5504	3675	7537	7055	6615	156	151	900	0	0	376	358	516	439	628
Extractable P(A)	e	28	83	113	117	48	140	40	164	101	57	50	53	189	235	162	105	441	158	107	395	127	73	97	14	75	90	55	34	331	65	697	304	106	13	8	18	5	20	11	30	226	95	100
Extractable Ca(B)	e	29	80	170	180	212	417	204	215	231	102	68	238	0	0	90	281	295	775	263	488	204	158	0	101	0	0	432	0	358	198	1466	766	608	0	42	0	52	0	88	122	1175	0	0
Extractable Mg(B)	e	30	1436	1378	1215	1271	3144	1944	581	1632	343	428	1116	718	2134	2102	1102	497	374	1811	77	26	475	1644	363	1320	1911	648	450	3898	791	5973	6139	1838	0	226	100	0	0	138	268	881	0	0
Extractable K (B)	e	31	3957	5400	4388	1152	4636	7000	3064	4851	511	503	2550	2115	6904	8100	4900	604	1384	3413	385	383	1450	6302	867	4196	4395	3900	876	5792	5800	6988	6336	5249	344	528	1300	192	353	1001	406	441	501	501
Extractable P(B)	e	32	86	120	140	70	129	53	144	103	52	30	53	64	342	143	85	118	349	66	198	163	33	99	20	81	120	40	36	285	50	591	309	125	88	24	56	21	85	90	18	206	83	75
Extractable Fe(A)	e	33	60	43	23	281	67	43	26	18	10	26	18	43	5	31	38	22	22	29	18	18	13	51	38	43	38	10	13	33	18	555	258	1593	0	5	0	0	5	8	13	2	13	8
Extractable Al(A)	e	34	786	1009	423	739	2043	863	390	360	491	1015	488	1067	896	961	449	860	917	1088	241	300	810	755	275	363	589	526	150	75	533	600	130	307	19	7	23	20	5	4	171	209	98	95
Extractable Fe(B)	e	35	11	13	18	7	36	5	0	8	8	5	5	13	8	5	13	8	6	8	13	8	0	22	7	30	26	18	18	156	5	576	166	756	5	16	0	0	5	8	0	2	5	8
Extractable Al(B)	e	36	708	699	450	856	2959	675	314	708	394	409	471	769	1085	581	429	644	858	945	231	281	302	751	357	528	1152	558	425	229	464	760	43	508	635	213	395	266	651	200	136	264	105	52
CEC(A)	c	37	13	25	15	29	31	19	14	11	9	18	11	40	21	20	21	12	13	39	8	51	17	18	31	25	26	39	26	39	20	67	66	43	164	149	100	210	147	25	67	12	8	38
CEC(B)	c	38	8	14	13	29	37	11	8	8	9	10	14	19	17	10	24	10	9	24	5	88	10	7	17	16	33	9	20	39	10	67	66	43	164									
CL(A)	b	39												For profiles 1-27,34,35,39 and 30, level 0.005 assumed													0.21	0.00	0.47	1.22	1.09	0.00			0.00	0.00					0.00	0.00	
CL(B)	b	40												For profiles 1-27,34,35,39 and 40, level 0.005 assumed													0.26	0.00	0.48	1.11	0.75	0.00			0.00	0.00					0.00	0.00	
SO_4(A)	b	41												For profiles 1-27,34,35,39 and 40, level 0.01 assumed													0.05	0.12	0.48	0.88	1.65	0.00			0.00	0.00					0.01	0.00	
SO_4(B)	b	42												For profiles 1-27,34,35,39 and 40, level 0.01 assumed													0.22	0.00	0.96	0.39	1.04	0.00			0.00	0.00					0.00	0.00	
Dispersible Clay(A)	f	43	59.9	41.7	43.9	24.5	0.7	80.3	79.8	83.8	76.6	84.8	22.1	70.6	21.8	3.6	80.4	0.2	7.5	2.3	67.2	62.3	71.3	62.3	29.7	78.8	76.7	80.8	60.7	70.7	76.2	17.9	34.0	18.7	28.6	34.1	29.3	39.6	38.1	92.7	100.00	0.0	46.8	38.5
Dispersible Clay(B)	f	44	5.4	5.5	4.5	0.3	0.0	1.7	2.4	2.5	8.4	0.9	0.9	10.0	2.7	1.2	75.1	1.1	0.6	1.1	33.4	6.8	8.7	8.2	17.8	75.7	12.8	89.4	90.6	78.3	4.8	14.7	83.2	16.1	76.3	82.6	39.8	20.3	47.0	63.9	97.4	0.0	34.3	13.2
Exchangeable Ca(A)	g	45	0	7	37	13	59	70	82	17	31	54	0	59	32	74	61	47	67	73	74	42	79	57	41	67	69	81	0	28	0	63	41	64	86	69	32	37	66	88	18	77	58	79
Exchangeable Mg(A)	g	46	50	11	37	16	28	12	0	33	21	14	0	14	30	12	22	16	14	7	5	19	0	4	47	23	16	7	57	35	0	21	32	25	6	13	0	0	16	0	35	11	0	11
Exchangeable K(A)	g	47	39	22	18	24	7	7	18	33	17	20	23	15	13	6	4	16	14	15	9	10	5	26	13	6	3	2	13	9	100	0	1	1	8	2	16	8	2	4	5	5	18	11
Exchangeable Na(A)	g	48	12	60	8	46	3	12	0	17	31	12	78	12	25	9	13	22	6	6	12	29	16	13	0	5	12	10	30	28	0	16	27	11	0	17	53	56	16	8	43	7	24	0
Exchangeable Ca(B)	g	49	54	0	28	4	55	72	100	74	35	65	0	63	44	52	71	60	72	62	71	28	81	25	0	29	70	75	0	35	0	69	44	54	0	64	25	54	63	79	15	74	64	90
Exchangeable Mg(B)	g	50	4	12	28	8	17	11	0	0	12	14	29	5	7	36	17	21	5	13	4	57	7	0	82	14	12	10	38	34	0	22	26	32	13	16	25	17	26	0	33	18	0	0
Exchangeable K(B)	g	51	29	12	28	24	17	7	0	17	21	7	17	15	16	4	3	6	15	15	13	4	1	50	18	19	7	0	13	1	36	0	8	1	50	4	13	5	1	11	0	0	17	10
Exchangeable Na(B)	g	52	13	76	8	64	11	10	0	9	11	14	54	17	33	8	9	13	8	11	11	11	11	25	0	38	11	15	50	30	64	9	22	14	38	16	38	24	11	11	52	8	19	0
Clay(A)	b	53	20	31	43	36	58	38	34	19	27	26	23	20	40	54	25	60	56	32	27	25	20	25	11	23	16	14	9	36	20	46	27	41	4	2	5	2	3	3	3	62	8	3
Silt + Clay(A)	b	54	43	62	89	61	82	56	51	51	33	36	49	33	79	99	59	85	79	50	32	28	34	55	36	56	47	29	19	68	43	89	78	79	5	47	5	5	4	21	19	86	10	4
Clay(B)	b	55	33	35	50	46	53	50	46	46	27	33	25	26	50	56	36	62	63	33	32	18	22	46	19	42	26	23	16	31	31	47	26	32	4	9	9	12	5	8	3	56	4	3
Silt + Clay(B)	b	56	53	66	91	65	80	62	61	81	32	40	56	38	74	98	69	84	83	52	41	22	35	77	46	72	69	41	30	60	56	96	76	58	4	33	3	15	5	21	20	84	4	3

a - scaled as detailed in text
b - per cent fine earth
c - me/100gm fine earth
d - per cent
e - ppm fine earth
f - per cent clay
g - per cent total bases

