SOILS OF GUNONG MULU NATIONAL PARK

By

TIE YIU LIONG
Department of Agriculture, Sarawak

I. C. BAILLIE
Polytechnic of North London, England

C. PHANG MIN SEN
Department of Forestry, Sarawak

LIM CHIN PANG
Department of Agriculture, Sarawak

September, 1979

Soil Survey Division
Research Branch

Dept of Agriculture
Sarawak

Ian Baillie

CONTENTS

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the participation, advice and assistance of the following:

Mr. Patrick Sibat, Soil Surveyor, for his participation in some of the fieldwork.

Messrs. Richard Padan, Keluni Mejeni, Wan Laeng and Gary Bagong for their assistance in the field and in the subsequent clerical work.

Messrs. Lim Chia Chuang and Chai Chin Chian for their assistance in planning and drafting the sketches and map.

Dr. Ahmed M. Iqbal and the staff of the Chemistry Laboratory of the Semongok Agricultural Research Centre, for all of the soil analyses.

Miss Lee Kok Ewe, Mrs. A. Ollis and Miss R. Hutchinson for typing the drafts and the final report.

The Royal Geographical Society, and especially Mr. Robin Hanbury-Tenison, the Expedition Leader, and the Expedition administrative staff, for logistical support.

The Royal Society, London, for financial assistance enabling one of us (I.C.B.) to participate in the Expedition.

Numerous colleagues in the Sarawak Government and on the Expedition for discussion and suggestions on all aspects of the Park and its soils.

SOILS OF GUNONG MULU NATIONAL PARK

by

Y.L. Tie, I.C. Baillie, C.M.S. Phang and C.P. Lim

1. INTRODUCTION

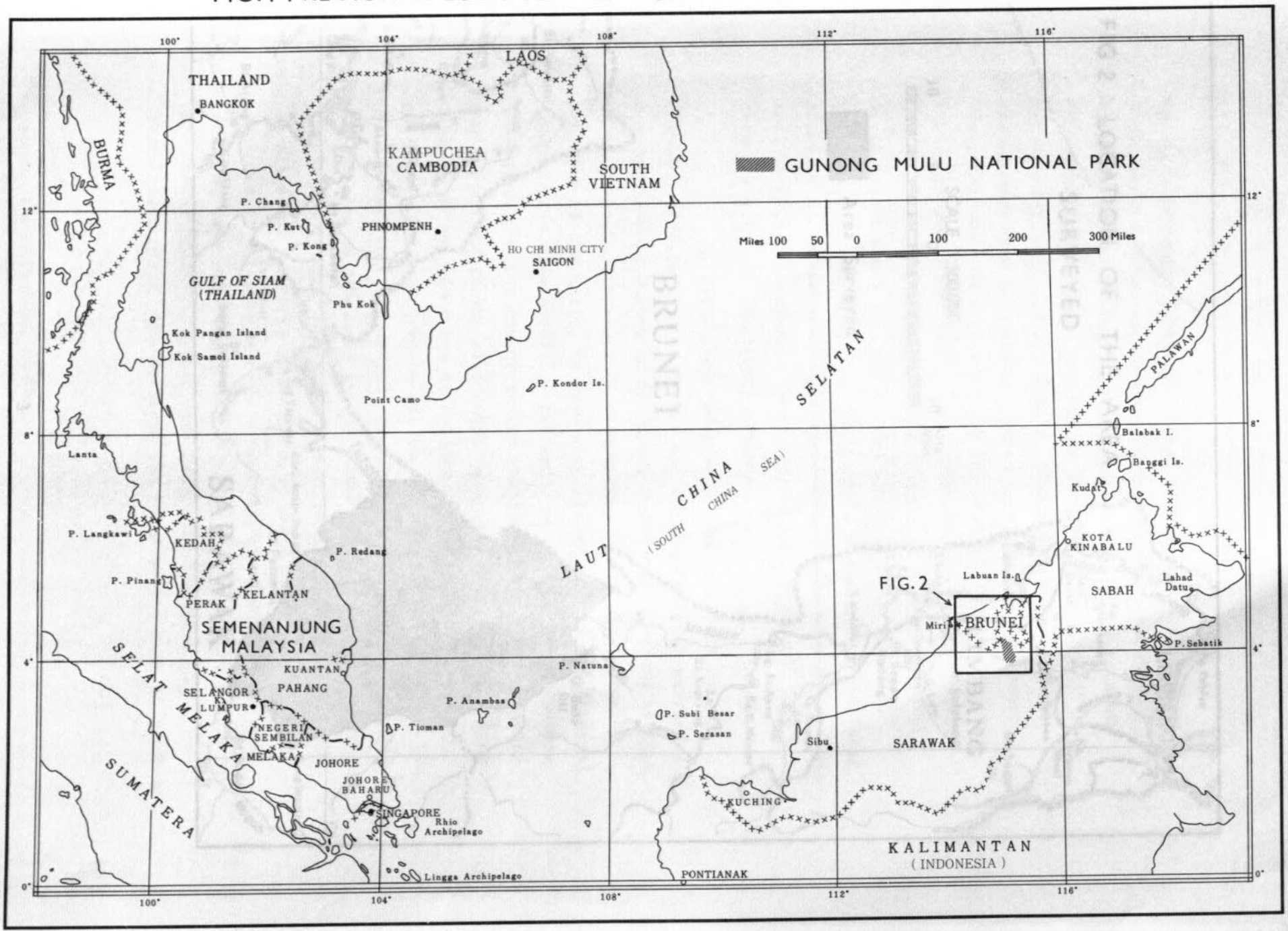
In conjunction with other comprehensive studies of the Gunong Mulu National Park under the aegis of the Royal Geographical Society's Mulu Expedition, the soils of the area were surveyed and studied. The soil survey was carried out jointly by Agriculture Department, Forest Department and the Royal Geographical Society. The main objective was to map the major soil types of the area. The information on the soils could then be used as basic data for the management and development plan and other scientific studies. Special attention was given to the Forest Ecological Plots as detailed soil information is required for a better interpretation of the detailed ecological data collected.

Gunong Mulu National Park lies between latitude 3^{o} 55'N and 4^{o} 15'N, and extends from longitude 114^{o} 48'E to 114^{o} 58'E. It is the largest protected area in Sarawak, covering 544 square kilometres (210 square miles) of primary forests. Fig. 1 shows the location of the Park. The actual Survey Area includes the whole of Gunong Mulu National Park and part of the adjacent area west of Sungai Melinau and Sungai Lutut (Fig. 2).

2. METHODOLOGY

The base map of the Gunong Mulu National Park at the scale of 1:50,000 was derived from the topographic maps (Sheets 4/114/12, 4/114/16 and 3/114/4) prepared by Land and

FIG.1 : REGIONAL LOCATION OF GUNONG MULU NATIONAL PARK



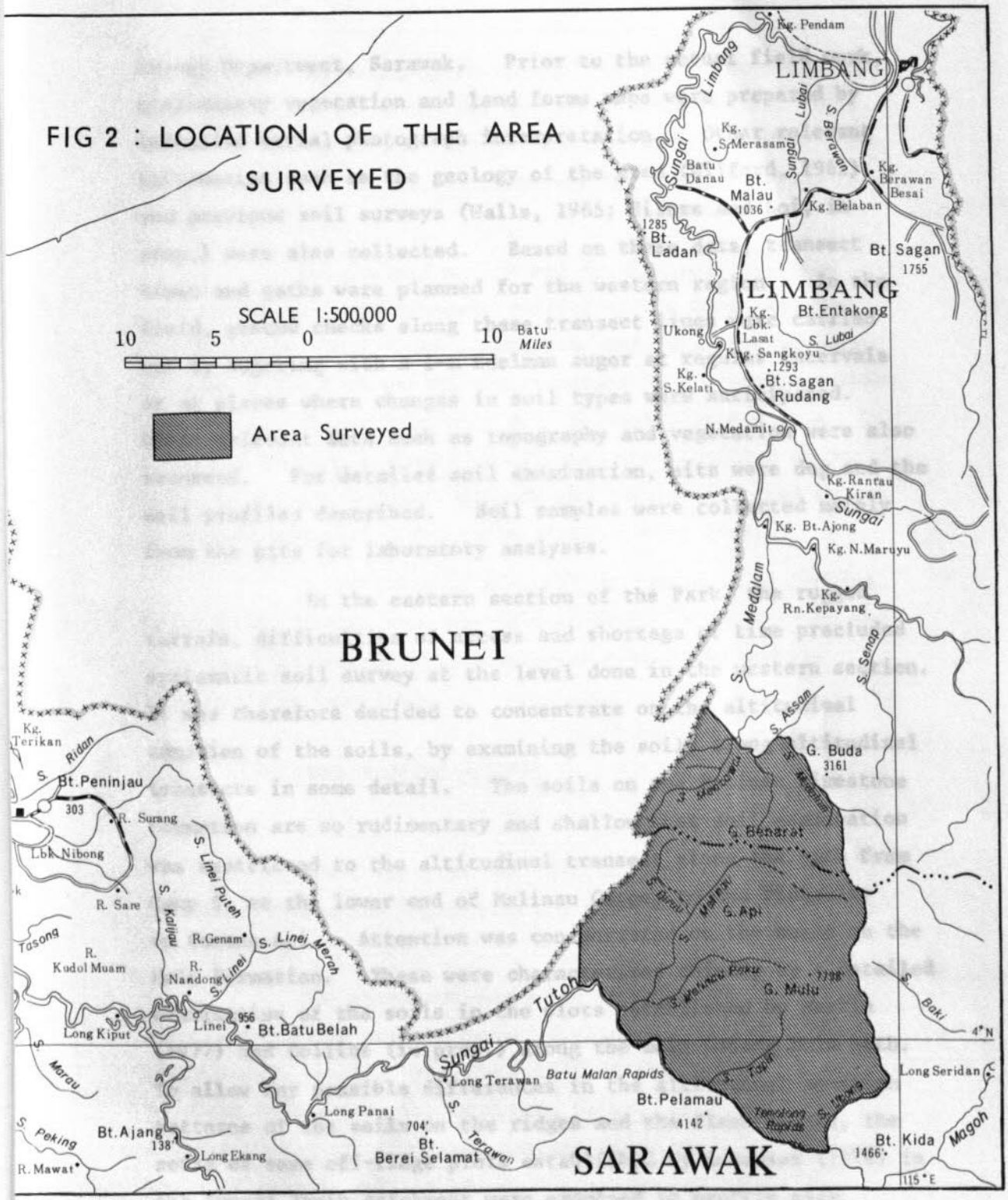


FIG 2 : LOCATION OF THE AREA SURVEYED
SCALE 1:500,000
10 5 0 10 Batu Miles
Area Surveyed
BRUNEI
SARAWAK
LIMBANG
LIMBANG
Kg. Pendam
Sungai Limbang
Sungai Lubai
S. Berawan
Kg. Merasamar
Batu Danau
Bt. Malau 1036
Kg. Belaban
Kg. Berawan Besai
1285 Bt. Ladan
Bt. Sagan 1755
Bt. Entakong
Kg. Lbk. Lasat
Ukong
S. Lubai
Kg. Sangkoyu
1293
Kg. S. Kelati
Bt. Sagan Rudang
N. Medamit
Kg. Rantau Kiran
Sungai
Kg. Bt. Ajong
Kg. N. Maruyu
Kg. Rn. Kepayang
S. Medalam
S. Senap
S. Assam
G. Buda 3161
G. Benarat
G. Api
G. Mulu 7795
Kg. Terikan
S. Ridan
Bt. Peninjau 303
R. Surang
Lbk. Nibong
R. Sare
S. Kalijau
S. Linei Puteh
S. Linei Merah
Tasong
R. Kudol Muam
R. Genam
R. Nandong
S. Linei
Linei 956
Bt. Batu Belah
Long Kiput
Tutoh
Sungai
Long Terawan
Batu Malan Rapids
Bt. Pelamau 4142
Long Seridan
S. Morau
S. Peking
Bt. Ajang 138
Long Ekang
R. Mawat
Long Panai
704
Bt. Berei Selamat
S. Terawan
Bt. Kida 1466
Magoh
S. Baki
4°N
115°E

Survey Department, Sarawak. Prior to the actual field work, preliminary vegetation and land forms maps were prepared by intensive aerial photograph interpretation. Other relevant information such as the geology of the area (Wilford, 1961) and previous soil surveys (Walls, 1965; Eilers and Loi, in prep.) were also collected. Based on these data, transect lines and paths were planned for the western region. In the field, ground checks along these transect lines were carried out by augering with a 1-m Edelman auger at regular intervals or at places where changes in soil types were anticipated. Other relevant data such as topography and vegetation were also recorded. For detailed soil examination, pits were dug and the soil profiles described. Soil samples were collected mainly from the pits for laboratory analyses.

In the eastern section of the Park, the rugged terrain, difficulties of access and shortage of time precluded systematic soil survey at the level done in the western section. It was therefore decided to concentrate on the altitudinal zonation of the soils, by examining the soils along altitudinal transects in some detail. The soils on the Melinau Limestone Formation are so rudimentary and shallow that soil examination was restricted to the altitudinal transect along the path from Camp 5, at the lower end of Melinau Gorge, to the Pinnacles on Gunong Api. Attention was concentrated on the soils on the Mulu Formation. These were characterized chiefly by a detailed examination of the soils in the plots established by Martin (1977) and Collins (in prep.) along the main Gunong Mulu path. To allow for possible differences in the altitudinal zonation patterns of the soils on the ridges and the flank slopes, the soils of some off-ridge plots established by Anderson (1978) in the Sungai Tapin catchment were examined in profile pits. Below these plots, the soils on the flank slopes down to 1,450 m

altitude were examined by free auger survey. Traverses were also made along the sandstone Northeast Ridge and the Pantu Ridge and the soils examined by augering and in profile pits. The pedological examination sites and the transect lines are shown in Fig. 3.

The lowland region and the Mentawai drainage area to the west were largely covered by the first and the third authors whereas the mountainous region in the eastern section of the Park was mainly traversed by the second author. However, all the authors were able to travel around as a group and examine a number of soil profiles together at one stage so as to coordinate methods and terminology, and to get an overall picture of the soils of the Survey Area.

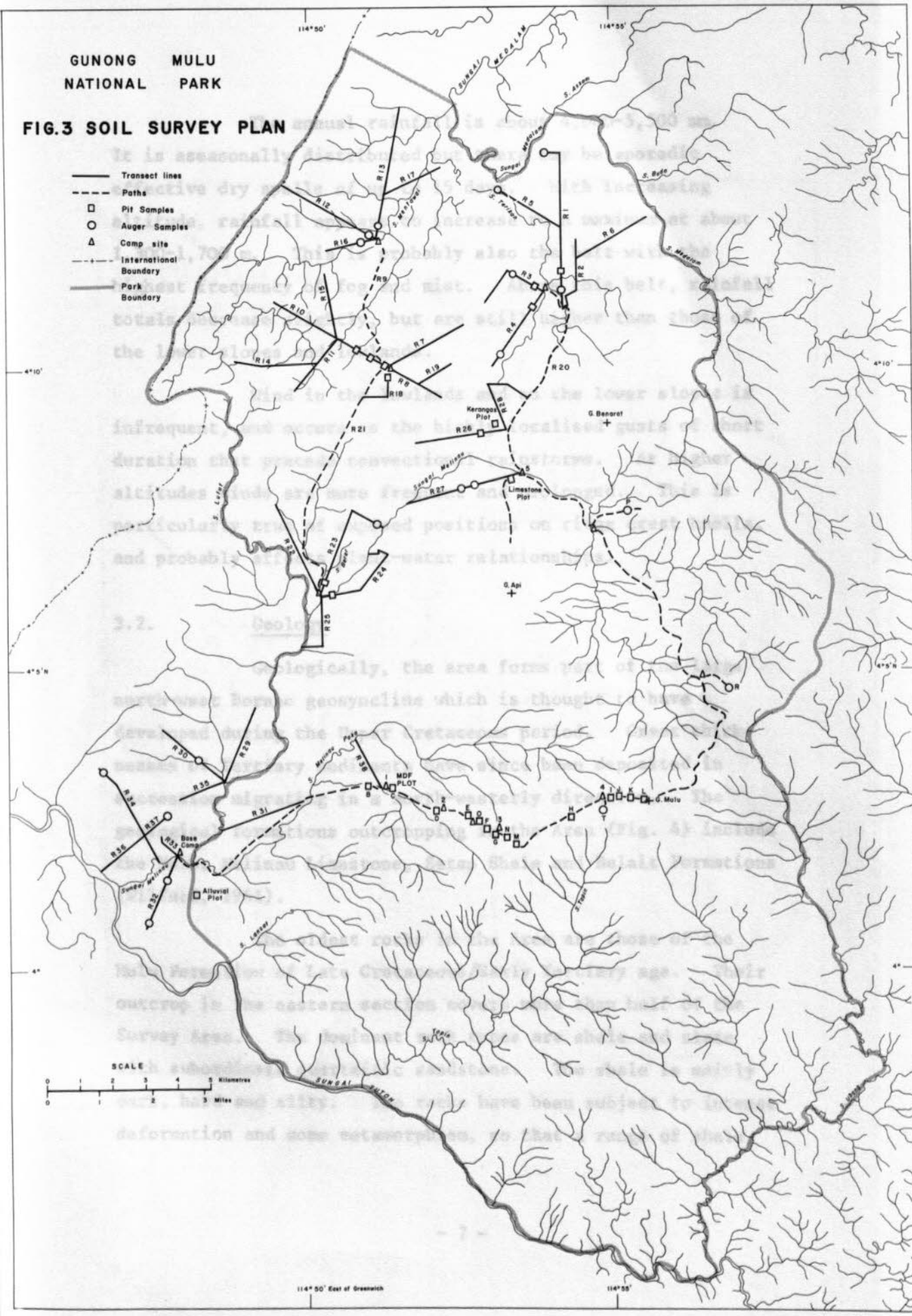
Compilation of the soil map was done in Kuching. Based on the field data, aerial photograph interpretation and other data collected, soil boundaries were drawn and the mapping units finalised.