Table 112: Numerical ordination study, raw data for 42 profiles

	6	7	4	5	a	1	2	13	10	G	J	8	38	33	39	25	26	24	23	b	17	14	19	15	16	S	e	41	40	Z	Y	44	28	29	31	27	T	30	12	d	37	36
1	75	50	50	50	75	75	75	75	75	75	75	75	50	75	75	50	75	63	63	75	100	75	100	75	100	25	75	75	50	0	0	25	75	25	75	75	75	50	100	0	50	75
2	40	60	40	40	80	40	40	60	40	40	60	60	60	60	60	60	40	50	40	40	60	80	80	80	60	60	40	40	80	0	0	40	80	90	50	100	100	100	40	40	40	60
3	100	75	75	75	100	100	100	75	100	75	63	75	75	75	100	100	75	88	100	100	25	25	25	63	25	13	25	13	0	13	13	13	25	13	25	13	25	0	75	100	80	75
4	30	60	40	40	80	60	80	40	80	60	80	80	60	40	60	60	80	70	70	60	100	0	100	80	100	40	80	80	60	20	20	40	80	60	50	40	40	60	80	20	80	80
5	60	60	60	70	100	80	60	40	60	60	100	80	60	80	80	60	60	70	60	80	100	100	100	100	100	80	100	40	100	20	20	40	0	20	20	0	0	30	80	40	80	80
6	100	100	100	100	75	100	100	100	100	100	75	75	75	100	100	100	75	88	100	75	50	0	25	13	25	38	25	13	0	13	25	13	25	25	25	13	25	0	75	100	38	38
7	33	67	67	67	100	67	67	33	33	33	0	17	67	67	33	33	67	0	67	0	0	33	0	67	33	0	33	0	0	0	0	0	0	0	0	0	0	0	0	83	0	0
8	56	67	67	56	56	56	44	56	44	44	33	33	44	89	67	44	89	44	44	44	33	56	44	44	44	44	44	67	67	67	67	67	0	27	33	67	0	100	22	44	0	0
9	100	67	67	67	67	67	100	67	100	67	67	100	67	67	50	67	67	100	67	33	67	100	67	67	33	67	67	67	67	17	100	67	33	67	0	67	33	33	83	67	67
10	0	83	83	67	100	0	67	33	67	67	0	0	67	67	0	67	67	0	67	17	33	33	33	67	0	0	67	0	0	0	0	0	0	0	0	0	0	0	0	83	0	0
11	80	80	60	50	60	60	70	60	40	30	30	40	40	80	50	40	80	40	40	50	30	60	50	60	60	60	60	60	60	60	60	60	20	60	40	100	80	100	40	40	0	20
12	100	33	67	67	50	67	67	67	100	67	67	67	67	33	0	67	67	67	67	0	0	33	67	33	67	67	17	0	33	67	17	100	33	0	33	0	33	33	33	50	0	33
13	75	75	75	0	75	0	0	100	0	0	50	75	75	75	100	0	0	0	0	0	0	100	100	75	75	0	0	75	75	100	100	0	0	75	0	0	0	0	0	0	75	0
14	80	60	40	0	80	0	0	80	0	0	40	100	40	40	80	0	0	0	0	0	0	60	80	40	80	0	0	80	70	80	100	0	0	80	0	0	0	0	0	0	60	0
15	100	100	75	50	100	50	0	100	0	0	75	0	75	100	100	0	63	0	0	0	0	75	100	100	75	75	0	50	100	100	0	0	0	100	0	0	0	0	0	0	0	50
16	60	70	40	40	80	60	0	80	0	0	60	0	60	40	80	0	60	0	0	0	0	60	80	100	80	40	0	60	70	80	0	0	0	100	0	0	0	0	0	0	0	60
17	55	41	45	41	39	18	25	43	36	36	20	36	55	30	18	48	45	41	52	64	32	39	30	41	20	34	48	73	39	91	100	0	55	61	11	82	55	68	39	36	59	68
18	46	37	44	49	37	17	17	49	32	20	17	46	54	32	10	54	51	51	54	61	22	41	39	46	17	32	44	85	34	93	100	0	44	51	17	5	15	29	49	39	59	68
19	100	28	40	49	28	41	46	19	23	71	10	49	25	46	53	51	57	18	51	42	60	9	22	28	41	22	32	14	10	41	16	35	7	5	31	42	0	1	8	76	17	11
20	4	4	10	7	8	4	4	4	4	5	1	1	5	4	5	4	9	2	11	9	1	1	2	4	5	2	3	3	2	6	3	2	28	39	34	100	32	5	1	0	1	0
21	24	17	13	20	9	19	19	13	17	41	18	25	9	12	30	23	20	12	23	25	32	17	32	14	35	32	20	2	8	2	2	6	22	16	32	100	1	0	11	21	33	21
22	6	4	5	5	4	4	3	2	5	8	3	2	2	2	4	6	7	4	9	16	3	2	6	5	4	6	7	1	2	1	1	2	24	33	100	61	24	11	4	0	5	4
23	10	23	6	19	10	13	4	9	12	20	57	8	7	13	13	7	7	5	27	3	17	5	9	16	22	16	10	63	0	44	51	43	38	69	20	100	100	17	41	24	89	51
24	8	20	2	11	3	15	0	9	32	24	44	7	4	22	9	9	6	4	28	2	38	1	4	2	10	29	4	60	2	41	63	44	0	4	1	5	13	14	12	14	100	32
25	0	14	19	9	27	19	18	0	9	6	21	0	10	19	23	30	60	15	28	11	0	0	17	2	0	18	0	28	13	100	71	81	0	8	17	0	0	8	8	86	20	0
26	15	17	18	6	60	16	9	10	5	7	13	6	44	36	12	4	5	21	1	0	6	14	2	13	11	6	3	57	12	93	100	36	0	5	0	0	0	0	4	12	0	0
27	30	55	70	5	50	27	54	20	7	5	32	16	100	82	28	2	14	33	5	3	17	31	3	34	21	24	5	73	49	99	93	87	2	2	12	0	0	5	5	7	6	8
28	12	17	17	7	21	5	24	15	8	7	7	28	35	24	15	67	23	16	60	19	10	14	1	11	13	8	4	50	9	100	46	15	1	0	2	0	2	1	4	34	14	15
29	5	12	12	14	28	14	15	16	7	5	16	0	0	6	19	20	53	18	33	14	11	0	7	0	0	29	0	24	14	100	52	41	0	3	0	4	0	6	8	80	0	0
30	23	22	20	21	51	32	9	27	6	7	18	12	35	34	18	8	6	29	1	0	8	27	6	22	31	11	7	63	13	97	100	30	0	4	2	0	0	2	4	14	0	0
31	48	66	53	12	56	86	36	59	4	4	30	24	85	100	60	5	15	41	2	2	16	77	9	51	53	47	9	71	71	83	78	64	2	4	14	0	2	10	3	3	4	4
32	12	18	21	9	19	6	22	15	6	2	6	8	57	22	12	17	58	8	31	25	3	14	0	11	18	4	3	47	6	100	51	19	12	1	7	1	12	13	0	33	11	10
33	4	3	1	18	4	3	2	1	1	2	1	3	0	2	2	1	1	2	1	1	1	3	2	3	2	1	1	2	1	35	16	100	0	0	0	0	0	1	1	0	6	1
34	38	49	21	36	100	42	19	17	24	50	24	52	44	47	22	42	45	53	12	15	40	37	13	18	29	26	7	3	26	29	6	15	1	0	1	1	0	0	8	10	0	0
35	1	2	2	1	5	1	0	1	1	1	1	2	1	1	2	1	1	1	2	1	0	3	1	4	3	2	2	20	1	72	21	100	1	2	0	0	1	1	0	0	1	1
36	23	22	14	28	100	22	9	23	12	13	15	25	36	18	13	21	28	31	6	8	9	24	11	17	38	18	13	6	14	25	0	16	20	6	12	8	21	5	3	8	2	0
37	14	34	17	41	44	24	15	10	7	22	10	60	27	26	27	12	14	58	5	78	20	22	44	34	36	58	36	58	26	100	100	51	31	63	27	0	19	72	17	9	0	10
38	1	4	4	12	16	3	1	1	2	2	4	7	6	2	9	2	2	9	0	40	2	1	6	5	14	2	7	17	2	30	30	19	78	70	46	100	69	10	30	3	1	16
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	39	100	89	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	43	100	68	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	7	29	53	100	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	93	37	100	0	0	0	0	0	0	0	0	0	0
43	60	42	44	24	1	80	80	84	77	85	22	71	22	4	80	0	8	2	67	62	71	62	30	79	77	81	61	71	76	18	34	19	29	34	29	40	38	93	100	0	47	38
44	6	6	5	0	0	2	2	3	9	1	1	10	3	1	77	1	1	1	34	7	9	8	18	78	13	89	92	80	5	15	85	16	78	85	41	21	48	66	100	0	35	14
45	0	8	42	15	67	79	94	19	35	62	0	67	36	84	54	53	76	83	84	48	90	64	46	77	78	91	0	32	0	71	46	72	98	78	34	42	75	100	20	88	65	90
46	88	19	65	29	49	21	0	59	37	24	0	24	54	21	39	28	24	13	9	34	0	8	83	40	29	12	100	61	0	37	56	44	10	22	0	0	29	0	62	19	0	19
47	39	22	18	24	7	7	18	33	17	20	23	15	13	6	4	16	14	15	9	10	5	26	13	6	3	2	13	9	100	0	1	1	8	2	16	8	2	4	5	5	18	11
48	15	77	10	60	4	15	0	22	40	15	100	16	32	11	16	29	8	7	16	37	20	17	0	6	15	13	39	36	0	21	35	14	0	22	68	72	21	10	55	8	31	0
49	54	0	28	4	55	72	100	74	35	65	0	63	44	52	71	60	72	62	71	28	81	25	0	29	70	75	0	35	0	27	31	38	15	19	30	21	32	0	40	22	0	0
50	5	15	34	10	21	14	0	0	14	17	35	6	8	44	21	25	6	16	5	69	8	0	100	17	15	12	46	41	0	27	31	38	15	19	30	21	32	0	40	22	0	0
51	58	24	56	48	34	13	0	34	43	13	34	29	31	7	7	12	31	30	27	9	2	100	35	38	13	0	25	2	73	0	16	1	100	9	25	11	2	21	0	0	33	19
52	17	100	11	85	15	13	0	11	14	19	71	23	44	11	12	17	10	14	15	14	14	33	0	50	15	20	66	39	84	11	29	18	50	21	50	32	14	14	69	11	26	0
53	30	47	69	56	92	60	52	28	41	40	34	30	63	86	39	96	90	49	42	37	29	38	15	34	24	19	12	56	30	72	42	65	3	0	4	0	1	2	1	100	9	2
54	41	61	90	60	82	55	49	50	31	34	47	31	80	100	58	86	79	49	30	26	31	53	34	55	46	26	16	67	41	89	78	79	1	45	1	1	0	18	16	87	6	0
55	50	54	78	72	84	78	72	72	40	50	37	39	78	89	56	99	100	51	49	24	31	72	26	65	38	33	21	46	47	74	38	49	1	10	9	15	3	8	0	90	1	1
56	53	67	92	65	81	62	61	82	31	39	56	37	75	100	70	85	85	52	40	20	34	78	45	72	70	40	29	60	56	98	77	58	1	32	0	13	2	18	18	86	1	0

Table 113: Numerical ordination study, scaled data for 42 profiles

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
1	100																																																									
2	35	100																																																									
3	18	28	100																																																						
4	61	17	12	100																																																					
5	42	1	29	42	100																																																			
6	11	33	88	2	17	100																																																		
7	0	11	61	4	25	60	100																																																	
8	20	13	9	32	1	7	31	100																																																
9	3	17	33	3	24	29	25	11	100																																															
10	2	6	48	7	25	49	81	21	25	100																																													
11	6	26	28	35	25	15	18	69	24	4	100																																												
12	7	26	30	8	8	41	32	14	59	22	1	100																																										
13	10	0	12	16	19	14	7	23	3	5	10	10	100																																									
14	10	2	14	7	15	2	19	6	19	9	10	10	95	100																																								
15	1	17	2	11	32	1	28	32	1	10	28	9	71	62	100																																							
16	4	19	5	2	30	9	24	22	5	3	21	3	67	61	95	100																																					
17	36	9	24	24	45	30	29	2	45	16	15	38	15	18	8	5	100																																				
18	37	47	0	12	10	8	9	2	10	1	20	16	32	34	8	12	73	100																																			
19	1	38	47	13	11	54	45	25	22	35	6	31	12	8	3	10	19	12	100																																		
20	5	44	30	15	59	27	20	6	50	20	7	35	20	17	17	14	28	27	7	100																																	
21	28	23	0	10	3	1	10	11	32	7	0	18	22	19	18	18	3	40	34	65	100																															
22	10	28	28	9	49	27	28	17	31	25	10	28	27	24	24	22	0	29	8	75	47	100																														
23	16	15	36	7	52	41	50	38	41	45	2	41	5	1	22	14	42	5	35	55	22	30	100																													
24	30	44	12	2	5	15	32	12	3	26	35	15	11	15	19	17	25	32	13	23	11	24	52	100																											
25	70	58	4	36	27	2	14	34	6	6	7	11	6	7	3	3	12	30	20	18	29	18	7	36	100																									
26	49	48	17	34	17	13	7	37	6	0	15	5	49	49	25	23	38	52	4	19	43	28	7	35	61	100																							
27	40	39	13	31	4	5	17	45	14	8	21	15	49	41	36	26	5	27	2	26	45	31	10	24	48	83	100																					
28	46	54	13	24	16	11	15	22	9	16	6	14	23	23	3	3	41	61	23	23	24	29	4	29	6	62	48	100																			
29	66	56	0	38	24	5	12	35	4	9	8	20	4	6	4	3	22	36	27	18	25	25	0	26	93	58	38	68	100																		
30	44	50	17	36	10	12	8	40	4	5	17	1	54	55	32	32	34	51	1	24	48	32	1	32	56	96	78	60	56	100																	
31	21	21	8	35	17	2	25	52	15	1	31	13	61	52	59	51	8	12	2	31	39	35	26	7	25	67	84	30	21	73	100																
32	48	53	3	29	29	4	17	35	2	12	13	10	28	24	16	17	46	59	13	15	37	22	1	24	70	72	62	81	73	68	41	100															
33	41	31	24	27	17	19	15	20	21	16	6	31	2	1	8	8	7	8	5	11	22	15	13	31	57	37	44	19	39	33	25	24	100													
34	13	5	42	5	45	46	54	30	36	45	5	38	17	18	32	24	29	8	36	31	9	32	53	23	1	25	26	15	8	26	39	8	3	100											
35	6	38	34	29	26	32	22	23	15	22	9	24	10	11	0	1	3	11	0	8	8	14	19	36	68	56	55	42	55	52	13	47	93	6	100										
36	11	17	21	5	23	16	48	14	20	34	13	31	21	23	37	35	19	10	8	8	19	13	30	32	0	28	20	6	6	28	31	12	2	78	2	100									
37	44	23	42	17	16	37	32	28	22	30	20	13	24	33	7	9	37	45	21	14	38	9	5	9	35	58	38	30	35	59	29	39	31	2	45	7	100								
38	1	34	4	13	68	43	44	29	53	42	17	43	18	12	24	17	39	6	30	84	33	66	64	15	9	3	21	19	11	10	32	6	2	44	7	10	16	100							
39	55	48	35	35	32	30	25	24	9	24	9	7	16	20	15	14	22	27	8	10	29	13	23	47	65	69	57	35	49	64	35	42	75	16	77	13	53	10	100						
40	56	51	37	35	34	31	26	25	13	25	9	2	21	26	13	11	32	37	9	10	31	14	25	49	66	75	59	41	52	71	37	48	67	16	73	14	57	11	99	100					
41	49	36	33	31	25	30	24	22	6	23	8	20	5	8	14	14	0	4	4	10	26	12	18	37	63	52	58	24	43	46	31	30	92	12	88	8	41	8	93	37	100				
42	53	45	36	33	31	33	26	24	9	24	9	21	13	14	1	0	14	20	0	9	29	13	21	40	73	64	60	50	62	60	36	56	88	9	98	3	51	10	81	47	87	100			
43	36	6	8	21	22	7	16	2	12	23	7	12	0	3	6	1	9	17	7	14	8	12	13	1	47	30	2	29	37	21	2	33	22	23	22	34	6	17	19	18	20	23	100		
44	9	9	44	8	22	46	39	18	42	36	3	49	0	4	12	5	26	19	43	13	11	17	34	13	8	3	12	14	10	1	14	10	7	56	1	35	31	36	18	21	6	3	34	100	
45	11	15	3	15	12	4	12	5	6	5	6	4	27	27	23	17	1	8	0	1	1	4	5	3	17	4	8	11	16	8	10	11	6	1	9	1	13	9	2	0	5	8	8	5	100
46	7	28	7	1	11	9	13	12	3	17	13	18	33	33	25	23	12	32	13	24	25	28	18	10	5	29	21	8	3	30	17	14	12	3	16	14	17	14	21	22	15	16	3	20	45	100
47	8	10	0	6	26	3	1	11	25	1	0	13	19	20	26	18	11	4	0	14	5	8	30	17	23	17	1	15	18	14	14	19	16	13	22	1	27	28	22	22	16	22	15	34	55	8	100
48	3	10	4	6	12	7	16	3	30	7	1	7	8	8	12	13	4	7	12	30	25	37	35	20	8	3	6	9	11	2	13	9	4	40	6	15	10	23	1	2	4	5	6	4	62	11	2	100
49	14	8	20	5	17	17	9	3	4	8	8	9	16	10	15	9	6	7	30	1	8	11	7	15	18	3	2	25	25	3	1	19	3	7	8	0	4	11	3	3	3	8	9	14	66	28	35	46	100
50	12	8	14	11	6	11	21	3	22	1	4	12	7	4	1	2	4	7	7	3	0	9	5	4	16	12	4	2	6	8	8	1	13	17	17	11	29	19	18	18	16	19	23	15	21	45	27	16	45	100
51	16	24	3	8	14	11	9	13	29	9	14	15	24	17	22	17	1	6	18	6	6	2	27	27	33	16	8	24	32	11	6	17	17	11	24	17	20	6	21	22	20	26	2	14	24	0	54	12	52	25	100
52	1	6	20	1	11	13	2	3	11	3	4	19	4	2	9	7	4	1	26	3	6	11	6	4	20	5	4	20	21	2	6	17	4	3	10	2	3	7	6	6	6	11	5	20	64	3	41	68	76	4	31	100
53	32	41	46	23	14	49	66	49	34	60	9	38	9	3	18	12	14	15	47	36	29	42	41	1	60	46	49	57	58	44	42	53	22	60	25	42	2	46	17	17	18	24	49	52	8	10	3	18	15	1	11	18	100
54	42	37	23	32	11	33	56	60	19	47	21	30	4	32	43	36	7	23	31	37	40	47	35	1	59	62	68	55	55	63	64	57	29	50	35	36	21	53	33	34	30	36	43	34	1	24	4	16	7	7	10	11	89	100
55	21	27	45	28	22	51	75	55	35	62	21	43	22	12	37	31	19	7	48	33	21	46	54	21	39	35	44	47	44	39	52	44	9	64	10	44	9	49	2	2	3	10	31	54	1	11	12	22	16	14	4	15	91	87	100
56	30	31	23	33	22	33	66	62	19	47	28	34	49	39	54	47	11	18	33	37	33	51	45	10	47	55	61	51	50	61	68	51	16	53	23	39	12	39	21	23	17	24	28	37	7	25	7	18	6	1	0	9	82	94	91	100