3. SOIL FORMING FACTORS

3.1. Climate

The climate of the Park and the climatic data collected during the Expedition are described in detail elsewhere (Walsh, in prep.).

The important pedogenic features are the high, even temperatures and the heavy, aseasonal rainfall. Mean temperatures decline from about 26°C in the Melinau Lowlands to about 18°C at the top of Gunong Mulu. Daily minimum temperatures in the lowlands average about 22-24°C. Minimum temperatures may fall to below 14°C at the top of the mountain.


GUNONG MULU
NATIONAL PARK
FIG.3 SOIL SURVEY PLAN
Transect lines
Paths
Pit Samples
Auger Samples
Camp site
International Boundary
Park Boundary
114°50'
114°55'
4°10'
4°5'N
4°
Sungai Medalam
S. Asson
S. Medium
S. Terisan
S. Melinau
S. Lenger
S. Tapie
Sungai Melinau
Sungai Buton
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
R24
R25
R26
R27
R28
R29
R30
R31
R32
R33
R34
R35
R36
R37
R38
Kerangas Plot
Limestone Plot
Alluvial Plot
Base Camp
MDF PLOT
G. Benarat
G. Api
G. Mulu
SCALE
Kilometres
Miles
114° 50' East of Greenwich

The annual rainfall is about 4,000-5,500 mm. It is aseasonally distributed but there may be sporadic effective dry spells of up to 15 days. With increasing altitude, rainfall appears to increase to a maximum at about 1,300-1,700 m. This is probably also the belt with the highest frequency of fog and mist. Above this belt, rainfall totals decrease slightly, but are still higher than those of the lower slopes and lowlands.

Wind in the lowlands and on the lower slopes is infrequent, and occurs as the highly localised gusts of short duration that precede convectional rainstorms. At higher altitudes winds are more frequent and prolonged. This is particularly true of exposed positions on ridge crest knolls, and probably affects plant-water relationships.

3.2. Geology

Geologically, the area forms part of the large north-west Borneo geosyncline which is thought to have developed during the Upper Cretaceous period. Great thicknesses of Tertiary sediments have since been deposited in succession migrating in a north-westerly direction. The geological formations outcropping in the Area (Fig. 4) include the Mulu, Melinau Limestone, Setap Shale and Belait Formations (Wilford, 1961).

The oldest rocks in the Area are those of the Mulu Formation of Late Cretaceous/Early Tertiary age. Their outcrop in the eastern section covers more than half of the Survey Area. The dominant rock types are shale and slate with subordinate quartzitic sandstone. The shale is mainly dark, hard and silty. The rocks have been subject to intense deformation and some metamorphism, so that a range of shale,

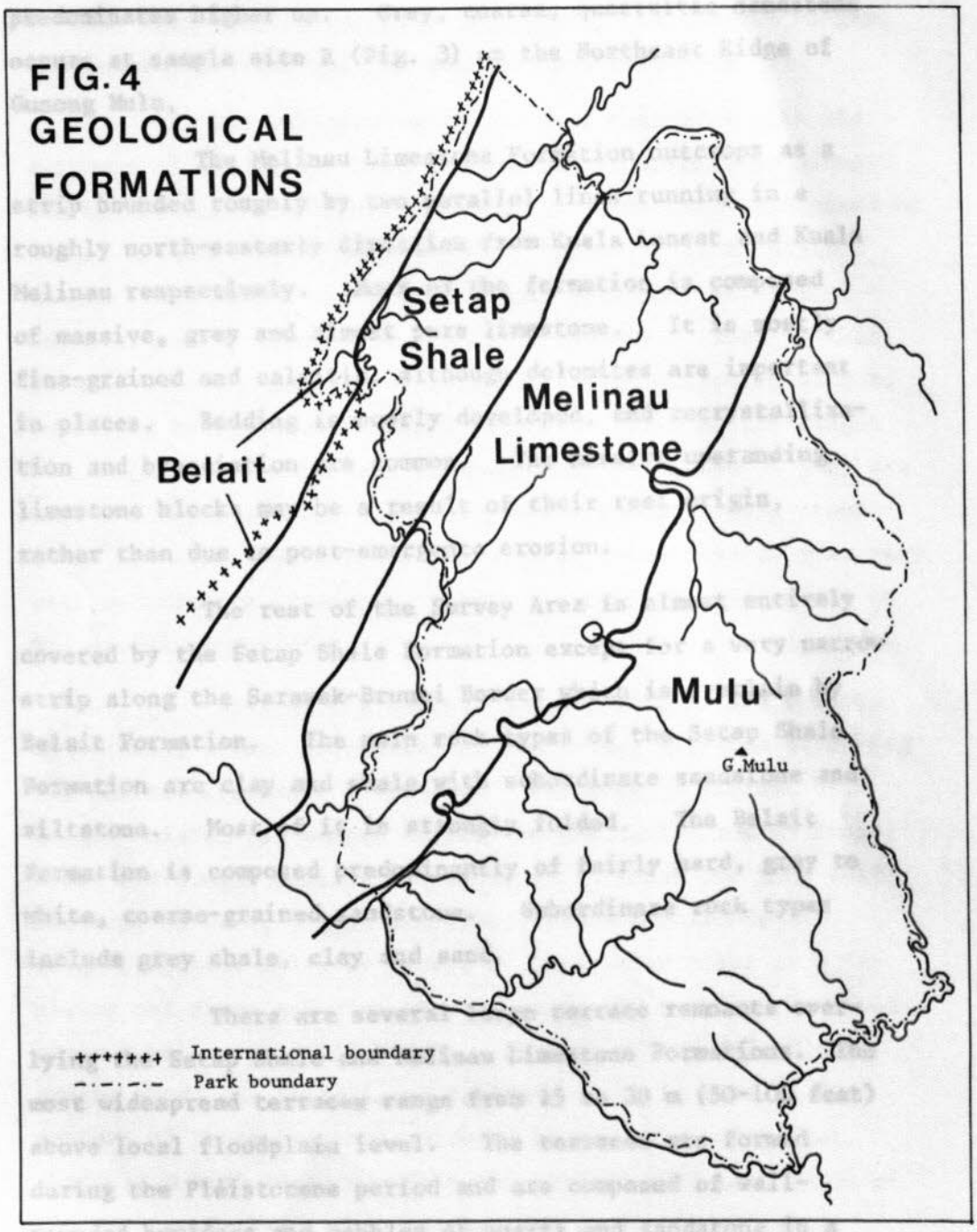


FIG. 4
GEOLOGICAL
FORMATIONS
Setap
Shale
Melinau
Limestone
Belait
Mulu
G.Mulu
International boundary
Park boundary

phyllite and slate is found. On the West Ridge of Gunong Mulu, shale is dominant at lower altitudes while slate predominates higher up. Grey, coarse, quartzitic sandstone occurs at sample site R (Fig. 3) on the Northeast Ridge of Gunong Mulu,

The Melinau Limestone Formation outcrops as a strip bounded roughly by two parallel lines running in a roughly north-easterly direction from Kuala Lansat and Kuala Melinau respectively. Most of the formation is composed of massive, grey and almost pure limestone. It is mostly fine-grained and calcitic, although dolomites are important in places. Bedding is poorly developed, and recrystallization and brecciation are common. The massive upstanding limestone blocks may be a result of their reef origin, rather than due to post-emergence erosion.

The rest of the Survey Area is almost entirely covered by the Setap Shale Formation except for a very narrow strip along the Sarawak-Brunei Border which is overlain by Belait Formation. The main rock types of the Setap Shale Formation are clay and shale with subordinate sandstone and siltstone. Most of it is strongly folded. The Belait Formation is composed predominantly of fairly hard, grey to white, coarse-grained sandstone. Subordinate rock types include grey shale, clay and sand.

There are several large terrace remnants overlying the Setap Shale and Melinau Limestone Formations. The most widespread terraces range from 15 to 30 m (50-100 feet) above local floodplain level. The terraces are formed during the Pleistocene period and are composed of well-rounded boulders and pebbles of quartz and sandstone in a matrix of sand or clayey sand. Recent alluvial and some peat deposits also occur along the major rivers and streams.

3.3. Topography

Topographically, the Survey Area can be roughly divided into three separate units, namely the Western Ridges, the Central Lowland and the Eastern Mountains (Fig. 5).

The upland area in the west coincides with the outcrops of the Setap Shale and the Belait Formations along the border between Sarawak and Brunei. The area is drained by Sungai Mentawai and Sungai Lutut. Narrow alluvial plain occurs along some stretches of Sungai Mentawai, but Sungai Lutut is mostly flanked by low hilly country. Most of this area is however composed of irregular, well-dissected ridges, separated by numerous V-shaped valleys. Most of the ridges are aligned in a northeast-southwesterly direction. They are narrow-crested and the flank slopes are steep to very steep ($>25^{o}$). The high terrace remnants in this area are also very well and steeply dissected, giving a very ridgy appearance on the aerial photographs.

Most of the Central Lowland area of the Park is an alluvial plain, consisting of Quaternary alluvium overlying the Melinau Limestone Formation. The area is drained by Sungai Medalam and Sungai Terikan in the north, and by Sungai Berar and Sungai Melinau in the south. There are many small outcrops of bare, jagged limestone within the floodplain. Large limestone hills or groups of hills also occur at a few places and these can rise steeply up to 200 m above the floodplain level, e.g. Bukit Berar. Several medium (15-30 m in height above the floodplain) terraces occur in area. The surface of these terraces tends to be slightly undulating. There is a high terrace within the lowland area north-west of the Melinau Gorge. This terrace top is dipping slightly towards the north-west, and becomes progressively more dissected

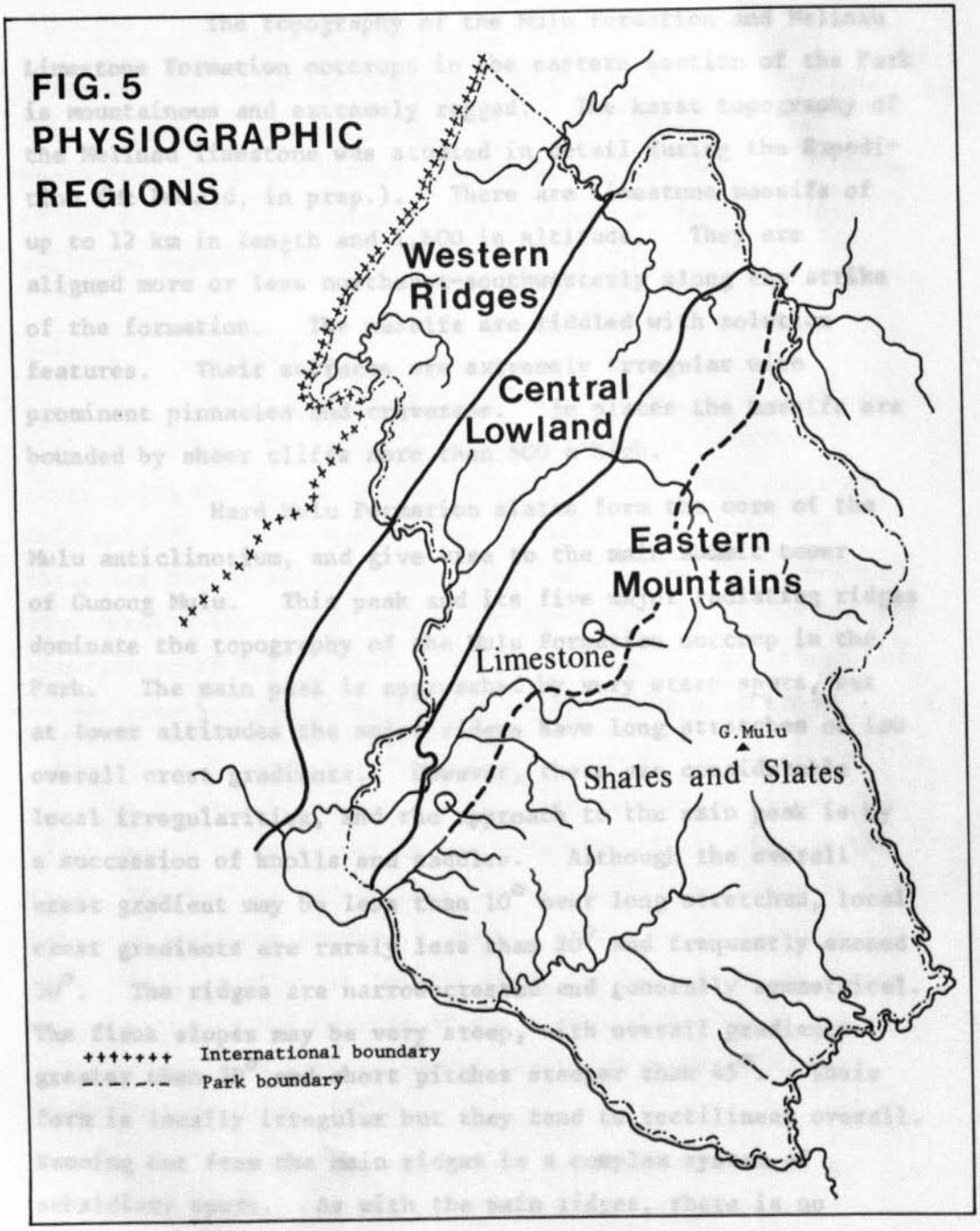


FIG. 5
PHYSIOGRAPHIC
REGIONS
Western
Ridges
Central
Lowland
Eastern
Mountains
Limestone
G.Mulu
Shales and Slates
International boundary
Park boundary

in that direction. Its margin can be precipitous, with slope angles up to 35° or more.

The topography of the Mulu Formation and Melinau Limestone Formation outcrops in the eastern section of the Park is mountainous and extremely rugged. The karst topography of the Melinau limestone was studied in detail during the Expedition (Mc Donald, in prep.). There are limestone massifs of up to 12 km in length and 1,600 in altitude. They are aligned more or less northeast-southwesterly along the strike of the formation. The massifs are riddled with solution features. Their surfaces are extremely irregular with prominent pinnacles and crevasses. In places the massifs are bounded by sheer cliffs more than 500 m high.

Hard Mulu Formation slates form the core of the Mulu anticlinorium, and give rise to the main summit tower of Gunong Mulu. This peak and its five major radiating ridges dominate the topography of the Mulu Formation outcrop in the Park. The main peak is approached by very steep spurs, but at lower altitudes the major ridges have long stretches of low overall crest gradients. However, there are considerable local irregularities, and the approach to the main peak is by a succession of knolls and saddles. Although the overall crest gradient may be less than 10° over long stretches, local crest gradients are rarely less than 20° and frequently exceed 30°. The ridges are narrow-crested and generally symmetrical. The flank slopes may be very steep, with overall gradients greater than 30° and short pitches steeper than 45°. Their form is locally irregular but they tend to rectilinear overall. Running out from the main ridges is a complex system of subsidiary spurs. As with the main ridges, there is no apparent lithological control of their alignment. The overall crest gradients of the spurs are generally steeper than on

the main ridges and usually exceed 25°. The flank slopes of the spurs are very steep and overall gradients exceed 30°.

As discussed elsewhere (Day, in prep.), mass movements are important geomorphic processes in this terrain. This is particularly noticeable on the main peak of Mulu, where many fresh and healed landslip scars can be seen. Many of the soils in this terrain are developed on fairly deep colluvial parent materials.

3.4. Vegetation

Mixed Dipterocarp Forest (MDF) covers a substantial area of the Park and is found on low hills, valley-ridge complexes of the Western Ridges and the lower parts of Mulu massif. Variations of MDF do occur in the Park and these are due to varying topography, soil types and temperature (See Section 7). Such variations are reflected in the species composition of the dominant tree canopy, the number of species in the canopy being reduced under unfavourable conditions.

At higher altitudes, temperature decreases and exposure to wind increases. This less favourable climate for plant growth is reflected in the reduction of the size of the trees, the smaller and thicker leaves and the reduction in the number of apparent storeys. Martin (1977) in considering the altitudinal zonation of forests along the West Ridge of Gunong Mulu designated the forests of the middle altitudes (1,000-1,750 m) as Lower Montane Forest (LMF) and above 1,750 m as Upper Montane Forest (UMF).