Negative values are underlined

Table 114: Numerical ordination study, correlation matrix

CUANALO de la C., H.E. and WEBSTER, R. 1970 A comparative study of numerical classification and ordination of soil profiles near Oxford, I: Analysis of 85 sites. *J. Soil Sci.*, 21: 340–352.

GRIGAL, D.F. and ARNEMAN, H.F. 1969 Numerical classification of some forested Minnesota soils. *Proc. Soil Sci. Soc. Amer.*, 33: 433–438.

HOLE, F.D. and HIRONAKA, M. 1960 An experiment in ordination of some soil profiles. *Proc. Soil Sci. Soc. Amer.*, 24: 309–312.

LANCE, G.N. and WILLIAMS, W.T. 1967 Mixed-data classificatory sorting strategies; I: Agglomerative systems. *Aust. Comput. J.*, 1: 15–20.

MOORE, A.W. and RUSSELL, J.S. 1967 Comparison of coefficients and grouping procedures in numerical analysis of soil trace element data. *Geoderma*, 1: 139–158.

RAYNER, J.H. 1966 Classification of soils by numerical methods. *J. Soil Sci.*, 17: 79–92.

RUSSELL, J.S. and MOORE, A.W. 1967 Use of a numerical method in determining affinities between some deep sandy soils. *Geoderma*, 1: 47–68.

SARKAR, P.K. 1965 Numerical taxonomy of soils. Ph. D. thesis, Kansas State Univ.

SOKAL, R.R. and SNEATH, P.H.A. 1968 *Principles of numerical taxonomy*. Freeman, San Francisco.

WEBSTER, R. and BURROUGH, P.A. 1972 Computer-based soil mapping of small areas from sample data; I: Multivariate classification and ordination. *J. Soil Sci.*, 23: 210–221.

	6	7	4	5	a	1	2	13	10	G	J	8	38	33	39	25	26	24	23	b	17	14	19	15	16	8	o	41	40	Z	T	44	28	29	31	27	T	30	12	4	37	36
6	-	729	741	665	657	738	597	806	677	664	665	738	679	689	741	636	617	664	592	540	582	715	590	697	735	639	583	497	640	489	397	466	397	501	414	370	423	461	465	509	499	476
7	729	-	797	752	725	748	624	741	666	660	717	667	755	768	735	650	669	671	604	549	546	688	635	764	701	630	593	543	671	466	433	468	420	506	459	339	375	449	496	535	474	478
4	741	797	-	714	755	732	659	774	684	645	668	648	782	794	740	697	744	679	637	624	544	693	626	765	673	636	574	548	627	499	431	509	373	498	464	346	394	449	498	587	471	456
5	665	752	714	-	655	746	609	677	723	716	637	628	702	651	652	706	735	676	646	602	570	581	596	671	623	648	630	456	538	422	365	473	451	481	512	362	417	493	574	597	443	502
a	657	725	755	655	-	693	573	687	580	570	582	637	738	754	718	635	692	690	582	543	499	632	597	757	695	583	516	563	548	509	458	485	375	500	421	325	377	433	456	571	442	447
1	738	748	732	746	693	-	696	720	723	762	689	680	698	773	796	723	751	766	662	605	645	640	569	709	753	743	580	522	593	472	396	538	443	501	515	403	480	537	546	609	460	536
2	597	624	659	609	573	696	-	654	694	692	589	608	580	628	614	689	662	675	654	593	664	577	551	594	562	601	562	420	556	349	339	478	414	361	505	390	373	498	547	633	466	471
13	806	741	774	677	687	720	654	-	688	646	661	698	729	723	745	682	702	659	603	566	594	758	623	716	726	630	576	518	646	478	421	462	376	488	414	335	409	474	494	542	495	514
10	677	666	684	723	580	723	694	688	-	848	629	705	633	630	648	784	705	715	760	710	721	576	623	649	612	685	711	445	539	358	386	499	471	493	555	428	466	573	655	634	536	525
G	664	660	645	716	570	762	692	646	848	-	607	704	614	679	673	802	725	720	751	670	727	558	592	633	648	686	684	416	501	362	368	486	476	523	542	443	494	587	612	648	578	498
J	665	717	668	637	582	689	589	661	629	607	-	631	630	633	668	577	598	668	528	508	616	602	638	648	637	654	574	524	727	419	400	455	439	493	523	363	385	446	551	453	523	517
8	738	667	648	628	631	680	608	698	705	704	631	-	684	630	703	675	664	723	656	604	693	692	610	693	759	660	665	479	552	430	443	504	484	531	532	418	479	509	549	550	577	525
38	679	755	782	702	738	698	580	729	633	614	630	684	-	757	662	671	718	673	587	558	502	672	606	740	671	565	563	564	574	516	468	479	423	520	487	351	407	413	465	542	477	469
33	689	768	794	651	754	773	628	723	630	679	633	630	757	-	737	696	739	678	592	550	562	653	577	719	676	628	507	540	573	510	432	509	373	487	417	337	422	471	465	593	444	459
39	741	735	740	652	718	796	614	745	646	673	668	703	662	737	-	658	649	679	617	612	621	644	613	753	810	697	560	601	600	496	462	510	391	588	478	405	441	512	520	550	503	472
25	636	650	697	706	635	723	689	682	784	802	577	675	671	696	658	-	792	732	745	678	637	550	570	599	596	627	653	433	474	405	399	494	468	491	506	408	480	534	575	702	495	490
26	677	669	744	735	692	751	662	702	705	725	598	664	718	739	649	792	-	711	706	599	614	592	583	652	627	652	603	446	498	451	359	465	421	478	464	351	427	497	564	655	441	530
24	664	671	679	676	690	766	675	659	715	720	668	723	673	678	679	732	711	-	663	662	637	599	588	658	649	706	598	504	578	430	449	589	499	501	543	424	480	591	583	592	526	527
23	592	604	637	646	582	662	654	603	760	751	528	656	587	592	617	745	706	663	-	702	644	508	549	591	579	643	645	460	429	384	407	490	502	492	522	423	480	581	590	672	523	515
b	540	549	624	602	543	605	593	566	710	670	508	604	558	550	612	678	599	662	702	-	641	490	584	549	547	578	628	488	466	366	424	480	531	551	564	541	536	598	622	540	565	533
17	582	546	544	570	499	645	664	594	721	727	616	693	502	562	621	637	514	637	644	641	-	564	576	565	637	706	645	452	523	356	365	502	464	490	572	519	496	557	611	581	523	499
14	715	688	693	581	632	640	577	758	576	558	602	692	672	653	644	550	592	599	508	490	564	-	566	739	708	582	551	480	654	425	384	421	426	454	432	311	391	415	430	455	485	482
19	590	635	626	596	597	569	551	623	623	592	638	610	606	577	613	570	583	588	549	584	576	566	-	641	628	620	671	485	607	404	379	396	484	562	506	370	387	493	546	427	481	505
15	697	764	765	671	757	709	594	716	649	633	648	693	740	719	753	599	652	658	591	589	565	739	641	-	764	658	648	555	621	464	439	475	468	544	501	353	428	472	512	537	491	485
16	735	701	673	623	695	753	562	726	612	648	637	759	671	676	810	596	627	649	579	547	637	708	628	764	-	700	604	543	566	519	463	519	453	573	501	405	497	496	491	505	485	537
8	639	630	636	648	583	743	601	630	685	686	654	660	565	628	697	627	652	706	643	645	551	671	648	604	620	-	620	527	606	486	443	571	477	596	528	418	491	574	590	559	490	526
o	583	593	574	630	516	580	562	576	711	684	574	665	563	507	560	653	603	598	645	628	645	551	671	648	604	620	-	433	513	292	394	431	565	492	599	453	501	553	638	514	496	501
41	497	543	548	456	563	522	420	518	445	416	524	479	564	540	601	433	446	504	460	488	452	480	485	555	543	527	433	-	504	644	692	606	331	508	395	370	353	385	453	365	432	385
40	640	671	627	538	548	593	556	646	539	501	727	552	574	573	600	474	498	578	429	466	523	654	607	621	566	606	513	504	-	406	374	419	394	459	414	301	318	503	453	350	452	443
Z	489	466	499	422	509	472	349	478	358	362	419	430	516	510	496	405	451	430	384	366	356	425	404	464	519	486	292	644	406	-	726	643	269	430	323	287	335	307	324	432	300	314
T	397	633	431	365	458	396	339	421	386	368	400	443	469	432	462	399	359	449	407	424	365	384	379	439	463	443	394	692	374	726	-	638	317	440	387	340	360	365	404	403	380	315
44	466	468	509	473	485	538	478	462	499	486	455	504	479	509	510	494	465	509	490	480	502	421	396	475	519	571	431	606	419	643	638	-	358	399	434	382	431	413	439	484	357	358
28	397	420	373	451	375	443	414	376	471	476	439	484	423	373	391	468	421	499	502	531	464	426	484	468	453	477	565	331	394	269	317	350	-	506	654	554	724	521	516	423	557	633
29	501	506	498	481	500	501	361	488	493	523	493	531	520	487	588	491	478	501	492	551	490	454	562	544	573	596	492	508	459	434	440	399	506	-	516	556	542	546	525	426	500	460
31	414	459	464	512	421	515	505	414	555	542	523	532	487	417	478	506	464	543	522	564	572	432	506	501	501	528	599	395	414	323	387	434	654	516	-	615	605	578	579	481	530	518
27	370	339	346	362	325	403	390	335	428	443	363	418	351	337	405	408	351	424	423	541	519	311	370	353	405	418	453	370	301	287	340	382	554	556	615	-	591	484	450	389	468	406
T	423	375	394	417	377	480	373	409	466	494	385	479	407	422	441	480	427	480	480	536	496	391	387	428	497	491	501	353	318	335	360	431	724	542	605	591	-	571	504	437	540	599
30	461	449	449	493	433	537	498	474	573	587	446	509	413	471	512	534	497	571	581	598	557	415	493	472	496	574	553	385	503	307	365	413	521	546	578	484	571	-	593	451	546	540
12	465	496	498	574	456	546	547	494	655	612	551	549	465	465	520	575	504	583	590	622	611	430	546	512	491	590	638	453	453	321	404	439	516	525	579	450	504	583	-	553	501	516
4	509	535	587	597	571	609	633	542	634	648	453	550	542	593	550	702	655	592	672	540	581	455	427	537	505	559	514	365	358	432	403	484	423	426	481	389	437	451	553	-	383	433
37	499	474	471	443	442	460	466	495	536	513	523	577	477	444	503	495	441	526	523	565	523	485	481	491	485	490	496	432	452	300	380	357	557	500	530	468	540	546	501	383	-	630
36	476	478	456	502	447	536	471	514	525	498	517	525	469	459	472	490	530	527	515	533	499	482	505	485	537	526	501	385	443	314	315	358	633	460	518	406	599	540	516	433	630	-

Table 115: Similarity matrix, Canberra Metric

	6	7	4	5	a	1	2	13	10	G	J	8	38	33	39	25	26	24	23	b	17	14	19	15	16	S	o	41	40	Z	T	44	28	29	31	27	T	30	12	4	37	36
6	–	714	761	709	658	719	655	819	697	690	687	735	727	681	738	649	670	673	658	635	610	696	684	689	710	647	617	625	666	501	485	499	545	598	585	501	559	551	606	587	594	629
7	714	–	780	789	716	702	646	757	675	667	764	675	798	748	721	664	685	653	652	638	616	711	655	744	690	640	644	663	704	513	512	500	545	618	602	519	550	555	615	607	589	589
4	761	780	–	768	748	753	725	797	721	717	689	701	845	820	735	742	764	708	711	660	636	733	683	748	703	657	642	657	661	545	534	547	558	598	585	500	558	569	599	697	582	610
5	709	789	768	–	671	746	706	707	778	769	756	695	742	691	660	774	753	740	750	718	675	680	636	701	663	675	709	607	653	472	482	541	617	592	666	561	604	597	673	700	611	645
a	658	716	748	671	–	686	635	694	605	617	618	643	775	772	678	660	716	647	611	566	576	667	628	709	679	580	542	590	590	521	467	476	477	551	490	421	483	186	498	612	510	548
1	719	702	753	746	686	–	807	743	754	782	698	729	738	750	748	735	765	782	757	702	727	686	628	720	746	738	631	623	630	492	478	567	584	591	629	537	610	629	652	687	613	689
2	655	646	725	706	635	807	–	681	791	823	628	734	696	698	670	769	757	779	829	698	754	630	579	665	677	694	630	577	568	451	455	559	591	550	628	535	624	642	634	735	620	681
13	819	757	797	707	694	743	681	–	695	692	708	735	771	725	796	664	692	675	674	638	635	747	705	749	764	677	613	672	701	530	514	500	555	657	589	517	582	590	615	602	616	650
10	697	675	721	778	605	754	791	695	–	859	716	757	680	631	648	765	710	780	829	750	745	639	642	662	666	694	724	590	601	418	455	548	660	569	695	568	662	647	733	680	681	715
G	690	667	717	769	617	782	823	692	859	–	686	772	676	656	676	780	728	785	843	772	812	641	634	668	696	724	709	592	599	433	465	554	651	590	698	602	672	670	716	710	683	723
J	687	764	689	756	618	698	628	708	716	686	–	703	702	654	692	663	646	999	658	678	679	690	703	691	718	678	667	658	712	477	491	535	614	638	683	570	622	584	695	580	686	676
8	735	675	701	695	643	729	734	735	757	772	703	–	695	654	726	702	660	783	739	733	754	708	698	695	766	710	671	656	662	486	523	549	652	644	671	557	651	664	685	620	721	910
38	727	798	845	742	775	738	696	771	680	676	702	695	–	806	713	711	731	709	677	633	628	728	651	749	711	652	620	689	671	583	554	544	552	601	580	489	554	556	585	649	584	616
33	681	748	820	691	772	750	698	725	631	656	654	654	806	–	731	701	744	689	649	611	625	702	630	714	692	636	563	643	619	555	517	538	495	570	537	470	521	540	533	665	541	573
39	738	721	735	660	678	748	670	796	648	676	692	726	713	731	–	639	670	663	666	662	665	700	697	772	775	706	621	687	662	514	520	499	558	688	595	524	578	601	645	599	635	649
25	649	664	742	774	660	735	769	664	765	780	663	702	711	701	639	–	797	785	798	715	698	619	594	636	631	648	639	583	560	480	478	551	582	549	619	534	597	586	622	805	607	644
26	670	685	764	753	716	765	757	692	710	728	646	660	731	744	670	797	–	733	756	661	672	650	617	690	676	666	608	600	593	526	471	550	556	570	586	517	566	595	574	768	562	635
24	673	653	708	740	647	782	779	675	780	785	699	783	709	689	663	785	733	–	765	761	761	669	637	656	689	733	662	625	619	500	516	597	671	603	687	560	668	670	673	698	666	731
23	658	652	711	750	611	757	829	674	829	843	658	739	677	649	666	798	756	765	–	749	758	623	601	671	664	710	683	601	568	459	483	540	654	589	669	580	662	665	700	756	694	731
b	635	638	660	718	566	702	698	638	750	772	678	733	633	611	662	715	661	761	749	–	758	613	658	650	664	699	740	631	596	448	508	526	683	634	728	635	693	692	767	638	685	731
17	610	616	636	675	576	727	754	635	745	812	679	754	628	625	665	698	672	761	758	758	–	648	643	671	728	748	747	708	624	618	427	469	548	676	622	711	622	697	720	716	628	727	771
14	696	711	733	680	667	686	630	747	639	641	690	708	728	702	700	619	650	669	623	613	648	–	695	776	743	685	625	661	782	517	512	518	601	639	608	520	581	619	588	564	614	631
19	684	655	683	636	628	628	579	705	642	634	703	698	651	630	697	594	617	637	601	658	643	695	–	737	763	662	674	652	687	469	473	494	605	682	616	523	601	596	634	521	617	660
15	689	744	748	701	709	720	665	749	662	668	691	695	749	714	772	636	690	656	671	650	671	776	737	–	787	727	689	697	718	504	504	506	611	696	606	523	596	633	646	583	620	671
16	710	690	703	663	679	746	677	764	666	696	718	766	711	692	775	631	676	689	664	728	743	763	763	787	–	741	647	693	711	519	511	535	608	701	636	568	628	661	647	563	653	701
S	647	640	657	675	580	738	694	677	694	724	678	710	652	636	706	648	666	733	710	699	747	685	662	727	741	–	693	670	665	513	530	586	671	710	696	598	698	766	702	613	665	743
o	617	644	642	709	542	631	630	613	724	709	667	671	620	563	621	639	608	662	683	740	708	625	674	689	647	693	–	643	628	399	490	514	680	612	714	595	668	672	801	566	646	664
41	625	663	657	607	590	623	577	672	590	592	658	656	689	643	687	583	600	625	601	631	624	661	652	697	693	670	643	–	659	650	704	571	579	678	596	534	601	622	635	536	638	616
40	666	704	661	653	590	630	568	701	601	599	712	662	671	619	662	560	593	619	568	596	618	782	687	718	711	665	628	659	–	489	494	498	585	635	610	516	556	607	591	495	595	609
Z	501	513	545	472	521	492	451	530	418	433	477	486	583	555	514	480	526	500	459	448	427	517	469	504	519	513	399	650	489	–	681	578	384	498	405	355	405	432	384	494	430	437
T	485	512	534	482	467	478	455	514	455	465	491	523	554	517	520	478	471	516	483	508	469	512	473	504	511	530	490	704	494	681	–	577	459	531	471	425	470	503	483	476	510	460
44	499	500	547	541	476	567	599	500	548	554	535	549	544	538	499	551	550	597	540	526	548	518	494	506	535	586	514	571	498	578	577	–	496	479	538	453	529	536	498	550	494	511
28	545	545	558	617	477	584	591	555	660	651	614	652	552	495	558	582	556	671	654	683	676	601	605	611	608	671	680	579	585	384	459	496	–	672	762	663	774	704	703	527	677	716
29	598	618	598	592	551	591	550	657	569	590	638	644	601	570	688	549	570	603	589	634	622	639	682	696	701	710	612	678	635	498	531	479	672	–	659	641	705	679	630	514	655	693
31	585	602	585	666	490	629	628	589	695	698	683	671	580	537	595	619	586	687	669	728	711	608	616	606	636	696	714	596	610	405	471	538	762	659	–	726	763	701	731	562	674	695
27	501	519	500	561	421	537	535	517	568	602	570	557	489	470	524	534	517	560	580	635	622	520	523	523	568	598	595	534	516	355	425	453	663	641	726	–	743	662	620	487	597	615
T	559	550	558	604	483	610	624	582	662	672	622	651	554	521	578	597	566	668	662	693	697	581	601	596	628	698	668	601	556	405	470	529	774	705	763	743	–	744	711	554	689	741
30	551	555	569	597	486	629	642	590	647	670	584	664	556	540	601	586	595	670	665	692	720	619	596	633	661	766	672	622	607	432	503	536	704	679	701	662	744	–	677	545	640	698
12	606	615	599	673	498	652	634	615	733	716	695	685	585	533	645	622	574	673	700	767	716	588	634	646	647	702	801	635	591	384	483	498	703	630	731	620	711	677	–	544	697	710
4	587	607	697	700	612	687	735	602	680	710	580	620	649	665	599	805	768	698	756	638	628	564	521	583	563	613	566	536	495	494	476	550	527	514	562	487	562	487	544	–	564	585
37	594	589	582	611	510	613	620	616	681	683	686	721	584	541	635	607	562	666	694	685	727	614	617	620	653	665	646	638	595	430	510	494	677	655	674	597	689	640	697	564	–	777
36	629	589	610	645	548	689	681	650	715	723	676	710	616	573	649	644	635	731	731	731	771	631	660	671	701	743	664	616	609	437	460	511	716	693	695	615	741	698	710	585	777	–