The LMF has many trees festooned with moss and consists of mainly members of the Fagaceae and Lauraceae families, while Myrtaceae and Ericaceae are the dominants of UMF. The UMF trees form only one storey and many species of

Nepenthaceae are found in the ground flora. In spite of high rainfall, the UMF shows xeromorphic features like dwarfing of trees, small leaf size, thick leaves and waxy cuticles.

Along the main limestone massif running north-easterly from Sungai Medalam to Sungai Melinau Paku, Limestone Forest occurs. On the scree slopes, the forest is quite open, dominated by few larger trees with sparse middle and lower storeys. Principal species are of *Eusideroxylon zwagerii* with common strangling figs. On cliffs, vegetation is sparse and scrubby and consists of mainly members of the Gesneriaceae family. High forest is found at lower altitudes which slowly changes into trees with lower stature and smaller girth at higher altitudes. On lower montane limestone where the limestone pinnacles are found, scrub moss forest appears.

Kerangas vegetation occurs on terraces and terrace remnants and is typified by relatively small, pole-like trees. Due to the sandy and highly-leached nature of these soils, growth of these trees to larger size is inhibited and the number of species that can grow in this habitat is also limited. Species of Nepenthaceae family also occur in this type of vegetation. On central portions of terraces where drainage is impeded and shallow peat has developed, Kerapa Forest is found. This grades to Peat Swamp Forests on the deeper terrace peats. Peat Swamp Forests are also sporadically distributed over the alluvial floodplains, and the principal species found are *Shorea albida*. This forest type is also characterized by the presence of pneumatophores in the form of knee roots.

The Alluvial Forest of principal species *Eusideroxylon melangangai* and *Pometia pinnata* are found on the

alluvial plains susceptible to periodic floodings. The riparian vegetation fringes the banks of rivers, with trees growing to large sizes forming a closed canopy over the river.

The vegetation and soil types are closely interrelated. The association between them is further discussed in Section 7.

4. SOILS OF THE AREA

The soil family forms the basic mapping unit in this study. Sixteen soil families comprising 20 dominant series are mapped in the Gunong Mulu National Park. Other families or series are represented in the Park, but they are not extensive and are therefore not discussed here. Table 1 illustrates the classification of the soils found in the Area according to the system of soil classification used in Sarawak (Lim, 1975). The descriptions and analytical data of some type profiles are presented in Appendix III. The following is a general description of the characteristics and occurrence of the soils.

4.1. Organic Soils

Organic or Peat Soils are locally defined as soils having 50 cm or more of organic soil materials (> 35% organic matter). Topogenic lowland peats have formed in fluvial basins or in any other places where permanent hydromorphic conditions prevent the decomposition of organic materials. Family classification of lowland Organic Soils is based on the thickness of the organic materials and the nature of mineral subsoil. In the Study Area, shallow peats of MUKAH Family and deep peats of ANDERSON Family are found. At higher elevation, climatogenic peats have developed as a result of

Table 1. Classification of Soils Mapped in the Area

Definitive Characteristics of Soil Group	Soil Group	Family	Family Characteristics	Dominant Series
1. Soils having >50 cm of organic soil materials (>35% organic matter)	Organic Soils	MUKAH	Organic layer 50-100 cm; clayey, non-sulphidic subsoil; lowland; topogenic	Mukah
		ANDERSON	Organic layer >100 cm; lowland; topogenic	Anderson
		MULU	Highland; climatogenic	Mulu
2. Very shallow (<50 cm) mineral soils over lithic or paralithic contact	Lithosols	MELUAN	Well drained	Meluan
3. Other soils having a spodic horizon	Podzols	MIRI	Bh horizon indurated	Miri
		BUSO	Bh horizon non-indurated	Buso
4. Other soils having a gleyed horizon within 50 cm	Gley Soils	BIJAT	Clayey; non sulphidic; lowland	Bijat, Mundai
		TUMAU	Highland; surface gleyed	Tumau
5. Other soils having formed from presently accreting alluvium	Alluvial Soils	SEDUAU	Clayey	Seduau, Paku
		BEMANG	Loamy	Bemang, Semilajau
6. Other soils having no horizon differentiation	Regosols	TIKA	Sandy; dominantly grey-white in colour	Kilong
		TUTOH	Skeletal particle-size class; colluvial	Tutoh
7. Other soils with weakly expressed argillic horizon; dominantly red-yellow in colour	Red-Yellow Podzolic Soils	MERIT	Clayey; non-calcareous	Merit
		BEKENU	Fine and coarse silty; non-calcareous	Bekenu
		NYALAU	Fine and coarse loamy; non-calcareous	Nyalau, Sabangan
8. Other soils with weakly expressed argillic horizon; dominantly grey-white in colour	Grey-White Podzolic Soils	SARATOK	Fine and coarse loamy; non-calcareous	Semeba

cooler temperature, persistent cloudiness and high humidity. These peats are classified as the MULU Family with no further subdivision into shallow and deep peats.

4.1.1. MUKAH and ANDERSON Families

All lowland topogenic peats are formed by accumulation of organic materials derived from a tree vegetation. The material consists of woody remains of trees in a watery matrix of dark brown to reddish brown, partly decomposed roots, leaves and wood. The surface peat horizons are usually fairly well decomposed, whereas subsurface materials are generally raw and fibric in nature. The water-table is commonly at or near the surface, and the groundwater is coloured dark brown by soluble organic materials.

ANDERSON Family soils (Appendix III, Profile2) have more than 100 cm of organic soil materials. In the Survey Area, this family consists purely of Anderson Series which are deep organic soils with more than 65 percent loss on ignition.

MUKAH Family soils have 50 to 100 cm of organic materials overlying non-sulphidic mineral soils which have more than 18 percent clay. The mineral subsoil is generally sandy clay loam to silty clay loam in texture. Where Organic Soils have developed on top of the terrace materials, it is not uncommon to find an old spodic (Bh) horizon beneath the organic layer. The dominant MUKAH soils found in the Area have more than 65 percent loss on ignition, and these are classified as Mukah Series.

Deep peats of ANDERSON Family generally have a high percentage of loss on ignition (more than 95 percent) whereas shallow peats of MUKAH Family contain relatively more

mineral matter. All lowland peats are characterized by a low pH of 4.0 or less. Total nitrogen is usually greater than 1 percent but a large proportion of this is present in stable lignoproteins and is therefore unavailable to plants. Total phosphorus and exchangeable cations determined on weight basis are generally moderately high compared to other soils in Sarawak but these values can be very misleading because of the low bulk density (0.1 g/cm^3 or less) of the soils. Organic Soils in Sarawak also have very low levels of available copper and other trace elements.

4.1.2. MULU Family (Appendix III, Profiles 37, 49, 53 and 54)

MULU Family soils are climatogenic Histosols developed on steep and apparently well-drained sites at high elevations. They are the dominant soils above 1,800 m on the main peak of Mulu.

The organic horizon of MULU soils have accumulated as a result of the cool climate and the perhumid conditions that prevail at high altitudes. It is formed largely from a mixture of woody and mossy materials in various stages of decomposition, and usually ranges from 60 to 150 cm in thickness. The peats are fibric at the surface and grade to hemic and sapric at depth. The main colours are dark brown and reddish brown in the upper fibric layers grading to very dark brown or black in the deeper hemic and sapric layers. The fibrous layers have an open, loose structure, but the darker, lower layers may be slightly more consolidated. The external drainage is good, but the peats are very wet as a result of the perhumid conditions and the spongy nature of the peats.

Beneath the peat, the mineral soil is often of the TUMAU Family type with a marked gleyed horizon overlying a

better drained and more brightly coloured subsoil. Soil textures tend to be heavy. Under some of the peats there is practically no mineral profile development and the peat directly overlies slightly weathered grey rock. The distribution of the peats is determined principally by the climate, so there may be deep montane peats over sandstone. However none were encountered and the underlying rocks were mostly slate.

The peats are oligotrophic with low pH values in the range of 3.0-4.3 and low levels of plant nutrients except available phosphorus (Table 2).

Table 2. Chemical Analyses of Surface Peats of Mulu Family

Analyses*	Mean	Standard Error	Range	No. of Samples
pH (H_2O)	3.5	0.4	3.0-4.3	12
N (%)	1.30	0.50	0.77-2.24	10
Ext. Ca (me/100g)	0.11	0.15	0.05-0.60	12
Ext. Mg (me/100g)	0.38	0.27	0.08-0.90	12
Ext. K (me/100g)	0.30	0.19	0.03-0.56	12
CEC (me/100g)	61.9	11.5	44.0-8.14	11
Base Sat. (%)	2.3	2.6	0.5-9.2	11
Av. P (ppm)	61	17	38-80	6
Av. Fe (ppm)	62	19	34-86	7
Av. Cu (ppm)	1.10	0.72	0.48-2.66	7

* For methods of analyses, refer to Appendix II.

Loss on ignition varies from 99.5 percent in some upper, fibric layers to about 50 percent in sapric materials close to the mineral contact. However, incorporation

and interlayering of colluvium (Profile 37) is not uncommon on such steep unstable landscape. Increase in the mineral content of these organic soils generally results in corresponding increases in trace elements and decreases in carbon: nitrogen ratio and available phosphorus. Fibre content also decreases with depth ranging from 60 percent in fibric layers to about 10 percent in sapric layers. Organic carbon contents may exceed 40 percent. Carbon:nitrogen ratios are generally high, decreasing from over 30 in upper fibric layers to about 20 in sapric layers. Total nitrogen is high in comparison with the mineral soils of Sarawak but a greater part of this may be present in stable lignoproteins and is therefore unavailable to plants. Mineralization of organic nitrogen is expected to be very slow because of the low pH, high carbon:nitrogen ratio and waterlogged conditions.

Contents of exchangeable bases are low and values for total exchangeable bases are generally less than 2 milliequivalents per 100 g soil. They are, however, generally higher than in the underlying mineral horizons, and in the mineral soils of TUMAU, TUTOH, MERIT and BEKENU Families downslope. The relatively high exchangeable base status is not reflected in the 'reserve' levels for these nutrients which are generally lower than in the mineral soils on the mountain. Although lower, the proportions of individual nutrients are similar to those in the mineral soils, with potassium always dominant followed consistently by magnesium.

The soils of MULU Family appear to have higher available phosphorus levels than any mineral soils in the Park, with values as high as 80 ppm. 'Reserve' levels of phosphorus in the peats range from 90 to 400 ppm and are generally higher than those in mineral soils derived from clastic sediments,

but are much less than those in the limestone-derived Lithosols of MELUAN Family.

The sponge-like nature of the peats is shown in the water retention data. On a weight basis, moisture contents ranged from 180 to 330 percent at 0.1 bar, and from 40 to 120 percent at 15 bars. This gives nominal available water capacities of 150-220 percent on a weight basis.

4.2. Lithosols

Lithosols are locally defined as very shallow soils which are limited in depth within 50 cm by solid bedrock. They are mainly found on very steep slopes where the very high rate of erosion prevents the development of a deeper profile. They are usually associated with limestone and igneous rocks. In the Park, Lithosols of MELUAN Family have been mapped.

4.2.1. MELUAN Family (Appendix III, Profiles 56 and 57)

Soils of this family are widespread on the Melinau limestones. They also occur in small patches on the Mulu Formation.

In the limestone area, much of the surface is completely bare rock. The MELUAN soils in the intervening crevices mostly consist of a mixture of mull humus and coarse fragments of limestone. Walls (1966) has classified similar soils found on the limestone outcrops at Subis as the KAPOR Family of Calcic Organic Soil Group. In places there are sufficient ferruginous impurities in the limestone to give rise to small patches of very shallow red or reddish brown clay loam, which have well developed, fine blocky structures.

The limestone-derived reddish clays are chemically very different from any other mineral soils in the Park. They are much less leached and acid, with pH in water ranging from 5.8 to 7.2.

Loss on ignition values are high, ranging from 26 to 38 percent. This is partly due to fragments of limestone gravel, but organic matter contents are also high. Organic carbon levels range from 7 to 11 percent in the topsoils, and are about 3.5 percent in the shallow subsoils. This organic matter is mineralising rapidly and carbon:nitrogen ratios are generally less than 10. This gives very high total nitrogen levels - almost 3 percent in the topsoil and more than 1 percent in the subsoil.

Because of the neutral reaction, the cation exchange capacity (CEC) values of 19-30 milliequivalents per 100 g soil at pH 7 are probably close to the field values. This capacity is largely satisfied with bases, with base saturation percentages of 40-100 percent. As is to be expected on such parent material, calcium is by far the predominant exchangeable cation.

'Reserve' levels for potassium are low and only moderate for magnesium. The levels for calcium are also surprisingly low. The HCl-extractable levels of Group III oxides are very high, accounting for about half of the total fine earth by weight. The high levels of these sesquioxides prevented satisfactory clay dispersion and made the results of granulometric analysis problematical. Much of the iron present is also dithionite-citrate extractable, indicating a high degree of division and activity. However very little of this iron registered as available in the trace element analysis.

Available phosphorus levels, at less than 10 ppm,

are low and similar to those in other mineral soils. The 'reserve' levels, however, are in the region of 1,000 ppm, and by far the highest of any soils in the Park. It is suspected that much of this phosphorus is associated with the sesquioxides. Little if any of it is likely to be involved in even the long term nutrient cycles of the Limestone Forest.

4.3. Podzols

Podzols are mineral soils having a spodic horizon within 1.1 m of the surface. A spodic horizon is a diagnostic, subsurface horizon where eluviated organic matter and aluminium, with or without iron, has accumulated. The genesis of podzols in Sarawak is related mainly to the kind of parent material and topography (Andriesse, 1969). They are generally associated with chemically almost inert and coarse-textured parent materials, and with relatively flat topography to prevent rapid lateral drainage.

Podzols of MIRI and BUSO Families are mapped in the Park. These are Humus Podzols where the spodic horizon is mainly due to the accumulation of humus materials (Bh horizon).

4.3.1. BUSO and MIRI Families

The soils of these two families are formed from coarse-textured, quartzitic terrace materials. They are associated with flat to gently undulating topography and very poor vegetation of the Kerangas Forest.

Typically, the soils have a mor litter layer of varying thickness (3-10 cm). Where drainage is impeded a peaty surface is present. The thin A1 horizon ranging from 5 to 10 cm thick is usually consisted of light greyish brown,

friable, weakly structured fine sandy loams. The bleached, single grained A2 horizon is sandy in texture, and may be fairly compact. The brown to dark reddish brown Bh horizon usually occurs at the depth of 40 - 60 cm. The Bh horizon is usually underlain by yellow or pale brown sandy loams to sandy clay loam. In some cases (e.g. Kerangas Forest Ecological Plot), the Bh horizon directly overlies unweathered sandstone pebbles and boulders which may also be coated with black, humus materials.

MIRI Family differs from BUSO Family (Appendix III, Profiles 5 and 71) in that it has a strongly cemented humus pan. Secondary differences resulting from the induration of the Bh horizon include shallower rooting depth, poorer drainage and thicker litter layer which may grade into a peaty surface (histic epipedon). It is not uncommon to find a perched water-table in MIRI soils. Where such hydromorphic conditions prevail, Organic Soils have developed. In the Park, the soils of both MIRI and BUSO Families have developed from terrace materials and are therefore classified as Miri and Buso Series respectively. Silantek Series of BUSO Family formed from sandstone in situ weathering has been encountered on the Northeast Ridge of Gunong Mulu. However, Silantek soils are not widespread and mappable in the Park, and are therefore not discussed any further.

The soils of both MIRI and BUSO Families are very low in levels of available nutrients and cation exchange capacity (CEC). The CEC mostly resides in the organic matter and exchangeable bases range from 0.3 in the bleached, sterile A2 horizon to about 7.0 milliequivalents per 100 g soil in the A1 horizon. Most of the available and 'reserve' nutrients are found in the A1 horizon. Only the level of 'reserve' potassium seems to increase down the profile.

As aforementioned, the spodic horizon in the soils of MIRI and BUSO Families is mainly due to the eluviation and illuviation of organic matter. However, amorphous iron oxides have also been leached from the surface and accumulated usually below the horizon of maximum humus illuviation (Appendix III, Profile 5).

4.4. Gley Soils

Gley Soils are mineral soils in which a gleyed horizon is found within 50 cm of the base of an O horizon. A gleyed horizon is one in which the greenish-grey, grey or bluish matrix colours denote that reduction is dominant over oxidation. Gley Soils occur in places where the drainage is poor or very poor. The water-table is generally at or close to the surface. The majority of these soils is associated with level to gently sloping topography and Alluvial Forest.

In the Survey Area, two families of Gley Soils have been identified and mapped. In the lowland alluvial floodplain, BIJAT Family occurs. At elevations above 1,000 m where the perhumid conditions and the spongy surface peat layer have caused intense surface gleying, TUMAU Family is found.

4.4.1. BIJAT Family

BIJAT Family soils are found on relatively flat alluvial floodplains. The soils are developed from recent riverine alluvium.

BIJAT Family soils are heavy in texture, consisting usually of dark greyish brown to light grey silty clay loam to silty clay. They are poorly to very poorly drained with a water-table close to the surface. BIJAT soils are

susceptible to flooding. Where the soils are very poorly drained, a peaty surface of less than 50 cm is present. The A1 horizon may be crumbly to subangular blocky in structure, whereas the subsoil is massive in structure and mostly wet, sticky and plastic in consistence.