Table 116: Similarity matrix, transformed Euclidean Distance

	6	7	4	5	a	1	2	13	10	G	J	8	38	33	39	25	26	24	23	b	17	14	19	15	16	S	o	41	40	I	T	44	28	29	31	27	P	30	12	4	37	36
6	–	819	837	799	760	825	781	887	816	802	785	836	797	777	836	761	771	800	768	744	734	823	775	795	814	762	738	710	798	591	567	619	654	708	678	622	673	674	704	706	716	728
7	819	–	865	868	805	817	776	844	780	784	832	778	857	844	822	774	784	781	760	727	720	811	757	842	788	747	749	735	832	600	592	612	658	707	705	620	651	670	713	720	703	708
4	837	865	–	854	827	838	824	864	805	799	783	781	887	880	815	830	839	799	794	758	718	815	769	836	783	761	742	739	776	645	618	666	695	685	691	610	664	668	705	789	703	709
5	799	868	854	–	754	852	813	817	847	849	819	792	833	789	767	851	842	830	824	793	764	777	751	800	758	779	805	683	761	569	558	645	716	682	756	659	695	701	774	789	708	748
a	760	805	827	754	–	792	748	803	714	718	728	759	834	840	794	773	805	775	716	685	680	771	752	822	787	702	664	707	730	632	571	602	601	670	607	532	605	610	624	736	639	668
1	825	817	838	852	792	–	883	842	837	870	802	822	823	846	867	835	850	867	841	794	818	805	738	819	849	843	745	719	762	612	566	691	691	698	735	655	723	740	748	797	714	787
2	781	776	824	813	748	883	–	801	872	878	757	826	778	799	794	849	839	864	883	801	835	759	714	787	780	797	761	669	718	540	542	677	763	650	734	656	718	751	743	833	725	770
13	887	844	864	817	803	842	801	–	808	807	799	828	839	809	875	792	799	800	781	745	755	854	809	843	847	788	737	742	811	643	607	618	662	742	693	627	693	706	727	733	727	753
10	816	780	805	847	714	837	872	808	–	918	801	856	777	741	779	859	799	858	892	854	847	760	771	784	770	802	842	684	728	510	560	667	756	689	793	703	756	764	829	795	784	798
0	802	784	799	849	718	870	878	807	918	–	785	870	775	777	805	879	826	864	901	843	883	756	759	782	803	827	821	666	721	533	553	666	753	709	792	720	774	782	808	821	780	803
J	785	832	783	819	728	802	757	799	801	785	–	803	786	749	788	750	747	806	749	752	792	787	802	805	853	820	790	718	769	581	610	656	752	755	768	680	748	765	788	741	817	802
8	836	778	781	792	759	822	826	828	856	870	803	–	792	763	821	814	785	883	834	828	854	807	802	805	853	820	790	718	769	581	610	656	752	755	768	680	748	765	788	741	817	802
38	797	857	887	833	834	823	778	839	777	775	786	792	–	859	782	820	831	805	772	731	711	807	746	830	787	738	722	761	761	667	641	643	651	689	683	585	645	650	691	743	699	715
33	777	844	880	789	840	846	799	809	741	777	749	763	859	–	815	810	836	785	753	714	734	789	723	812	778	750	683	712	734	653	593	656	618	670	653	588	658	663	657	783	664	702
39	836	822	815	767	794	867	794	875	779	805	788	821	782	815	–	775	764	787	779	782	782	806	791	853	870	815	734	768	789	628	628	635	669	774	711	648	694	720	742	723	737	743
25	761	774	830	851	773	835	849	792	859	879	750	814	820	810	775	–	876	859	882	818	797	731	719	745	743	763	768	663	679	590	576	662	706	675	738	664	725	717	745	879	735	752
26	771	784	839	842	805	850	839	799	799	826	747	785	831	836	764	876	–	822	841	755	768	750	724	781	763	763	728	671	691	620	554	646	673	667	687	621	684	704	692	847	688	762
24	800	781	799	830	775	867	864	800	858	864	806	883	805	785	787	859	822	–	848	832	830	781	756	781	795	835	768	707	751	593	606	722	761	719	773	675	753	776	777	800	768	802
23	768	760	794	824	716	841	883	781	892	901	749	834	772	753	779	882	841	848	–	842	841	720	728	772	758	812	799	689	687	556	581	653	756	702	765	694	757	780	802	851	748	794	810
b	744	727	758	793	685	794	801	745	854	843	752	828	731	714	782	818	755	832	842	–	835	721	773	743	758	789	835	718	707	545	621	645	777	759	813	763	790	802	811	810	758	807	837
17	734	720	718	764	680	818	835	755	847	883	792	854	711	734	782	797	768	830	841	835	–	767	789	771	832	858	823	692	746	532	566	663	783	736	807	743	794	811	810	758	807	837
14	823	811	815	777	771	805	759	854	760	756	787	807	807	789	806	731	750	781	720	721	767	–	796	863	838	781	747	731	861	617	606	625	721	726	709	637	696	714	693	683	719	736
19	775	757	769	751	752	738	714	809	771	759	802	802	746	723	791	719	724	756	728	773	789	796	–	819	843	790	812	717	804	582	575	598	742	786	753	660	720	722	752	649	743	771
15	795	842	836	800	822	819	787	843	784	782	797	805	830	812	853	745	781	781	772	743	771	863	819	–	858	809	810	760	827	599	597	617	742	779	721	632	709	733	747	705	730	758
16	814	788	783	758	787	849	780	847	770	803	805	853	787	778	870	743	763	795	758	758	832	838	843	858	–	843	760	749	803	640	611	659	710	790	736	674	735	750	735	688	741	779
S	762	747	761	779	702	843	797	788	802	827	790	820	738	750	815	763	763	835	812	789	858	781	790	809	843	–	799	742	788	621	627	709	770	801	783	707	784	833	787	738	763	818
o	738	749	742	805	664	745	761	737	842	821	772	790	722	683	734	768	728	768	799	835	823	747	812	810	760	799	–	722	751	484	594	621	814	738	830	732	785	789	869	696	770	778
41	710	735	739	683	707	719	669	742	684	666	735	718	761	712	768	663	671	707	689	718	692	731	717	760	749	742	722	–	744	729	797	698	660	748	676	630	674	694	714	618	716	702
40	798	832	776	761	730	762	718	811	728	721	824	769	761	734	789	679	691	751	687	707	746	861	804	829	803	788	751	744	–	591	587	611	712	742	715	636	672	738	710	617	713	721
I	591	600	645	569	632	612	540	643	510	533	566	581	667	653	628	590	620	593	556	545	532	617	582	599	640	621	484	729	591	–	784	715	680	613	504	465	529	534	477	512	523	544
T	567	592	618	558	571	566	542	607	560	553	576	610	641	593	628	576	554	606	581	621	566	606	575	597	611	627	594	797	587	784	–	712	560	646	583	553	587	611	596	588	610	559
44	619	612	666	645	602	691	677	618	667	666	636	656	643	656	635	662	646	722	653	645	663	625	598	617	659	709	621	698	611	715	712	–	597	596	646	583	649	645	610	677	593	613
28	654	658	655	716	601	691	703	662	756	753	726	752	651	618	669	706	673	761	756	777	783	721	742	742	710	770	814	660	712	680	550	597	–	801	867	790	891	823	818	663	797	845
29	708	707	685	682	670	698	650	742	689	709	722	755	689	670	774	675	667	719	702	759	736	726	786	779	790	801	738	748	742	613	646	596	801	–	772	770	829	805	754	637	777	783
31	678	705	691	756	607	735	734	693	793	792	777	768	683	653	711	738	687	773	765	813	807	709	753	721	736	783	830	676	715	504	583	646	867	772	–	833	861	807	827	687	790	801
27	622	620	610	659	532	655	656	627	703	720	669	680	585	588	648	664	621	675	694	753	743	637	660	632	674	707	732	630	636	465	553	583	790	770	833	–	856	795	741	616	739	742
P	673	651	664	695	605	723	718	693	756	774	708	748	645	658	694	725	684	753	757	790	794	696	720	709	735	784	785	674	672	529	587	649	891	829	861	856	–	850	–	802	687	774	814
30	674	670	668	701	610	740	751	706	764	782	685	765	650	663	720	717	704	776	780	802	811	714	722	733	750	833	789	694	738	534	611	645	823	805	807	795	850	–	802	687	774	821
12	704	713	705	774	624	748	743	727	829	808	788	788	691	657	742	745	692	777	785	851	810	693	752	747	735	787	869	714	710	477	596	610	818	754	827	741	807	802	–	693	798	821
4	706	720	789	789	736	797	833	733	795	821	684	741	743	783	723	879	847	800	849	748	758	783	649	705	688	738	698	618	617	612	588	677	663	637	687	616	686	687	693	–	680	715
37	716	703	703	708	639	714	725	727	784	780	770	817	699	664	737	735	688	768	797	794	807	719	743	730	741	763	770	716	713	523	610	593	797	777	790	739	804	774	798	680	–	868
36	728	708	709	748	668	787	770	753	798	803	786	802	715	702	743	752	762	802	809	810	837	736	771	758	779	818	778	702	721	544	559	613	845	783	801	742	839	814	821	715	868	–

Table 117: Similarity matrix, transformed Mean Character Distance

APPENDIX VIII

CORRELATIONS BETWEEN THE PROPOSED CLASSIFICATION AND CLASSIFICATIONS USED ELSEWHERE IN MALAYSIA

SARAWAK

Survey reports issued prior to 1973 followed the classification developed locally in 1966 (Soil Survey Staff, 1966). This was also used for the regional coverage of west Sarawak (Andriesse, 1972). Correlations between the 1966 system and that proposed for the Area are given in Table 111. Great Soil Groups which have not been recognised in the Area are not discussed.

Major differences are confined to (1) the introduction of medium-textured Families in certain Groups (Grey-White Podzolic, Gley and Alluvial Soils); (2) the deletion of some minor Families and their inclusion as Series in other Families; (3) the introduction of a Group of Hydromorphic Upland Soils and a Group of Regosols; and (4) the renaming of the Groups of Peat and Skeletal Soils as Organic Soils and Lithosols respectively, to agree with usage elsewhere in the region. There has also been extensive redefinition of the classification units at all levels (discussed in Chapter 7) but the central concept of established Families and Series has been maintained as far as possible.

SABAH

The classification currently used in Sabah (LRD, 1975) employs the Units and Subunits of the World Soil Map Legend (FAO, 1970 edition) above the Family level. Families are separated on a number of grounds, but particular emphasis is given to parent material and to the colour and texture of the B horizon. No Series division are made. The difficulties of correlating the proposed classification with the FAO and USDA systems have been discussed above (Chapter 11). Possible correlations are given in Table 112 between the Soil Series of the Area and the Families used in Sabah, but these are very tentative. They are based on the published classification parameters and, for a limited number of soils, on the writer's field work (Scott, 1978). A major difficulty in correlating upland soils with those of the Area concerns the argillic horizon requirement in many important soils in the Sabah system.

Suggested correlations are based largely on physical properties. There may be chemical contrasts not indicated by the few type profiles published for Sabah Families.

Despite the broad range of parent materials in Sabah no close equivalents are found in the Sabah classification to the soils of the Area developed over acid igneous rocks. Sabah soils over these materials are either stony, shallow or have markedly high cation exchange capacities.

WEST MALAYSIA

Soils in West Malaysia were classified at Series level (Leamy and Panton, 1966) and were broadly grouped following the Thorp and Smith (1949) nomenclature. Series being characterised on parent material, landform, subsoil texture and other characteristics. Some preliminary correlations with Sarawak soils were made by Paramananthan (1975) and, for some soils, on field work by the writer (Scott, 1975). The key for West Malaysian soils was revised by Law et al. (1975) and Law and Tan (1975) and more recently a 'field legend' was drafted (Paramananthan, 1980). All these revisions concentrate on establishing the existing classification situation (which is both inconsistent and confusing) rather than attempting improvements on it, and correlation with other areas remains difficult. Table 120 indicate possible correlations between the Area and West Malaysia on the basis of the 1966 West Malaysian system. Correlation with more recent West Malaysian presentations is best not attempted in the present fluid situation. It is to be hoped that a definitive West Malaysian system is developed in the near future. In correlation with the 1966 system a number of interesting contrasts are noted, among which are the following:

(a) There appear to be no equivalent soils in West Malaysia to the upland residual Podzols of the Area. West Malaysian Podzols are confined to low-level terrace alluvium with the exception of one Series (Gunong Padang) which is developed over granitic parent materials and is confined to sites above 4,000 feet altitude.