Two series of BIJAT Family have been recognised in the Study Area, namely Bijat and Mundai Series. Within the Park, Mundai is the dominant series, but Bijat Series becomes more abundant along Sungai Tutoh below Kuala Melinau. The majority of the BIJAT Family soils in Sarawak however belongs to the Bijat Series which has developed from riverine alluvium derived from non-calcareous sedimentary rocks. Mundai Series differs essentially from Bijat Series in that it is higher in pH and base saturation as a result of the limestone influence in the parent material and the flood waters. On comparison with upland soils, BIJAT Family soils generally have a higher level of available and 'reserve' phosphorus and base saturation.

4.4.2. TUMAU Family (Appendix III, Profiles 45 and 46)

Soils of this family are widespread at intermediate and higher altitudes on the Mulu Formation. The profile morphology is similar to that of the Peaty Gley Podzols of cool wet temperate regions, such as Scotland. These soils are widespread on the slopes of Gunong Mulu. At intermediate altitudes they are associated with the soils of TUTOH Family. Higher up the mountain they are intermixed with the deeper Organic Soils of MULU Family.

The surface layer is peat of 5-50 cm thickness. In the thicker peats, a distinction is possible between fibric upper layers and hemic/sapric peat beneath. The upper mineral

horizon is strongly gleyed. Matrix colours are white, light grey, or very pale yellow. There may be prominent rust mottling along old root channels. This horizon is generally very wet, and of a very plastic and sticky consistence. Structures tend to be massive, although a weak medium subangular blocky structure may sometimes be apparent.

The lower boundary of this horizon is generally sharp and slightly wavy. It is often marked by a thin iron pan. This is reddish or dark brown, often with darker colours on the upper surface. It is generally wavy in shape, and may pass through rock fragments, cutting right across the slaty cleavage or bedding planes. The pan is usually thinner, less continuous and less indurated than those found in the Peaty Gley Podzols of temperate regions.

Beneath the sharp boundary, with or without an iron pan, the subsoil is well drained. Matrix colours are red, yellowish red, reddish yellow or strong brown. There may be a prominent mottling, but this is bright coloured and due to incomplete weathering rather than hydromorphism. In some soils, there is marked dark brown organic staining on the blocky ped faces. In the deeper profiles, this horizon has a moderately developed coarse or medium blocky structure. However in many soils, there are many rock fragments in this horizon which obscure the soil structure. This horizon is less wet, plastic and sticky than the overlying gleyed horizon.

The parent materials of these soils in the Park are largely colluvial. The stone content therefore tends to be constant or vary erratically rather than increase steadily with depth. The depth of the colluvial material

may exceed 1.5 m in place, but generally gives way to in situ rock within a metre. The underlying rock tends to be less weathered than at lower altitudes.

In the Park, these soils are mostly heavy-textured, often with high silt contents. Fine earth textures range from silty loam to clay. Clay content increases with depth in some profiles. However these are not generally apparent in the field because of the higher moisture content and plasticity of the upper gleyed horizon.

As is to be expected from their morphology and their position on the midslopes of the mountain, these soils are chemically intermediate between the Organic Soils of MULU Family and the colluvial soils of TUTOH Family.

The surface peat layers are as acid and leached, with pH values in the range 3.5-4.5. In the shallower peats, losses on ignition are in the range 40-60 percent, but they rise to 95 percent in the fibric surface layers of the deep peats. The organic matter is not highly humified, with carbon:nitrogen ratios greater than 20.

Exchangeable base status is low with base saturation percentages of less than 5 percent, although these values are of doubtful validity as the CEC is measured at pH 7. Raising the pH so far above the field level will cause a great increase of exchange sites. Sodium is a minor exchangeable cation, and potassium and magnesium predominate. These are also the dominant 'reserve' cations, and calcium is present at very low levels.

As in MULU Family, 'reserve' phosphorus levels are intermediate. The available phosphorus levels are consistently relatively high and include the highest values recorded in the Park.

The subsoil mineral horizons are chemically similar to TUTOH Family. They are acid, with pH values in the range 4.2-5.0. Exchangeable base status is low. The importance of micaceous minerals in the parent material is shown by the moderate CEC levels (in the range of 10-20 milliequivalents per 100 g soil), and the predominance of potassium in the 'reserve' nutrients. 'Reserve' magnesium levels are only moderate, generally less than 1,000 ppm. Calcium is present at very low levels.

The main difference from TUTOH Family is in the higher organic matter levels, with organic carbon values in the mineral subsoil horizons in the 1-4 percent range. Unlike the overlying peat this is well humified, with carbon: nitrogen ratios less than 12. This organic matter is thought to be illuviated from the overlying peat. It is noticeable that organic matter levels are higher in the gleyed horizons than in the subjacent well-drained horizons, despite the marked humus staining on ped faces in the latter.

4.5. Alluvial Soils

Alluvial Soils are defined as those developed from presently accreting alluvial deposits and having no diagnostic horizon except for a well-developed A1 horizon. They are assoicated with Alluvial Forest and level to gently undulating ($< 6^{o}$) floodplain topography. The soils may be well, moderately well and imperfectly drained; poorly and very poorly drained members are classified under Gley Soils. Textures cover the whole range from sands to clay and structures are usually weakly developed. The fertility shows much variation depending on the texture and the origin of

the deposit. All Alluvial Soils are subject to seasonal flooding. In some cases, layering of the alluvium laid down by successive floods can be clearly seen within the profile.

Four families in this group of soils have been identified, but only two of them have been mapped in the area. They are BEMANG and SEDUAU Families.

4.5.1. BEMANG Family (Appendix III, Profiles 4 and 9)

BEMANG Family soils have a loamy particle-size class. They are moderately well to well drained, and generally occur along the upper reaches of streams and rivers. The soils usually have thin litter layers at the surface. The A1 horizon is generally a well-rooted, dark brown to brown loam with very friable crumb structure. The deep yellowish brown A3 horizon ranges in texture from loamy sand to sandy clay loam, and structure is weakly developed. Faint mottles commonly occur in the lower portions of some moderately well-drained members; otherwise the colour is rather uniform.

In the Survey Area, the BEMANG Family consists mainly of Bemang and Semilajau Series which are differentiated on the basis of particle-size class. Bemang Series is fine loamy to fine silty, whereas Semilajau Series has a coarse loamy particle-size class. Soils of Bemang Series occur more extensively and Semilajau soils are usually found on the levees close to the streams and rivers.

Exchangeable potassium and total nitrogen are moderately high in the top few centimetres of BEMANG Family soils and decrease sharply to low levels in the subsoil. Irregular decrease of organic carbon content with depth is

seldom encountered in these well-drained Alluvial Soils. Available phosphorus is low in the top soil and is almost non-existent in the lower horizons. 'Reserve' phosphorus is also low and tends to decrease with depth.

Due to the limestone influence, soils of Bemang Series found in the central lowland region of the Park are chemically different from similar soils in the Mentawai area and other parts of Sarawak. The pH of the former soils is medium to high, approaching 6.0 in some samples and levels of exchangeable calcium and base saturation are high.

Being coarser in texture, soils of Semilajau Series are lower in cation exchange and moisture-holding capacity than soils of Bemang Series. They are also slightly more acidic in nature with pH values ranging from 4.0-4.5 even in areas where limestone influence is present. This could be due to the higher rate of leaching in these highly permeable soils.

4.5.2. SEDUAU Family

SEDUAU Family soils have a clayey particle-size class. They occur in areas of deposition by less turbulent waters such as backswamps and low level floodplains along the lower stretches of rivers. The soils are usually moderately well to imperfectly drained, and are commonly found in association with the poorly drained soils of the BIJAT Family. The family is characterized by generally deep, yellowish brown to yellow coloured clay loam to heavy clay in which mottling and gleization is not uncommon in the lower subsoil. Surface litter is usually thin and the A1 horizon is well-rooted, dark brown to brown, friable and crumbly. Beneath the A1 horizon, the structure is generally weak to moderate medium subangular blocky grading to massive with depth.

Two series in SEDUAU Family soils are identified and mapped in the Area. Seduau Series occurs in the lower stretch of Sungai Mentawai and along Sungai Tutoh below Kuala Melinau, and the soils are derived from riverine alluvium of non-calcareous sedimentary rocks. Paku Series is found in the central lowland region of the Park. Due to the limestone influence, soils of Paku Series are higher in pH and base saturation than Seduau Series.

4.6. Regosols

Regosols are soils formed from unconsolidated materials, exclusive of presently accreting alluvial deposits, having little or no horizon differentiation. The lack of diagnostic horizons is mainly due to immaturity and/or the uniform, coarse-textured parent materials which preclude much pedogenic development. In some cases (e.g. Giant Podzols) however, soils are classified under Regosols not because of the lack of diagnostic horizon but because the diagnostic horizon lies outside the arbitrarily fixed control section.

Two families of Regosols, namely TIKA and TUTOH, have been mapped in the Park.

4.6.1. TIKA Family

In the Park the soils of this family are found on well-dissected terraces and terrace remnants where the topography is not conducive to the formation of Humus Podzols. They are classified under Kilong Series and are mapped in association with BUSO and SARATOK Families.

The parent material of Kilong Series is alluvial in origin and consists mainly of unconsolidated deposits of quartzitic sand and sandstone boulders and pebbles. The

uniform, coarse-textured profile shows no horizon differentiation except for a thin, dark brown A1 horizon. The subsoil consists of white to light greyish sands to loamy sands, and gravels are usually present at the lower part of the solum. The soils are excessively drained and leached. The moisture-holding capacity is very low and the nutrient status is also very poor. They can therefore only support Kerangas type of forest.

4.6.2. TUTOH Family (Appendix III, Profile 19)

TUTOH Family soils are derived from recent colluvial deposits of sedimentary rock material. The youthfullness of the deposits is evidenced by the occurrence of many to abundant, randomly oriented stone fragments throughout the solum, with little apparent pedogenic sorting yet effective. Because of the current or recent mobility of the parent materials, profile development is rudimentary, and textural and structural horizonations are only weakly apparent.

A typical low altitude profile of TUTOH Family has a thin (5-20 cm) organically darkened mineral topsoil under a more or less continuous, thin (0-4 cm) litter layer. The subsoil shows no marked horizonation and a mixture of rock and interstitial fine earth continues down to the bedrock, which is more or less weathered. The colluvial deposits in the Park are thicker than in much of Sarawak, often exceeding 1.5 m in depth.

The soils of this family in the Park are predominantly heavy textured. Subsoil fine earth textures range from silty clay loam to clay. The stones are mostly fine grained, with shale, slate and siltstone predominating.

Colours of the subsoil interstitial fine earth material are variable. In well-drained soils on the more ferruginous parent materials, the colours may be yellowish red, and relatively unmottled. Other soils are quite yellowish possibly due to low iron contents in the parent materials. Other pale coloured soils are also slightly mottled, and they appear to be imperfectly drained. In some subsoils, there are weak and discontinuous patches of brown humic staining on vertical ped faces.

At higher altitudes (700-1,300 m), the soils of this family in the Park show some characteristics of the TUMAU Family. The litter layers tend to become more continuous and thicker, reaching 25 cm depth in places. The profiles with these slightly peaty surface layers often show rudimentary surface gleying, with prominent gley and rust mottling in the upper 10-15 cm of the mineral profile. The tendency to humic staining of the vertical faces of the subsoil peds also becomes more pronounced.

These soils are widespread on the lower and middle slopes of the Mulu Formation outcrop. They also occur on very steep slopes of the Setap Shale Formation. At low altitudes, these soils are intimately intermingled with the more developed Red-Yellow Podzolic Soils of MERIT and BEKENU Families. At intermediate altitudes they are associated with the soils of TUMAU Family.

Chemically the soils of TUTOH Family are somewhat similar to the Red-Yellow Podzolic Soils, except that there tends to be less systematic variation with depth. The soils are well drained and highly leached. The soil pH is in the 4.5-5.0 range throughout the profile. Base saturation is usually less than 10 percent. Unlike most fine-

textured Red-Yellow Podzolic Soils, these soils do not have exchangeable potassium or magnesium as the most important basic cations. Calcium is often the main exchangeable basic cation.

'Reserve' levels of the main nutrients are very similar to those in the Red-Yellow Podzolic Soils, with 'reserve' phosphorus less than 100 ppm in the subsoils, less than 100 ppm 'reserve' calcium, about 1,000-2,500 ppm 'reserve' magnesium and 3,000-8,000 ppm 'reserve' potassium.

Despite their immaturity these soils may have quite high organic matter contents. This is particularly true at the upper end of their altitudinal range, where topsoil organic carbon contents may be as high as 5 percent. This organic matter is not very humified, with carbon:nitrogen ratios of 15-20, and represents the gradation towards the peaty surface layers of the TUMAU Family soils upslope. At lower altitudes, organic matter contents are lower, but the material is better humified with carbon:nitrogen ratios of less than 12. Subsoil organic matter contents are usually quite low, with organic carbon values below 1 percent.

The main distinction from the Red-Yellow POdzolic Soils is in the lack of textural horizonation. Clay contents are usually about 30 percent and vary only slightly and erratically with depth. Silt and fine sand contents are fairly high. Although these give silty field textures, the levels are not usually sufficient to take the laboratory textures out of the clay loam class.

4.7. Red-Yellow Podzolic Soils

The Red-Yellow Podzolic Soils are residual or non-accreting soils developed on a variety of parent materials

and over a wide range of topography. Most of these soils show a gradual increase in clay content with depth. Clay cutans may be found on ped faces and along old root channels, but they are usually very faint and rare. The textures vary from sandy loams to clay, and the structure may be crumbly to subangular blocky depending on the texture. Internal drainage ranges from slow to rapid. Depth is also variable and shallow phases are usually found on steep slopes.

Classification of Red-Yellow Podzolic Soils at family level is based on the parent material and the texture. Only three families consisting dominantly of four series are mapped in the Survey Area; they are MERIT, BEKENU and NYALAU Families.

4.7.1. MERIT Family (Appendix III, Profile 7 and 27)

The MERIT Family soils are the most widely distributed soils in the Survey Area. They form the dominant soil type on the Setap Shale Formation in the Western Ridges and on the lower montane slopes of the Mulu Formation. They are derived mainly from argillaceous sedimentary rocks like shales and mudstones and are usually covered with high stature Mixed Dipterocarp Forest.

These soils have a clayey particle-size class, i.e. more than 35 percent clay content. In the Area, the textures usually change from sandy clay loam to clay loam in the A2 horizon to clay loam or clay in the B horizon. The clay content of the B horizon ranges from 35 to 45 percent, and the silt plus very fine sand content is generally greater than 50 percent. Clay cutans can usually be observed in the B horizon but they are normally patchy and discontinuous.

The structure is usually moderate subangular blocky, but some MERIT soils with heavier texture can be quite massive and compact, particularly in the lower subsoil. Colours of the subsoil materials are variable, and are dependent on the parent materials and drainage. In the Park, they usually range from brownish yellow to reddish yellow. Soil drainage ranges from good to imperfect. The soil is usually quite deep, the top 75 cm being relatively stone-free even on fairly steep slopes.

The dominant soils are those of Merit Series. Classification of MERIT Family soils at series level is based mainly on the colour of the soil. Soils of Merit Series have a matrix hue of 10YR or yellower in some part of the control section above a depth of 50 cm. Some MERIT soils in Jakar Series were also seen in the Altitudinal Zonation Plots. Jakar Series has a matrix hue redder than 10YR within 50 cm.

A few profiles particularly in the Mixed Dipterocarp Forest (MDF) plot were intensively sampled and analysed. The results (Table 3) show that, in many ways, the soils of the plot are chemically typical of fine-textured Red-Yellow Podzolic Soils in Sarawak.

Organic carbon content decreases very sharply from nearly 3 percent in the A1 horizon to below 0.5 percent in the B2 horizon. The organic matter is fairly well mineralised, with carbon:nitrogen ratios of less than 15 in topsoils, and often below 10 in subsoils. Total nitrogen contents are usually low, but may reach 0.2 percent in some topsoils.

The soils are acid and highly leached. Values for pH (water) range from 4.0 to 4.4 in topsoils and from

Table 3. Chemical Analyses of Merit Series

Analyses*	A1 Horizon			B2 Horizon		
	Mean	S.E.	No. of Samples	Mean	S.E.	No. of Samples
Clay (%)	30.6	4.8	4	36.7	2.1	8
pH (H_2O)	4.5	0.3	4	4.5	0.3	8
C (%)	2.87	0.90	3	0.28	0.11	7
N (%)	0.22	0.04	3	0.04	0.01	8
C:N	13	2	3	7	1	9
Ext. Ca(me/100g)	0.50	0.03	3	0.52	0.02	7
Ext. Mg(me/100g)	0.08	0.01	2	0.04	0.03	7
Ext. K (me/100g)	0.06	0.04	3	0.06	0.02	7
CEC (me/100g)	14.93	2.16	3	7.93	1.50	6
Base Sat. (%)	4.5	0.8	3	9.1	2.5	5
Av. P (ppm)	4	5	3	1	0	7
'Reserve' Mg (ppm)	1159	282	4	1863	323	8
'Reserve' K (ppm)	3004	781	4	4652	1042	7
'Reserve' P (ppm)	114	6	4	66	21	8
P Retention (%)	63.1	9.1	4	44.6	6.3	7
Group III oxides (%)	-	-	-	11.54	2.46	8
Free Fe_2O_3 (%)	-	-	-	3.08	0.65	8

* Refer to Appendix II for methods of analyses.

4.4 to 4.8 in subsoils. Cation exchange capacities range from 6 to 12 milliequivalents per 100 g soil in the subsoil horizons, indicating a significant proportion of illitic clay minerals. Because of their organic matter, the CEC of topsoils

are considerably greater and may reach 25 milliequivalents per 100 g soil. Exchangeable bases always total less than 1 milliequivalent per 100 g soil and base saturations are very low, often less than 10 percent in subsoils. Calcium is the main exchangeable base but aluminium is clearly the dominant exchangeable cation.

Phosphorus levels are low, with less than 1 ppm of available phosphorus in most subsoils, although up to 7 ppm may be found in topsoils. Within the Survey Area, it was noted that MERIT soils formed from the shales of Setap Shale Formation are higher in 'reserve' phosphorus and Group III oxides (mainly iron and aluminium oxides) than those developed from the shales and siltstones of Mulu Formation. 'Reserve' phosphorus levels of MERIT soils in the MDF plot are particularly low, usually well below 100 ppm, even in topsoils. These levels are lower than is normal for fine-textured Red-Yellow Podzolic Soils in Sarawak. The low phosphorus levels may account for the anomalous arenaceous rock floristic composition of the forest on the plot, as soil phosphorus status is an influential determinant of floristic variation in the Sarawak MDF (Ashton, 1973; Baillie, 1978).

Like must residual soils in Sarawak, most of available plant nutrients in Merit soils are held within the generally thin A1 horizon of a few centimetres thick. This has an important bearing on the management of these soils whereby all efforts must be exercised to conserve the topsoils.

4.7.2. BEKENU Family (Appendix III, Profile 31 and 34)

BEKENU Family is composed of silty textured soils belonging to the Red-Yellow Podzolic Group. The soils are derived from very fine sandstone, sandy shales or

siltstones. They seldom occupy large areas in the Park and are commonly found in association with MERIT soils in the valley-ridge complex of the Mulu and Setap Shale Formations.

The BEKENU soils mapped in the Study Area belong exclusively to the Bekenu Series. Bekenu Series soils are residual soils having a hue of 10YR or 2.5Y in some part of the control section above a depth of 50 cm. The textures usually vary from very fine sandy clay loam or silt loam in the top 50 cm to clay loam or silty clay loam in the subsoil. The top soil is friable and crumbly whereas the B horizon is slightly firm and is subangular blocky in structure. As in MERIT Family soils, patchy and discontinuous argillan can usually be found in the B horizon. The colours of the subsoil usually range from brownish yellow to yellow. Bekenu soils are usually of moderate to good drainage.

The pooled results of the chemical analyses of Bekenu soils are shown in Table 4. All the samples analysed were sampled along the main Gunong Mulu path. Most of the chemical characteristics of Bekenu Series are comparable to those of Merit soils except that Bekenu soils are significantly lower in exchangeable calcium in the A1 horizon and lower in 'reserve' phosphorus, phosphorus retention and free iron oxides in the B2 horizon. Bekenu soils also seem to have higher carbon, nitrogen and available and 'reserve' phosphorus contents in the A1 horizon than Merit soils though differences are not statistically significant due to the large standard deviations. These could be explained by the fact that the type profiles of Bekenu soils were all sampled at a higher altitude than those of Merit soils. The change in the

microclimate probably accounts for a higher organic matter content in these soils thus leading to higher levels of carbon and nitrogen. Since organic phosphorus accounts for a large proportion of total phosphorus in the residual soils of Sarawak (Anon, 1964), the higher organic matter content of these Bekenu soils at higher altitudes therefore also results in a better phosphorus status.

Table 4. Chemical Analyses of Bekenu Series

Analyses*	A1 Horizon			B2 Horizon		
	Mean	S.E.	No. of Samples	Mean	S.E.	No. of Samples
Clay (%)	28.8	5.3	6	32.8	1.8	11
pH (H_2O)	4.0	0.3	6	4.7	0.2	8
C (%)	5.48	2.15	3	0.25	0.11	5
N (%)	0.38	0.15	3	0.03	0.01	5
C:N	14	2	3	9	3	5
Ext. Ca(me/100g)	0.21	0.01	3	0.47	0.05	4
Ext. Mg(me/100g)	-	-	-	0.04	0.02	4
Ext. K (me/100g)	-	-	-	0.12	0.04	5
CEC (me/100g)	15.93	4.74	3	6.28	0.95	5
Base Sat. (%)	4.3	1.6	3	10.5	3.4	5
'Reserve' Mg(ppm)	1224	245	3	1624	337	5
'Reserve' K (ppm)	2925	642	3	5051	1246	5
'Reserve' P (ppm)	186	90	3	26	15	4
P Retention (%)	61.6	14.9	3	35.6	6.5	5
Av. P (ppm)	20	14	3	1	0	5
Group III oxides(%)	-	-	-	10.24	1.03	5
Free Fe_2O_3 (%)	-	-	-	2.28	0.24	4

* Refer to Appendix II for methods of analyses.

4.7.3. NYALAU Family (Appendix III, Profiles 8 and 10)

Soils of the NYALAU Family have a coarse to fine loamy particle-size class. They are derived from medium to coarse-grained sandstones. There are two series of NYALAU Family soils mapped in the Park. Nyalau Series are formed by the in situ weathering of arenaceous sedimentary materials and have a hue of 10YR or 2.5Y in the top 50 cm. The soils of Sabangan Series are developed on presently non-accreting alluvium and generally have matrix colours throughout the control section of 10YR or yellower.

In the Survey Area, Nyalau Series soils are the dominant soils found on the Belait Geologic Formation, whereas the Sabangan soils are generally associated as a subordinate member with soils of SARATOK Family in Mapping Unit 6 on some of the well-dissected terrace remnants. Some Nyalau Series soils also occur sporadically on the Setap Shale Formation.

Surface litter of NYALAU Family soils is usually a few centimetres thick, overlying a distinct dark yellowish brown to dark greyish brown A1 horizon. The textures usually range from sandy loams in A1 horizon to sandy clay loam in the B horizon which is generally yellow to yellowish brown in colour. The structure is very weakly developed and the soil is friable throughout the control section. NYALAU Family soils are generally well drained. Where the particle-size class is fine loamy (Profile No.10), soils of NYALAU Family are fairly similar to MERIT Family soils chemically except that levels of 'reserve' magnesium and potassium and exchangeable calcium are slightly lower in the former. However, NYALAU soils with coarse loamy particle-size class (Profile No.8) do show marked differences on comparison with MERIT soils. In such cases, soils of NYALAU Family are lower in organic carbon, total

nitrogen, exchangeable bases, cation exchange capacity, available and 'reserve' phosphorus, phosphorus retention, and sesquioxides. Being coarser in texture, NYALAU soils are also more erodable and lower in moisture-holding capacity than MERIT soils.

4.8. Grey-White Podzolic Soils

Grey-White Podzolic Soils are also residual or non-accreting soils with weak podzolic features. The soil profiles show gradual increase of clay content with depth and faint clay cutans have been identified. The major difference between these soils and Red-Yellow Podzolic Soils is that the matrix colours are much paler. The hues of the B horizon of Grey-White Podzolic Soils are yellower than 2.5Y and/or the chromas are 4 or less and the values are 6 or more. The pale colours are due to a low iron content resulting from the leaching of iron and/or the inherent low iron content of the parent material. These soils are usually found on low hilly terrain. Textures range from sandy loams to heavy clay. Structures are generally poorly developed.

Only SARATOK Family of Grey-White Podzolic Soils has been mapped in the Park. KERAIT Family soils also occur sporadically on the upland areas in the Park. These are Grey-White Podzolic Soils of clayey particle-size class. However, KERAIT Family soils are not widespread and mappable, and are therefore not discussed any further.

4.8.1. SARATOK Family

SARATOK Family comprises Grey-White Podzolic Soils of coarse loamy or fine loamy particle-size class. In the Survey Area, SARATOK soils are found on steeper, well-

dissected terrace remnants where the lateral drainage has prevented the formation of Humus Podzols. They are mapped in association with TIKA and BUSO Families or with NYALAU Family. The dominant series is therefore the Semeba Series which consists of SARATOK soils developed on presently non-accreting alluvial materials. They are usually associated with poor Mixed Dipterocarp Forest.

The surface of the soils is fairly well littered. The thin A1 horizon usually consists of dark greyish brown sandy loams to loam which are of friable consistence, and of crumb structure. Subsoils are characterized by very pale brown to very pale yellow colours. Textures generally range from sandy loams to sandy clay loam, and the structures tend to be weak subangular blocky. In places, there is a weak indication of dark-coloured humus accumulation in cracks or on ped faces. Drainage is generally good. Well-rounded gravels of sandstone are usually found at a depth of 50-100 cm. Chemical analyses of Semeba soils have not been made but the vegetation and analytical results of similar soils from other parts of Sarawak indicate that these soils are of low inherent fertility.

5. SOIL DISTRIBUTION AND MAPPING

Table 5 shows the areal extent and the percentage of the various mapping units in the Survey Area.

In much of Sarawak. topography and parent material are the main differential soil forming factors. In most localities, variations in the atmospheric climate are not of major importance. At Gunong Mulu, however, there is a sufficient altitudinal range for climatic differences to play a major role in soil formation. There are two major

altitudinal soil sequences, one on the Mulu Formation and the other on the Melinau Limestone.

Table 5. The Area and Percentage of Each Mapping Unit

Mapping Unit	Soil Association*	Area (Km^2)	Percentage (%)
1	MELUAN	75.5	11.9
2	MERIT, NYALAU, BEKENU	85.0	13.4
3	TUTOH, MERIT	298.0	46.9
4	SARATOK, BUSO, TIKA	37.2	5.8
5	BUSO, MIRI, MUKAH, ANDERSON	15.4	2.4
6	SARATOK, NYALAU	6.3	1.0
7	TUMAU	14.1	2.2
8	BEMANG, BIJAT, SEDUAU	89.3	14.0
9	BEMANG, NYALAU, BEKENU	12.5	2.0
10	ANDERSON	2.0	0.3
11	MULU	0.7	0.1
	TOTAL:	636.0	100.0

* Soil families of each association are arranged in the order of dominance.

On the lower slopes of the Mulu Formation, the heavy-textured colluvial parent materials give rise to a mixture of TUTOH and MERIT Families (Mapping Unit 3), with minor occurrence of BEKENU Family. These are highly weathered and highly leached red and yellow soils, without marked surface accumulations of organic matter. They tend to be deeper than similar soils elsewhere in Sarawak, due to the thicker colluvial

deposits. This is because the slopes, although no steeper than in many areas of upland Sarawak, are considerably longer, and therefore provide larger catchment areas for the supply of colluvium.

At intermediate altitudes, the well-drained red and yellow soils give way to surface-gleyed soils of TUMAU Family (Mapping Unit 7). These have good under-drainage, as evidenced by the bright red and brown colours in the subsoil and weathering parent material. The surface accumulation of peat and the gleying in the upper mineral horizon occur in soils on quite steep and well-drained sites, and are due to the moister atmospheric climate and the nature of the surface peat. The rainfall is higher, and it is assumed that evapotranspiration is lower, than on the lower slopes.

Although the rainfall does not continue to increase with altitude right to the top of the mountain, temperature and, presumably, evapotranspiration do decrease steadily. The resulting atmospheric climate appears to be increasingly wet, and peat thicknesses increase with altitude. The well-developed highland Organic Soils of the MULU Family (Mapping Unit 11) are common on the upper slopes and summit of the mountain.

Because of the constraints mentioned above (See Section 2), only a few and broadly defined soil mapping units were used in the eastern section of the Park. They are delineated mainly by extrapolation from the few foot traverses by means of air photograph and contour map interpretation. Mapping Unit 11 (MULU Family) was delineated more or less by the 2,000 m contour of the main peak of Mulu. The lower boundary of Mapping Unit 7 (TUMAU Family) was mapped by aerial photographic interpretation. It was assumed that this association is coincident with the distinctive low, even and

high albedo canopy of the Upper Montane Forest and some of the upper variants of the Lower Montane Forest. The areas with the higher, darker and less even canopies of the lower types of Lower Montane Forest and the Mixed Dipterocarp Forest are mapped as the TUTOH/MERIT association (Mapping Unit 3), which is the most extensive mapping unit in the Park.

This sequence is highly generalised. The altitudinal soil zones interdigitate considerably. Thus at 800-1,300 m there is a zone of mixed TUTOH/MERIT and TUMAU Family soils. Similarly at intermediate and higher altitudes, soils of TUMAU and MULU Families occur in a complex mosaic, with the deeper peats tending to be found in the flatter and less well-drained sites. Peats of almost 1 m depth can be found as low as 1,300 m in sites with very restricted external drainage.

It is difficult to give precise altitudinal limits for the soil zones. As with the vegetation, the lower boundary of each zone tends to be depressed along the ridge and spur crests and elevated on flank slopes and in valley heads. Thus the upper limit of the TUTOH and MERIT soils is about 1,000-1,200 m along the main Mulu path, but these soils are found above 1,400 m on the valley sides in the Sungei Tapin catchment. Conversely the peats of the MULU Family extend further down the ridge crests than they do on the flank slopes.

The altitudinal sequence of Red-Yellow Podzolic - Peat is similar to those described on the other Western Malesian mountains (e.g. Burnham, 1974; Askew, 1965). In a sequence on sandstone on the lower slopes (up to 2,700 m) of Mount Kinabalu, Askew (op.cit.) described a belt of well-drained humus podzols between the lowland soils and the peaty gley podzols.

On the predominant slates and shales of Gunong Mulu, soil textures are thought to be too heavy to permit the rapid through leaching of the upper horizons needed in the formation of true spodic horizons. However, the organic matter in the soils at intermediate and higher altitudes is clearly quite mobile, as can be seen by the humic staining on subsoil ped faces in soils of TUTOH and TUMAU Family. In some of these soils, the subsoil organic matter appears to be in transit by throughflow rather than illuviated vertically, as the horizon of most intense staining is also the level of maximum lateral seepage.

During the descent of Gunong Mulu by the North-east Ridge, an altitudinal sequence of sandstone-derived soils was seen. These soils are better drained and leached than those on fine-grained rocks. A zone of incipient Humus Podzols in a belt just beneath the Peaty Gley Podzols was seen. These Humus Podzols are classified as the Silantek Series of BUSO Family. However, they are rather shallow and grade towards the soils of TUTOH or MELUAN Families.

The soils on the massifs of the Melinau Lime-stone is mapped as MELUAN Family (Mapping Unit 1). Soil formation on this almost pure limestone is so rudimentary that it is difficult to perceive much altitudinal zonation. The patches of organic-rich soil are slightly more extensive, deeper and less mull-like at higher altitudes, but bare rock still accounts for most of the land surface. There are small pockets of shallow red or reddish brown clay loams. These appear to be related to ferruginous impurities or cements in the limestone and are not associated with altitudinal changes.

On the Setap Shale Formation in the west, the dominant soil group is the Red-Yellow Podzolic Soils consisting

mainly of MERIT Family (Mapping Unit 2). In association with these MERIT Family soils, lighter-textured soils of NYALAU and BEKENU Families are found where the parent material is sandstone or siltstone. On some very steep ridges, some stony TUTOH soils have also developed on the colluvial materials. On the Belait Formation where the parent material is mostly coarse-textured sandstone, NYALAU Family soils predominate and MERIT and BEKENU Families are mapped as subordinate soils. Along the upper reaches of Sungai Mentawai and Sungai Lutut, a narrow belt of alluvium and low hills border the stream. The soils are mapped as a complex of Alluvial Soils of BEMANG Family and Red-Yellow Podzolic Soils of NYALAU and BEKENU Families (Mapping Unit 9). Along the lower stretch of Sungai Mentawai before it joins Sungai Medalam, the alluvial belt is wider and the soils include BEMANG, BIJAT and SEDUAU Families (Mapping Unit 8). Some pockets of Organic Soils are also found in depressions where waterlogged condition prevails.

The Pleistocene terraces and terrace remnants are by no means flat, and the soil type which occurs at a particular site is closely related to the microrelief of the area. The major soils found on the terraces include Humus Podzols, Regosols, Grey-White Podzolic and Organic Soils. On the low (<15 m), relatively flat terraces, drainage seems to be very much impeded and Organic Soils mainly of the ANDERSON Family form the dominant group with subordinate Humus Podzols (Mapping Unit 5A). On the medium (15-30 m) and high (>30 m) terraces, the soils are very closely related to the local topography. On the relatively flat undissected portions of these terraces, Humus Podzols of the BUSO and MIRI Families are the dominant soil types (Mapping Unit 5S). In depressions and where drainage has been impeded by the advanced development

and impermeability of the subsurface humus pan, subordinate Organic Soils of MUKAH and ANDERSON Families have developed as a result of the permanently waterlogged conditions. Some of the medium and most of the high terraces are highly dissected, particularly at the edges. The steeply sloping topography as a result of the dissection is not conducive to the formation of Podzols and Organic Soils. The humus colloids are carried away by rapid lateral drainage before they can be deposited. Here, the coarse-textured members of the Grey-White Podzolic Soils and Regosols are also found. The soils are therefore mapped as an association of SARATOK, BUSO and TIKA Families (Mapping Unit 4). Where the steeply dissected terrace remnants is mainly composed of slightly heavier-textured materials, soils of SARATOK Family with subordinate NYALAU Family soils are found (Mapping Unit 6).