Table 118

Correlation between the proposed classification and that previously developed for local use (Soil Survey Staff, 1966)

1966 Classification		*Proposed Classification*	
Great Soil Groups	Families	Families	Great Soil Groups
Lateritic Soils (1)			
Brown Forest Soil (1)	Kabuloh (1)	Kabuloh (1)	Red-Yellow Podzolic Soils
	Kedadum (1) (2)		
Red-Yellow Podzolic Soils	Matang (1) (2)		
	Nyalau, Sabangang	Nyalau	
	Bekenu	Bekenu	
	Merit, Lupar	Merit	
	Abok	Serin, Abok and Gading	
	Semilajau (3) Malang (4)	(classed under Alluvial Soils)	
Grey-White Podzolic Soils	Kerait	Kerait	Grey-White Podzolic Soils
	Saratok	Bandang	
		Saratok	
	Lubai, Triboh (1) (2)		
Groundwater Laterite Soils (1)			
Podzols	Bako, Miri	Miri	Podzols
	Silantek, Buso	Silantek	
	Jerijeh (1) (2)		
Gley Soils	Gerawat, Embang and Samadoh (1)	Ajoh (5)	Hydromorphic Upland Soils
		Timang (5)	
	Gong (1)	Penipah (5)	
	Bijat, Sebandi, Daro	Bijat	Gley Soils
		Pakan	
	Plan, Luis	Plan	
	Tatau, Matu	Tatau	
Saline Grey Soils	Nonok, Belat (6)	Nonok, Belat	
	Rajang, Pendam (6)	Paloh, Sirik	
		Rajang, Pendam	

Table 118 (continued)

Recent Alluvial Soils	Kayan	Kayan	Alluvial Soils
	Seduau	Bemang (3)	
	Kabong	Seduau (4)	
	Sematan, Ramun and Terbat (1)	Kabong	
Skeletal Soils	Meluan	Meluan	Lithosols
	Kapit, Sedong, Binatang and Kelupu	Kapit	
	Gaya (1)	Lalis (5)	
	some Nyalau and Sabangang	Peninjau	Regosols
	some Saratok and Miri	Tika	
Peat Soils	Mukah	Mukah	Organic Soils
	Igan	Igan	
	Mulu (1) (2)		
	Anderson	Anderson	

(1) Groups and Families not recorded in the Area; (2) Families recorded in other regions which have uncertain status in the proposed classification; (3) Semilajau is now classed as a Series of Bemang Family (Alluvial Soils); (4) Malang is now classed as a Series of Seduau Family (Alluvial Soils); (5) Correlation is partial and uncertain; (6) Division between these Families is now made on changed criteria.

(b) It is surprising that no equivalents appear to be recognised in West Malaysia for Seduau and Malang Series, well-drained clay profiles developed in recent riverine alluvium. Soils developed in such material in West Malaysia appear to have either medium or coarse textures or to be imperfectly or poorly drained.

(c) Lithosols are difficult to correlate as those shallow steepland soils named by Leamy and Panton (1966) appear to include shallow phases of related Red-Yellow Podzolic Soils in the proposed classification for the Area. The revised key of Law et al. (1975), however, suggests that Lithosols as defined for the Area would, on current thinking in West Malaysia, be classed as 'shallow soils' and remain unnamed.

(d) Many of the bottomland soils recognised in the classification proposed for the Area have received little consideration in West Malaysia, where they are isolated in the classification under 'miscellaneous land units'. The latter include Peat, Muck, Organic Clay, Local Alluvium, Colluvium, Riverine Alluvium and Inland Swamp. Further difficulties in bottomland tracts result from Series being distinguished for 'floodplains', 'river basin deposits', 'plain tracts' and 'valley tracts'. These land units are of doubtful relevance in a soil classification and are also difficult to recognise in a consistent manner.

The Leamy and Pantom (1966) key emphasises subsoil texture. The later key of Law et al. (1975) isolates soils with moderate to strong subsoil structure and moderate to strong clayskin development. Neither key, however, stipulates an argillic or textural B horizon in defining any Series. This simplifies possible correlations with soils in the Area. A correlation of West Malaysian soils with the USDA taxonomy (Paramananthan and Law, 1974) complicates the picture, however, and casts doubt on many of the pairings given in Table 120. Considering those Series correlated with the Area's Red-Yellow and Grey-White Podzolic Soils, Paramananthan and Law class Hollyrood, Marang, Serdang and Tampoi as

Table 119

Possible correlations between soils of the Area and the Soil Families established in Sabah (LRD, 1975)

Soil Series in the Area	*Soil Families in Sabah*
Merit; Jakar	Batang*; Kumansi*
Bekenu	Laab, Tanjong Lipat*; Sipit*
Sarikei	Luasong; Tanjong Lipat*; Sipit*
Nyalau	Laab; Antulai; Tanjong Lipat*; Kepilit*; Sipit*
Pasai	Luasong; Tanjong Lipat*; Kepilit*; Sipit*
Lupar	Kelawat; Lumisir*
Sabangang	Kelawat
Nyaroh; Piring; Arip; Changgan	No close equivalents
Kerait; Bandang; Durin; Saratok	No close equivalents
Bako; Silantek; Tunggal; Bakau	Sibuga (if well-drained); Pa Sia (if poorly-drained)
Miri; Buso; Metading	Keramatoi (if well-drained); Baiayo (if poorly-drained)
Grang	Baiayo
Ajoh	Masaum*
Timang	Gunong Alab*
Penipah	No close equivalent
Rajang; Paloh	Weston
Pendam; Sirik	Kalibong
Jol; Sebandi; Luis; Matu	Guan
Bijat; Plan; Pakan; Tatau	Koyah
Seduau; Bemang; Semilajau;	Luba; Kelawat
Malang	Luba; Mangkawagu
Kayan	Kelawat; Tenghilan
Kabong; Belawai	Tamanong; Tanjong Lita
Tika	Serai
Bintulu; Peninjau; Sebaya	No close equivalents
Meluan (shallow)	Lithosols (unnamed)
Meluan (deep); Kapit; Lalis; Suka	Included with associated Red-Yellow Podzolic Soils
Mukah; Igan; Anderson	Klias

* These Families in Sabah require an argillic horizon.

Table 120

Possible correlations between soils of the Area and Soil Series established in West Malaysia

The Area	*West Malaysia*	*The Area*	*West Malaysia*
Merit	Durian	Ajoh; Timang; Penipah	—
Lupar	Tampoi		
Jakar	Munchong; Jempol		
Bekanu	Bungor	Rajang; Pendam	Kranji
Sarikei	Munchong	Paloh; Sirik	? Kranji
Nyalau	Bungor; Kuala Brang	Bijat	Briah
Pasai	Serdang	Pakan	Merbau Patah
Sabangang	Hollyrood	Plan	Kampung Kubor
Piring Arip	Rengam; Kampung Kolam	Tatau	Rusila
Changgan	Jerangau	Jol; Sebandi	? Organic Clay
Nyaroh	—	Luis; Matu	? Shallow Peat
Kerait	Batu Anam; Apek	Seduau; Malang	—
Bandang	Apek	Bemang	Telaga; Akob
Durin; Saratok	? Marang	Semilajau	Akob
		Kayan	Telemong
		Kabong; Belawai	Baging
Miri; Buso; Grang; Metading	Rudua	Peninjau; Sebaya; Bintulu	—
Bako; Silantek; Tunggal; Bakau	—	Tika	Marang
		Lithosols	Lithosols
		Organic Soils	Peats; Mucks

Inceptisols, Apek, Batu Anam, Bungor, Durian, Kuala Brang and Rengam as Ultisols, and Jerangau, Jempol, Kampong Kolam and Munchong as Oxisols. Comparison of these correlations with those made between the Area's soils and the USDA taxonomy (Table 40 and Appendix V) shows many inconsistencies and indicates that the correlations suggested in Table 120 are at best only partial.

REFERENCES

ANDRIESSE, J.P. 1972 Soils of West Sarawak (East Malaysia). *Sarawak Dept. of Agric.*, Res. Br. Mem. 1. Kuching.

FAO (United Nations Food and Agriculture Organisation) 1970 *Key to soil units for the soil map of the World*. 1970 draft. Rome.

LAW, W.M. and TAN, M.H 1975 Range in properties of Peninsular Malaysia soils. *Proc. 3rd ASEAN soils conf.*, Kuala Lumpur.

LAW, W.M., PARAMANANTHAN, S., LIM, J.S. and SELVADURAI, K. 1975 Key to the common soils of Peninsular Malaysia. Soil Correlation Seminar, Kuala Lumpur. Malaysian Soc. Soil Sci. (unpub.)

LEAMY, M.L. and PANTON, W.P. 1966 Soil survey manual for Malayan conditions. *Min. Agric. and Coop., Div. of Agric., Kuala Lumpur,* Bull. 1.

LRD (UK Min. of Overseas Dev., Land Res. Div.) 1975 *The soils of Sabah,* 1: Classification and description. Land Resources Study 20.

PARAMANANTHAN, S. 1975 Some correlations between soils in Sarawak and Peninsular Malaysia. *Soil Correlation Seminar* Kuala Lumpur. Malaysian Soc. Soil Sci.

——— 1980 Field legend. Unpublished draft, Soil and Analyt Services Branch, Division of Agriculture, Kuala Lumpur.

——— and LAW, W.M. 1974 The taxonomy of Peninsular Malaysian soils — an approximation. *Symp. on classification and management of soils in Malaysia,* Kota Kinabalu.

SCOTT, I.M. 1975 (in) *The Trans-Perak Development Project.* Consultancy report, Malaysia.

———1978 *The soils of the Mandalom area.* Consultancy report, Sabah, Malaysia.

SOIL SURVEY STAFF 1966 A classification of Sarawak soils. *Sarawak Dept. of Agric.*, Res. Br. Tech. Paper 2. Kuching.

THORP, J. and SMITH, G.D. 1949 Higher categories of soil classification: Order, Suborder and Great Soil Groups. Soil Sci., 67: 117–126