The central lowland area is an alluvial plain with many streams, depressions and bare limestone outcrops. The soils on the plain are mapped as an association of BEMANG, SEDUAU and BIJAT Families (Mapping Unit 8). Subordinate soils of MUKAH and ANDERSON Families can be found in places. SEDUAU soils generally occupy position closest to the streams and rivers on the lower stretches, whereas BEMANG soils usually occur at similar position on the upper reaches of the drainage systems. BIJAT Family soils are found on slightly lower and poorly drained sites. BEMANG soils form the dominant soil type in most of the lowland area, but along the lower stretch of Sungai Melinau, BIJAT Family soils predominate.

6. SOILS OF THE FOREST ECOLOGICAL PLOTS

Special attention had been paid to the soils of the Forest Ecological Plots (Proctor et al in prep.). Detailed soil information of these plots should be useful in

understanding the ecology of the vegetation. On the Alluvial and Kerangas Forest Plots, soil augering was done at all the points of intersection of the sub-plot boundaries and in addition, soil pits were dug for detailed soil examination. The soils of the Mixed Dipterocarp Forest and Limestone Forest Plots were examined in a few randomly distributed profile pits. Some supplementary auger inspections were also made.

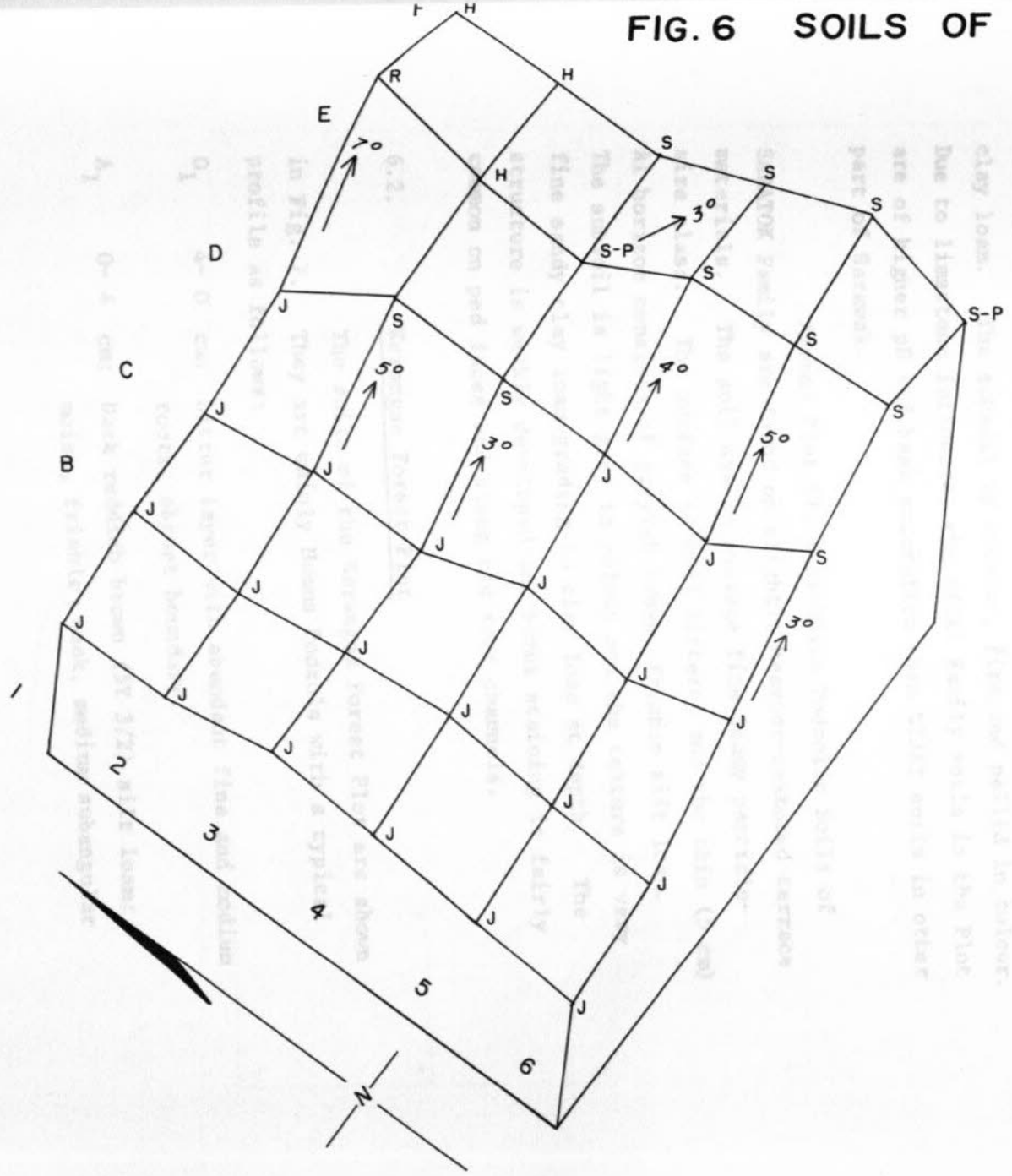
6.1. Alluvial Forest Plot

The result of the soil investigation is depicted in Fig. 6. The microrelief within the plot is by no means flat, and the soils are closely related to the topography. Between Lines A and C, the plot is fairly flat. There is a slight rise of 1-2 m at angles ranging from 3 to 7° between C and D along Lines 2, 3 and 6, and between D and E along Lines 1, 4 and 5. The higher ground is probably a low terrace remnants with a depression at the northeastern corner where peat has accumulated.

On the drier parts of the terrace, weak incipient Humus Podzols of BUSO Family are found. Gravel beds are encountered at shallow depths ranging from 20 to 40 cm. A thin layer of illuviated organic materials is found just above the gravel beds and/or around the pebbles. The top soil is pallid in colour and the textures range from loamy sands to sandy loams. Where drainage has been impeded, a thin layer of peat has accumulated on top of the Humus Podzol as at Points F6 and E3.

At the north-eastern corner, drainage is very poor and shallow (<100 cm) Organic Soils of MUKAH Family are found. These Mukah soils have a layer of reddish brown,

FIG. 6 SOILS OF ALLUVIAL FOREST PLOT



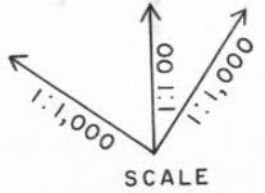
J - GLEY SOIL / BIJAT FAMILY

S - PODZOL / BUSO FAMILY
(P — Peaty Phase)

R - GREY – WHITE PODZOLIC SOIL / SARATOK FAMILY

H - ORGANIC SOIL / MUKAH FAMILY

5° - Slope in degrees



moderately well-decomposed hemic materials overlying dark yellowish brown, silty clay loams or silty clays.

On the lower relatively flat ground, the drainage is poor and Gley Soils of BIJAT Family occur. These soils are clayey in texture but the sand content of BIJAT soils in the Plot tends to increase with depth and many grits and gravels are found at depths below 60 to 90 cm. The water-table generally occurs close to the surface. The A1 horizon usually consists of dark greyish brown, friable loam to silty clay loam. The subsoil is massive, firm and pallid in colour. Due to limestone influence, the BIJAT Family soils in the Plot are of higher pH and base saturation than BIJAT soils in other part of Sarawak.

Around Plot E1, Grey-White Podzolic Soils of SARATOK Family are found on slightly heavier-textured terrace materials. The soil has an average fine loamy particle-size class. The surface is well littered and the thin (5 cm) A1 horizon consists of greyish brown, friable silt loam. The subsoil is light grey in colour and the texture is very fine sandy clay loam grading to clay loam at depth. The structure is weakly developed and humus staining is fairly common on ped faces and along old root channels.

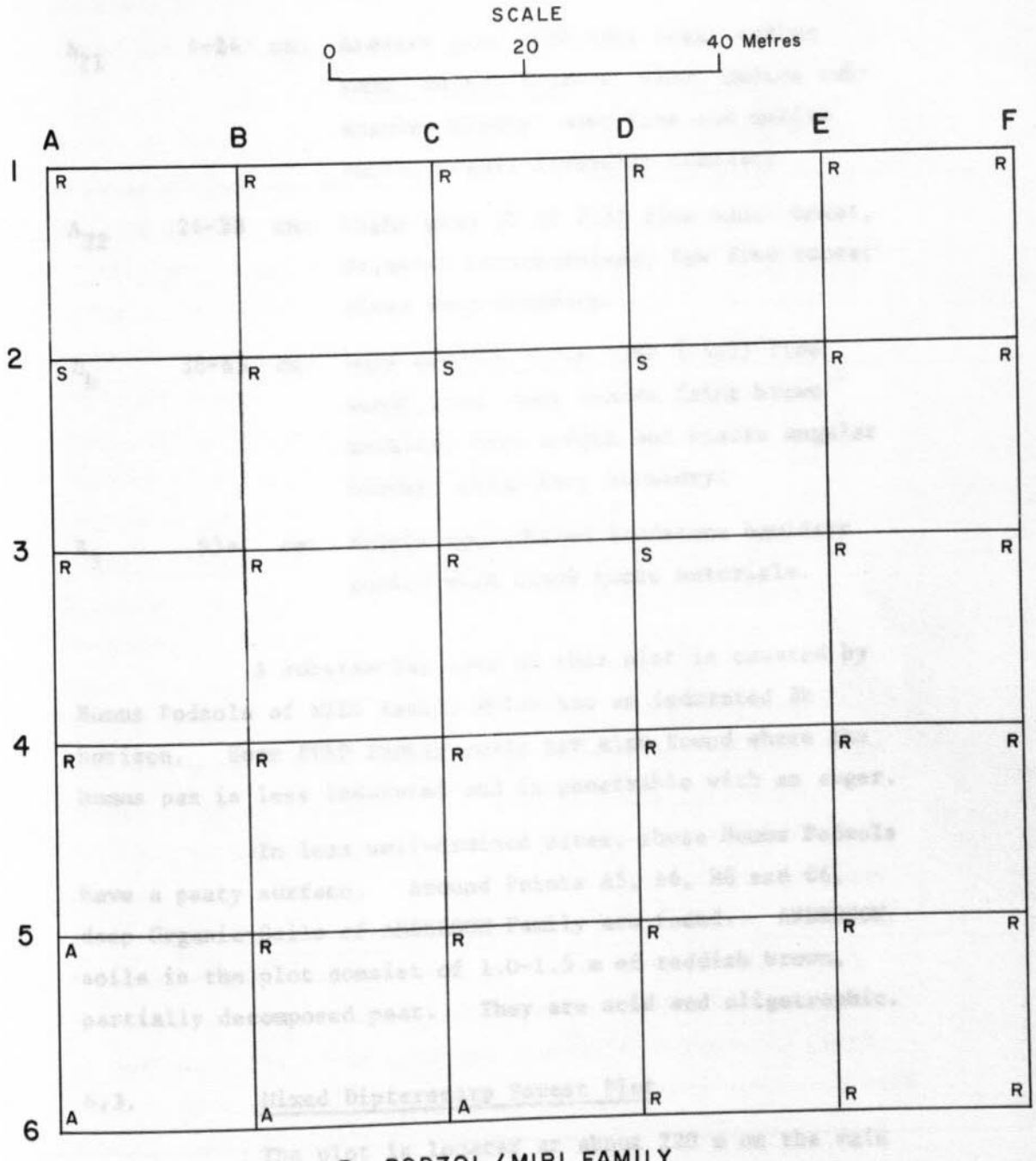
6.2. Kerangas Forest Plot

The soils of the Kerangas Forest Plot are shown in Fig. 7. They are mainly Humus Podzols with a typical profile as follows:

O_1 4- 0 cm: Litter layer with abundant fine and medium roots; abrupt boundary.

A_1 0- 4 cm: Dark reddish brown (5Y 3/2) silt loam; moist, friable; weak, medium subangular

FIG.7 SOILS OF KERANGAS FOREST PLOT



blocky; many fine and medium roots; clear wavy boundary.

A_{21} 4-24 cm: Reddish grey (5YR 5/2) loamy medium sand; moist, friable; weak, medium sub-angular blocky; many fine and medium roots; clear, irregular boundary.

A_{22} 24-38 cm: Light grey (2.5Y 7/2) fine sand; moist, friable; structureless; few fine roots; clear wavy boundary.

B_h 38-63 cm: Dark reddish brown (5YR 2.5/2) fine sandy loam, many coarse faint brown mottles; weak medium and coarse angular blocky; clear wavy boundary;

B_3 63+ cm: Mainly unweathered sandstone boulders coated with black humic materials.

A substantial area of this plot is covered by Humus Podzols of MIRI Family which has an indurated Bh horizon. Some BUSO Family soils are also found where the humus pan is less indurated and is penetrable with an auger.

In less well-drained sites, these Humus Podzols have a peaty surface. Around Points A5, A6, B6 and C6, deep Organic Soils of ANDERSON Family are found. ANDERSON soils in the plot consist of 1.0-1.5 m of reddish brown, partially decomposed peat. They are acid and oligotrophic.

6.3. Mixed Dipterocarp Forest Plot

The plot is located at about 220 m on the main Mulu path, just above Camp 1. It occupies the crest and flank slopes of the lower end of an intermediate spur from

the West Ridge of Mulu. The crest line of the spur and the plot are interrupted by a saddle. Slopes are moderately steep and are mostly in the 15-25° range.

The plot is located on Red-Yellow Podzolic Soils of heavy texture. The typical profile is capped by a layer of reddish brown fibrous litter, which may be as much as 5 cm thick. The upper mineral horizon is darkened by organic matter and colours range from dark brown to yellowish brown. There may be some patches of grey or light grey, indicating very localised intensification of leaching or hydromorphism. This horizon is generally less than 15 cm deep, and gives way to the reddish yellow or yellowish colours of the subsoil. Within the plot there is a considerable range in subsoil matrix colours. In general, colours become redder with depth. Mottling also tends to increase, as patches of incomplete weathering increase in frequency. The mottles range from red through yellow to white and grey. The topsoils commonly have silty loam and very fine sandy loam textures, but clay contents increase with depth, and silty clay loam or heavier are usually found within 15 cm of the surface. Clay contents apparently continue to increase and in the lower subsoil, textures of clay or silty clay are common. Topsoil structures are weak or moderate medium crumb or fine subangular blocky. Subsoil structures are usually medium or coarse blocky, but may be obscured in horizons with high contents of weathering rock fragments. The stone contents generally increase in depth, but not in a gradual or regular way. Slightly weathered rock usually comes to dominate the soil volumetrically at between 1 and 2 metres.

These soils are classified as MERIT or TUTOH Families. The main differential is on the way in which stony

material and clay increase with depth. In MERIT Family, horizonation is more strongly developed and the increase in clay and stones with depth is quite marked. TUTOH Family soils are developed on more recently deposited colluvial parent materials, and show only rudimentary horizonation. The granulometric analyses of five profiles in the plot show that only two profiles have a clear increase in clay content with depth. In two other profiles, clay contents remain fairly constant, and in the other profile, the clay percentage of the fine earth fraction actually decreases. These results indicate the poor horizonation and immaturity of these soils, and suggest that many of them should be classified as Regosols rather than Red-Yellow Podzolic Soils. Most of the soils in the plot are sufficiently well developed to qualify for MERIT Family. Within the MERIT Family, Merit Series is dominant in the plot with subordinate Jakar Series. Other minor soils present in the plot include BEKENU and KERAIT Families.

In general morphology, the soils of the plot are similar to the Red-Yellow Podzolic Soils that are widespread in other non-alluvial landscapes of Sarawak. However, there are some features which are not typical. One is the unusually thick surface litter layers. Litter layers of up to 5 cm thickness are found in Sarawak Red-Yellow Podzolics, but usually only in light-textured soils. On heavy-textured, shale-derived soils, litter is usually less than 2 cm thick and is often patchily absent. This 'sandstone' feature in the soils of the plot, combined with the 'sandstone' floristic composition of the forest are clearly anomalous and need further examination. The other atypical feature is the soil depth. Most upland Sarawak Red-Yellow Podzolic Soils are less than 1 metre deep. The unusal depth of the plot soils

is a consequence of the importance of colluviation, and the long catchment slopes above the plot.

The analytical data of MERIT soils from this plot have been discussed in comparison with other Sarawak Red-Yellow Podzolic Soils in Section 4.7.1. The chemical characteristics of TUTOH Family soils have also been described in Section 4.6.2.

6.4. Limestone Forest Plot

This plot is situated at about 200 m on the lower scree on the northern slope of the Gunong Api massif. The ground surface is very irregular with limestone boulders protruding up to 2-3 metres. The ruling slope is quite steep, in the 20-25° range.

The soils are classified as the MELUAN Family of Lithosols. They are very shallow and stony, and it was not possible to auger or dig beyond 15 cm depth. The surface material was examined and sampled at 7 sites in or close to the plot. The chemical data have been discussed in Section 4.2.1.

The soils are dark brown, brown or reddish brown humose silty, or clay loam as interstitial material between hard, sharply angled or pointed limestone stones and rocks.

7. SOILS OF THE ALTITUDINAL ZONATION PLOTS

In addition to the Forest Ecology plots established in the four main forest types, a number of smaller plots were established along the main Mulu path from the floodplain to the summit. These altitudinal zonation plots correspond to some of the original botanical zonation plots of Martin (1977). During the Expedition they were used as

Table 6. Soils of the Altitudinal Zonation Plots

Plot	Altitude (m)	Main Soil Families	Other Soils Present
A (Alluvial Forest Plot)	60	BIJAT	BUSO MUKAH SARATOK
B	130	TUTOH	
C (MDF Plot)	220	TUTOH MERIT	BEKENU KERAIT
D	500	MERIT TUTOH	BEKENU
E	830	TUTOH BEKENU	MERIT
O*	1,010	TUTOH	
F	1,130	TUTOH	TUMAU
G	1,310	TUMAU MULU	TUTOH
N+	1,480	TUTOH TUMAU	
M*	1,580	TUMAU	
H	1,650	TUMAU	MULU
I	1,860	TUMAU MULU	
J	1,930	MULU TUMAU	
K	2,090	MULU	TUMAU
L	2,370	MULU	

* Plot not used in biological studies during Expedition, but close to one of Martin's (1977) botanical plots.

\+ Plot not used in biological studies during Expedition.

characteristic sampling areas for a number of biological studies, particularly by the soil zoologist.

The soils of these plots were examined and sampled in multiple pits and augerings as part of the altitudinal transect of the soils on the Mulu Formation. The soils found on each plot are summarized in Table 6.

8. SOIL-FOREST RELATIONS

The altitudinal zonation in the floristics and physiognomy of the Limestone Forest is almost entirely determined by climate. As there are practically no soils in this area, there can be no marked parallel altitudinal pedological zonation. In contrast, it is clear from the above descriptions of the soils and their distribution that there is a clear altitudinal zonation of soils on the Mulu Formation, in parallel with altitudinal changes in the forest.

The zonation of vegetation along the main Mulu path has been described and discussed in detail by Martin (1977). Because the path follows spur and ridge crests for almost its entire length the findings can be extrapolated to off-ridge sites only with caution. As noted above, the altitudinal limits of the various vegetation zones tend to be depressed along exposed crests. Martin described three major forest types along his transect: the Mixed Dipterocarp, the Lower Montane and the Upper Montane Forests. The two montane forests were subdivided on floristic grounds. The floristic subtypes also tend to be distributed in altitudinal sequences. However, as Martin notes, their distribution is also much affected by local factors, such as exposure and external site drainage. Thus Lower Montane Forest (LMF) was found in a sheltered gully as high as 2,070 m on the Northeast

ridge. Conversely Upper Montane Forest (UMF) occurs as low as 1,600 m on exposed knolls on the West Ridge (e.g. Bukit Tumau).

On the whole, the UMF is associated with the deeper peats of the MULU Family and the LMF with the peaty, surface-gleyed soils of TUMAU Family. However, there are numerous local exceptions to this trend. In the succession of knolls and saddles along the West Ridge between Bukit Tumau and Camp 4, the LMF of the sheltered saddles is often found to be growing in pockets of deep swampy peat. The UMF on the exposed sites is usually growing on climatogenic peat, but this is often shallower than the topogenic peat of the hollows. The lower boundary of the LMF appears to coincide roughly with the lower limits of the soils of TUMAU Family. However both the soil and vegetation boundaries are gradual and interdigitated, so that it is not possible to postulate close correspondence.

As noted above, the soil sequence on sandstone differs from that on argillaceous parent materials in that a zone of incipient Humus Podzols occurs between the Peaty Gley Podzols and the Red-Yellow Podzolic Soils. The vegetation zonation also appears to differ considerably, as far as could be seen from casual inspection by a non-botanist. On the traverse down from the Northeast Ridge of Mulu, it was noted that the stunted physiognomy and abundance of *Nepenthes* typical of the UMF persisted to much lower altitudes on the sandstone than shales. Thus apparent UMF was found in patches on knolls at altitudes of less than 1,300 m. Another feature peculiar to this ridge is the occurrence of open, treeless patches on some of the more exposed knolls particularly in the 500-1,200 m altitude range. These are usually covered

with ferns *(Gleichinia)* or grasses, although small areas of bare soil or weathering rock were also seen. It is thought that these clearings may be the results of small lightning fires.

Their occurrence on this ridge, and not on the slates and shales, is thought to be a reflection of drier soil moisture regimes, due to the lighter textures and generally shallower sola. This may also be a factor in the extension of the UMF to lower altitudes on sandstone. This reinforces the idea that the UMF/LMF division is as much due to moisture changes as to temperature. The more xeromorphic UMF is better able to withstand the comparatively high runs-of-wind experienced on the exposed knolls. On this basis the UMF could be designated as a 'wind forest', whereas the LMF may be a 'mist forest'. The stunted UMF found on the sandstone ridge may be a 'fire forest'. However this is all highly speculative and needs considerably more evidence and discussion.

Mixed Dipterocarp Forest covers a substantial area of the Park and is found on the valley-ridge complexes of the Setap Shale Formation and the lower slopes of the Mulu Massif. High stature MDF occurs where deep, well-drained Red-Yellow Podzolic Soils of MERIT and BEKENU Families are found. These deep soils occur even on some areas of very steep complex slopes (33^{o}+). However, on some very steep ridges of Setap Shale Formation, shallow MERIT and BEKENU soils are found. Where the parent materials are coarse-textured soils are only able to sustain poor MDF with trees of smaller girth and shorter stature. In some cases, the poor MDF almost grades into Kerangas type of forest. Similar intergrades occur in areas where the terrace remnants are well and steeply dissected.

On the terrace and terrace remnants, Humus Podzols of BUSO and MIRI Families are only able to support a Kerangas type of forest. The low fertility status of these soils is reflected by the abundance of *Nepenthes* and trees of relatively low stature and small girth. Where waterlogging occurs, a Kerapa type of forest is found. In this forest type, mosses are found in abundance on roots and dead wood. Where deep peat of Anderson Series has formed as a result of waterlogging, Kerapa Forest grades into Peat Swamp type of forest.

Peat Swamp Forest with *Shorea albida* as principal dominant occurs sporadically in the alluvial floodplains where the Alluvial Forest, with principal species *Eusideroxylon melangangai* and *Pometia pinnata*, dominate. In the Mentawai drainage area, however, *Shorea macrophylla* is common, and to a lesser extent, *Shorea ovalis*. Under this Alluvial Forest, soils of BIJAT, BEMANG and SEDUAU Families are found. On river banks where the Alluvial Soils are well drained, Riparian Forest exists. The trees are able to grow to large sizes, forming a close canopy above the river.

REFERENCES

Anderson, J.A.R. 1978. Preliminary Report on Gunong Mulu National Park (unpubl.). Anderson and Marsden (Forestry Consultants) Ltd., Singapore.

Andriesse, J.P. 1969. A study of the environment and characteristics of tropical podzols in Sarawak (East Malaysia). Geoderma 2: 201-227.

Anonymous. 1964. Annual Report on the Research Branch, Dept. of Agriculture, Sarawak. Pp. 67-69.

Ashton, P.S. 1973. Report on research undertaken during the years 1963-67 on the ecology of the Mixed Dipterocarp Forest in Sarawak. Forest Dept., Sarawak.

Askew, G.P. 1965. The mountain soils of the east ridge of Mount Kinabalu. Proc. Royal Soc. London B 161. Pp. 65-74.

Baillie, I.C. 1978. Studies of site-forest relationships in the Mixed Dipterocarp Forest of Sarawak. O.D.M., London/Forest Dept., Sarawak.

Burnham, C.P. 1974. The role of the soil forming factors in controlling altitudinal zonation on granite in Malaysia. Pp. 59-74 in 'The altitudinal zonation of forests in Malesia' (ed. J.R. Flenley), Univ. of Hull.

*Collins, N.M. in prep. Soil invertebrates from Mulu forests.

*Day, M.J. in prep. Geomorphic hazards in the management of the Park.

Eilers, R.G. and Loi, K.S. in prep. Soils of Northern Interior Sarawak. Dept. of Agriculture, Sarawak.

Lim, C.P. 1975. Notes on soil classification in Sarawak. Dept. of Agriculture, Sarawak (unpubl.).

*Mc Donald, R.C. in prep. The origin of the foot caves and tower karst.

Martin, P.J. 1977. The altitudinal zonation of forests along the West Ridge of Gunong Mulu. Forest Dept., Sarawak.

*Proctor, J., Chai, P.P.K., Anderson, J.M. and Vallack, H. in prep. Permanent plots in contrasting forest types.

Walls, J.R.D. 1965. Report on a reconnaissance soil survey of Marudi-Linei-Long Lama Area (4th Division), Soil Survey Report No.62, Dept. of Agriculture, Sarawak (unpubl.).

Walls, J.R.D. 1966. The Bekenu-Niah-Suai Area, Sarawak, Malaysia. Ph.D. Thesis, University of Reading, U.K.

*Walsh, R.P. in prep. Climate of Gunong Mulu National Park.

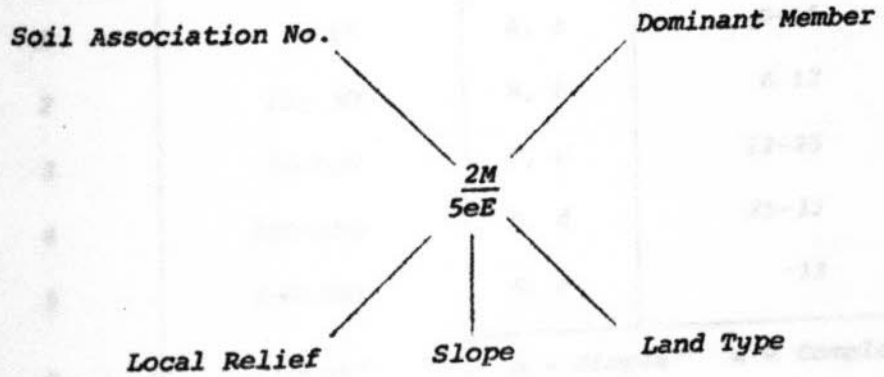
Wilford, G.E. 1961. The geology and mineral resources of Brunei and adjacent parts of Sarawak. Memoir 10, Geol. Survey Dept., British Territories in Borneo, Brunei Press Ltd., Brunei.

* Papers to be presented at Mulu Symposium organised by the Royal Geographical Society from the 12th to 14th of September, 1979.

APPENDIX I

HOW TO USE THE SOIL AND TERRAIN MAP

The complex map symbols identify in general terms the soil and terrain of the mapping units. Example:



The soil association (or consociation) is identified in the numerator, and where possible, the dominant soil member is indicated. The dominant soil member is defined as one which occupies more than 60 percent of the mapping unit. The denominator identifies the physical characteristics of the terrain in terms of local relief, slope and land types. In the absence of topographic contours, six ranges of elevation defined in terms of the local base level are shown in the map. The slopes are divided into five ranges, with each range having two classes of slope complexity. The geomorphic pattern of the landscape is indicated by the land type.

TERRAIN CLASSIFICATION

LOcal Relief		Slope	
Symbol	Range (Metres)	Symbol	Range (Degrees)
1	< 15	A, a	0- 6
2	15- 50	B, b	6-12
3	50-100	C, c	12-25
4	100-150	D, d	25-33
5	150-300	E, e	>33
6	>300	A = Simple a = Complex	

LAND TYPES

A - Alluvial Plain

D - Dissected hills or Mountains

R - Ridge

V - Valley Complex

E - Valley-Ridge Complex

H - Low Hills

T - Terrace

O - Peat Swamp

APPENDIX II

METHODS OF SOIL ANALYSIS

All the soil samples were analysed in the laboratory at Agricultural Research Centre, Semongok, Sarawak. Only very brief accounts of the methods used are given below. For more details, readers are kindly referred to:

i. Sim, P. 1974. Manual of laboratory methods of chemical soil analysis. Dept. of Agriculture, Sarawak.

ii. Soil Conservation Service. 1972. Soil survey laboratory methods and procedures for collecting soil samples. U.S. Dept. of Agriculture. SSIR 1. U.S. Govt. Printing Office, Washington, D.C.

1. Particle Size Analysis

20 g of soil were boiled with 20-volume hydrogen peroxide and then dispersed by shaking overnight with 1N sodium hydroxide. Fractionation was done according to the Pipette Method.

2. pH in Water and 1N Potassium Chloride

10 ml of distilled water or 1N potassium chloride were added to 10 g of air-dried soil. The suspension was stirred and left overnight before the pH was measured by a Pye pH-meter. A soil:water ratio of 1:2.5 was used for the pH determination of organic soils.

3. *Organic Carbon (Walkley-Black's Wet Digestion Method)*

A weighed sample (2 g) of finely ground soil was digested with a known volume of standardised potassium dichromate solution and concentrated sulphuric acid. The excess dichromate was back titrated with ferrous ammonium sulphate using diphenylamine as indicator.

4. *Loss on Ignition*

10 g of soil were heated at 800°C for 1 hour. The percentage of the loss of weight due to the ignition was computed.

5. *Total Nitrogen (Semi-Micro Kjeldahl's Method)*

A weighed sample (1 g) of finely ground soil was digested with concentrated sulphuric acid, potassium sulphate and selenium. The digested sample was made alkaline with sodium hydroxide and the released ammonia was steam-distilled into boric acid containing a mixed indicator of bromocresol green and methyl red. The ammonia was then titrated against standardised sulphuric acid.

6. *'Reserve' Analyses (P, K, Ca, Mg, Gp III oxides)*

Soil extract for the above analyses was prepared by igniting finely ground soil (1 g) at 800°C in a furnace for 30 minutes and then extracting with 10 m- concentrated hydrochloric acid. The filtrate after extraction was made up to 50 ml in a standard flask with distilled water.

(i) 'Reserve' P

5 ml of the extract were allowed to

react with ammonium molybdate solution and ascorbic acid. The intense blue colour of the solution was then measured photometrically using Technicon auto-analyser.

(ii) 'Reserve' K

K in the extract was determined by flame photometry using Technicon auto-analyser.

(iii) 'Reserve' Ca and Mg

After the addition of radiation buffer and releasing agent, Ca and Mg were determined by atomic absorption spectrophotometric method.

(iv) Group III oxides

25 ml of the extract were made alkaline with ammonia solution. After adding 2 drops of ferric chloride solution and 1-2 ml of bromine water, the solution was boiled and filtered while hot. The precipitate was washed several times with 2% ammonium chloride solution and then ignited at 800°C for ½ hour. It was then cooled in a dessicator and weighed.

7. Available P (Bray's and Kurtz's method)

2 g of soil were extracted using Bray and Kurtz No.2 extractant. The extract was measured colorimetrically using ammonium molybdate .. stannous chloride blue method.

8. Cation Exchange Capacity and Extractable Bases (Ca, Mg, K, Na)

(i) Cation Exchange Capacity (C.E.C.)

A known weight of soil was leached with neutral normal ammonium acetate, and the leachate was collected for the determination of bases. Excess ammonium acetate was removed by percolating wash-alcohol through the soil. The adsorbed ammonium ions in the soil were displaced by 0.1N potassium sulphate and then determined by steam distillation and titration against standardised 0.1N hydrochloric acid.

(ii) Extractable Ca and Mg

Ca and Mg were determined by atomic absorption spectrophotometric method after adding radiation buffer and releasing agent.

(iii) Extractable K and Na

K and Na of the leachate were determined by flame photometer.

9. Morgan-Extractable Fe, Mn, Zn and Cu

5 g of fine earth were shaken with 50 ml of Morgan's solution (anhydrous sodium acetate in acetic acid) for ½ hour. After filtration, the filtrate was used for determining Fe, Mn, Zn and Cu using atomic absorption spectrophotometer.

10. Water Content at 1/10, 1/3 and 15-bar Pressures

Determined by Pressure Plate Apparatus in the case of 1/10 and 1/3 - bar pressures and Pressure Membrance apparatus in the case of 15 - bar pressure.

11. Bulk Density (Organic Soils)

Core samples were over-dried and weighed. The bulk density was calculated from the over-dried weight and the volume of the sampler.

12. Total P, K, Ca, Mg (Organic Soils)

A ground sample of known weight was ignited at 550°C in a silica basin. After ignition, the residue was treated with 20 ml of hydrochloric acid, digested for 20-30 minutes in a water bath, and then evaporated to dryness. The contents were taken up in dilute hydrochloric acid and filtered with several washings of hot water.

For the determination of P, K, Ca and Mg in the extract, refer to Section 6 ('Reserve' Analyses).

13. Fiber Content (Organic Soils)

A weighed sample (100-200 g) at field moisture content was soaked for 15-20 hours in a 5% Calgon solution. Then it was washed through a 100-mesh (0.15 mm) sieve using a gentle stream of water. Wood fragments that cannot be crushed in the hand and are larger than 2 cm in the smallest dimension were picked out. Materials left in the sieve were over-dried and weighed.

14. Total Silicate and Sesquioxides Analyses (Na_2CO_3 Fusion)

1 g of fine soil or clay was fused with sodium carbonate. It was then digested with concentrated hydrochloric acid. Silica was precipitated by treatment with 2% gelatine, filtered, washed, ignited and weighed. The filtrate was made up to 250 ml and used for iron and aluminium determinations by atomic absorption spectrophotometric method.

15. Free Iron and Aluminium (Dithionite-Citrate Extraction)

A weighed sample of fine soil was shaken overnight in a solution containing sodium dithionite and sodium citrate. The filtrate was then used for iron and aluminium determination by atomic absorption spectrophotometer.

16. Pyrophosphate-extractable Iron and Aluminium

2 g of soil were shaken overnight with 0.1N sodium pyrophosphate solution. After adding a few drops of Superfloc solution, the suspension was centrifuged. The supernatant liquid was used for iron and aluminium determinations by atomic absorption spectrophotometric method.

APPENDIX III

PROFILE DESCRIPTION AND ANALYTICAL DATA OF SOILS

Profile No: 2

Soil Group: Organic Soil

Family: ANDERSON

Series: Anderson 1

Location: N of Lobang Cina Rentis 1A tape 18

Latitude: 4° 13' 32" N

Longitude: 114° 53' 57" E

Date Sampled: 24/4/78

Lab. No: SS.5615/17

Parent Material: Forest litter

Vegetation: Primary Peat Swamp Forest

Slope: Flat

Rainfall: 4,000-5,500 mm p.a.

Drainage: Very poorly drained

Surface features: Thickly littered

Horizon	Depth (cm)	Description
O_{e1}	0 - 25	Dark reddish brown (2.5YR 3/2) partially decomposed hemic materials; wet; gradual boundary;
O_{e2}	25 - 75	Dark reddish brown (2.5YR 3/2) fairly well decomposed materials; clear boundary;
O_a	75 - 120	Dark reddish brown (2.5YR 3/2) well decomposed sapric materials; wet.

Note: Auger hole description.

Profile No : 2 Soil Group : ORGANIC SOIL Family : ANDERSON Series : Anderson Lab. No : SS 5615 - 5617

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1	0.05				
Oe1	0-25										0.11	43.4		
Oe2	25-75										0.11	36.8		
Oa	75-120										-	18.5		

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B. Sat. %	Ext. by KCl (me/100g)	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
Oe1	96.9			41.86	1.46	29	0.81	1.32	0.58	0.50				
Oe2	95.9			40.81	1.47	28	0.46	0.44	0.40	0.39				
Oa	79.6			34.04	0.55	62	0.59	0.28	0.18	0.34				

Horizon	"Reserve" analysis					Total analysis of fine earth			Free Fe_2O_3 %	Avail P ppm	P. Ret %	PH(Moist)		
	ppm				% OD	% OD						H2O 1:2.5		
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
Oe1	334	231	2318	1130						51	10.8	3.8		
Oe2	190	71	1293	527						24	10.8	3.8		
Oa	70	189	1351	495						3	6.2	3.7		

Horizon	Available T.E. (ppm)					B	Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo		1/10 bar	1/3 bar	15 bars	Avail. water				
Oe1	76	7	12.6	1.6	-	-								
Oe2	106	2	5.5	0.8	-	-								
Oa	50	2	2.8	0.9	-	-								

Profile No: 37

Soil Group: Organic Soil

Family: MULU

Series: Mulu

Location: Altitudinal Zonation Plot G Line 1

Latitude: 4° 2' 13" N

Longitude: 114° 53' 8" E

Date Sampled: 2/8/78

Lab. No: SS.6375/79

Parent Material: Mulu Formation colluvium

Vegetation: Lower Montane Rainforest

Slope: 1°, NW, Crest

Altitude: 1,310 m (4,360 f)

Rainfall: 4,000-5,500 mm p.a.

Drainage: Poorly drained

Surface features: Mossy logs and roots

Horizon	Depth (cm)	Description
O_i	0 - 15	Dark brown (10YR 3/3) fibric peat; wet, loose; many medium and coarse roots; gradual regular boundary;
O_e	15 - 55	Dark brown (7.5YR 3/2) hemic peat; wet, slightly loose; many medium and coarse roots; gradual regular boundary;
O_a	55 - 75	Dark reddish brown (5YR 3/3) sapric peat; common dark brown (10YR 3/3) patches; wet, slightly compact; many medium and coarse roots; clear wavy boundary;
IIA_1	75 - 87	Yellowish brown (10YR 5/4) silty clay loam; wet, firm, slightly plastic and sticky; massive; common medium pores; common medium to fine roots; gradual wavy boundary;
IIA_{2g}	87 - 115/125	Light grey (10YR 7/1) loam; moist, very firm, slightly plastic and sticky;

Profile No: 37

Soil Group: Organic Soil

Family: MULU

Series: Mulu

Location: Altitudinal Zonation Plot G Line 1

Latitude: 4° 2' 13" N

Longitude: 114° 53' 8" E

Date Sampled: 2/8/78

Lab. No: SS.6375/79

Parent Material: Mulu Formation colluvium

Vegetation: Lower Montane Rainforest

Slope: 1°, NW, Crest

Altitude: 1,310 m (4,360 f)

Rainfall: 4,000-5,500 mm p.a.

Drainage: Poorly drained

Surface features: Mossy logs and roots

Horizon	Depth (cm)	Description
O_i	0 - 15	Dark brown (10YR 3/3) fibric peat; wet, loose; many medium and coarse roots; gradual regular boundary;
O_e	15 - 55	Dark brown (7.5YR 3/2) hemic peat; wet, slightly loose; many medium and coarse roots; gradual regular boundary;
O_a	55 - 75	Dark reddish brown (5YR 3/3) sapric peat; common dark brown (10YR 3/3) patches; wet, slightly compact; many medium and coarse roots; clear wavy boundary;
IIA_1	75 - 87	Yellowish brown (10YR 5/4) silty clay loam; wet, firm, slightly plastic and sticky; massive; common medium pores; common medium to fine roots; gradual wavy boundary;
IIA_{2g}	87 - 115/125	Light grey (10YR 7/1) loam; moist, very firm, slightly plastic and sticky;

massive; few medium pores; common medium to fine roots; clear wavy boundary;

$III0_a$	115/125 - 135	Very dark brown (7.5YR 2/2) peat; moist to wet; dense and compact; common medium and fine roots.

		massive; few medium pores; common medium to fine roots; clear wavy boundary;
$IIIO_a$	115/125 - 135	*Very dark brown (7.5YR 2/2) peat; moist to wet; dense and compact; common medium and fine roots.*

Profile No : 37 Soil Group : ORGANIC SOIL Family : MULU Series : Mulu Lab. No : SS 6375 - 6379

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2 0.05 0.002			2	1 0.5 0.25 0.1 0.05								
Oi	0-15	-	-	-	-	-	-	-	-					
Oe	15-55	-	-	-	-	-	-	-	-					
Oa	55-75	-	-	-	-	-	-	-	-					
IIA2g	87-115/125	27.8	43.8	25.4	0.0	0.0	0.0	0.7	27.1	L				
IIOa	115/125-135	-	-	-	-	-	-	-	-					

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B. Sat %	Ext. by KCl (me/100g)	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
Oi	42.1	3.9	2.8	13.12	0.77	17	0.11	0.30	0.48	0.10	45.35	2.2		
Oe	45.5	3.8	2.8	16.95	0.81	21	0.12	0.19	0.28	0.02	58.46	1.0		
Oa	66.2	3.7	2.7	28.91	-	-	0.10	0.22	0.22	0.02	63.18	0.9		
IIA2g	4.3	4.0	3.0	0.92	0.05	18	0.61	<0.01	0.06	0.02	8.10	8.6		
IIIOa	32.0	3.8	3.2	12.81	0.21	61	0.11	<0.01	0.07	0.02	40.60	0.5		

Horizon	"Reserve" analysis					Total analysis of fine earth			Free Fe_2O_3 %	Avail P ppm	P. Ret %			
	ppm				% OD	% OD								
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
Oi	280	T	597	3418	2.93				0.07	37	27.8			
Oe	170	T	769	3184	3.44				0.08	16	40.8			
Oa	246	29	617	2865	3.64				-	13	45.5			
IIA2g	49	T	734	3188	2.71				0.00	1	14.2			
IIIOa	52	T	403	3115	2.95				0.01	3	48.8			

Horizon	Available T.E. (ppm)					B	Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo		1/10 bar	1/3 bar	15 bars	Avail water				
Oi	161	14	3.7	1.1			189.8	75.2	51.4	23.8				
Oe	200	10	3.9	0.8			195.9	83.0	49.8	33.2				
Oa	327	18	6.9	0.6			234.6	86.0	70.7	15.3				
IIA2g	15	<1	0.9	0.5			56.2	38.0	9.5	28.5				
IIIOa	29	<1	0.8	0.4			106.6	62.2	24.6	37.6				

Profile No: 49

Soil Group: Organic Soil

Family: MULU

Series: Mulu

Location: Altitudinal Zonation Plot J Line 1

Latitude: 4° 2' 47" N

Longitude: 114° 55' 0" E

Date Sampled: 11/7/78

Lab. No: SS.6380/83

Parent Material: Colluvium from Mulu Formation slate

Vegetation: Primary Upper Montane Forest

Slope: 25°,S, Upper slope

Altitude: 1,930 m (6,330 f)

Rainfall: 4,000-5,500 mm p.a.

Drainage: Poorly drained

Surface features: Moss peat and old log hummocks

Horizon	Depth (cm)	Description
O_e	0 - 15	Dark reddish brown (5YR 2/2) hemic moss peat; very wet; abundant medium and fine roots; gradual regular boundary;
O_a	15 - 60	Dark reddish brown (5YR 2/2) sapric moss peat; very wet, amorphous; many coarse and medium roots; clear regular boundary;
IIA_1	60 - 66	Light yellowish brown (2.5Y 6/4) silty clay, many medium distinct reddish brown, reddish yellow and grey mottles; wet, sticky and very plastic; very weak fine subangular blocky to massive; few coarse pores; common medium roots; clear slightly wavy boundary;
IIA_{2g}	66 - 78	Light grey (2.5Y 7/2) silty clay, many fine to medium reddish yellow mottles and reddish brown along root channels; wet, very plastic and sticky; massive;

		common medium to coarse pores; few medium roots; clear wavy boundary;
IIB_2	78 - 115	Yellow (10YR 7/8) silty clay loam; common reddish brown or red, discontinuous thin iron pans; moist, plastic and non-sticky; weak medium subangular blocky to massive; common fine slightly hard reddish yellow, weathering slate often with iron staining; weak discontinuous moisture films; rare medium roots; gradual regular boundary;
IIC_1	115 - 150	Mixed yellow and red, soft to hard weathering slate, patches of interstitial gritty clay;
IIC_2	150 - 160	Red, slightly hard weathering slate with black partings; becomes greyer and harder with depth.

Profile No : 49 Soil Group : ORGANIC SOIL Family : MULU Series : Mulu Lab. No : SS 6380 – 6383

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1	0.05				
Oe	0-15	–	–	–	–	–	–	–	–			23.5		
Oa	15-60	–	–	–	–	–	–	–	–			26.9		
IIAg	66-78	7.1	47.2	45.7	0.2	0.6	0.6	0.8	4.9	SiC				
IIB2	78-115	18.2	51.7	30.1	5.0	4.4	1.8	2.2	4.8	SiCL				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100g	B. Sat %	Ext. by KCl (me/100g)	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
Oe	98.0	3.4	2.0	42.48	1.81	23	0.05	0.72	0.56	2.82	73.80	5.6		
Oa	94.1	3.5	2.2	39.39	–	–	0.60	0.52	0.55	3.74	59.00	9.2		
IIAg	12.0	4.0	3.1	3.43	0.92	4	0.42	0.10	0.05	0.07	20.60	3.1		
IIB2	8.4	4.6	3.7	0.99	0.39	3	0.42	0.05	0.01	0.05	20.60	2.6		

Horizon	"Reserve" analysis ppm				% OD	Total analysis of fine earth % OD			Free Fe_2O_3 %	Avail P ppm	P Ret %			
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
Oe	359	61	17	365	1.68	1.7	0.3	0.6	–	7.8	12.1			
Oa	–	–	–	–	–	3.6	0.1	1.0	–	5.8	–			
IIAg	81	T	1870	5870	9.25	63.4	3.3	17.4	1.64	1	76.4			
IIB2	99	T	3837	5533	18.58	55.5	0.8	20.1	8.25	<1	63.9			

Horizon	Available T.E. (ppm)					Water content (%OD)						
	Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water		
Oe	84	5.5	17.0	1.2			143.8	128.4	–	–		
Oa	–	–	–	–			126.3	114.3	–	–		
IIAg	605	<1	1.7	2.1			80.9	64.3	31.5	32.8		
IIB2	667	<1	1.9	1.5			70.6	60.3	24.1	36.2		

Profile No: 53

Soil Group: Organic Soil

Family: MULU

Series: Mulu

Location: Altitudinal Zonation Plot K Line 5

Latitude: 4° 2' 47" N

Longitude: 114° 55' 11" E

Date Sampled: 11/7/78

Lab. No: SS.6384/89

Parent Material: Mulu Formation

Vegetation: Primary Upper Mon- Forest

Slope: 34°, SE, Upper flank slope

Altitude: 2,090 m (6,860 f)

Rainfall: 4,000-5,500 mm p.a.

Drainage: Poorly drained

Surface features: Very hummocky moss peat and fallen logs

Horizon	Depth (cm)	Description
O_e	0 - 45	Dark reddish brown (5YR 3/2) partly decomposed hemic materials; very wet, loose; many medium and coarse roots; clear regular boundary;
O_a	45 - 90	Very dark brown (7.5YR 2/2) sapric peat; wet compact; common coarse and medium roots; clear regular boundary;
IIA_1	90 - 95	Light yellowish brown (2.5Y 6/4) clay, many medium faint brown and grey mottles; wet, sticky and plastic; massive; few medium and coarse roots; gradual slightly wavy boundary;
IIA_{2g}	95 - 109	White (5Y 8/2) clay, many medium prominent reddish yellow streaks; wet, very plastic and very sticky; massive structure; clear wavy boundary;
IIB_{2ir}	109 - 110	Reddish brown; thin iron pan, hard very distinct and continuous;

IIC	110 - 130+	Yellow (10YR 7/8) stony silty clay, many medium faint to distinct reddish yellow weathering mottles; moist, firm; weak medium subangular blocky; abundant yellow; orange, slightly hard to soft weathered slate; few medium pores.

Profile No : 53 Soil Group : ORGANIC SOIL Family : MULU Series : Mulu Lab. No : SS 6384 -6389

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1 0.05					
Oe1	0-15	-	-	-	-	-	-	-	-			59.4	84.7	
Oe2	15-45	-	-	-	-	-	-	-	-			39.7	87.7	
Oa1	45-70	-	-	-	-	-	-	-	-			21.9	88.1	
Oa2	70-90	-	-	-	-	-	-	-	-			10.5	81.8	
IIA2g	95-109	18.6	33.8	47.6	0.5	0.4	0.2	0.6	16.9	C		-	-	
IIC	110-130+	28.9	36.5	34.6	3.3	3.0	1.9	3.0	17.7	CL		-	-	

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100g	B. Sat %	Ext by KCl (me/100g)	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
Oe1	99.4	3.0	2.7	43.17	1.40	31	0.12	0.68	0.05	0.29	52.80	1.1		
Oe2	87.4	4.3	2.7	40.06	1.18	34	0.05	0.07	0.03	0.05	44.00	0.5		
Oa1	95.7	3.4	2.3	43.46	2.24	19	0.05	0.18	0.42	0.10	68.80	1.1		
Oa2	96.6	3.3	2.0	43.78	1.85	24	0.05	0.26	0.53	0.17	67.40	1.5		
IIA2g	5.3	3.8	3.1	0.77	0.33	2	0.10	0.03	0.04	0.05	8.40	2.6		
IIC	7.0	4.5	3.8	0.57	0.28	2	0.52	0.06	0.01	0.03	6.80	9.1		

Horizon	"Reserve" analysis					Total analysis of fine earth			Free Fe_2O_3 %	Avail P ppm	P. Ret %			
	ppm				% OD	% OD								
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
Oe1						0.6	0.1	T	-	68	-			
Oe2						7.3	0.8	1.9	0.25	8	57.4			
Oa1						1.7	0.1	0.2	-	46	-			
Oa2						0.1	0.1	T	-	80	-			
IIA2g						70.2	1.5	19.2	0.16	3	40.4			
IIC						60.3	12.7	17.9	10.02	<1	34.1			

Horizon	Available T.E. (ppm)						Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water				
Oe1	34	18	15.7	2.7			230.1	188.4	128.5	59.9				
Oe2	57	90	6.5	0.5			70.7	68.9	58.0	10.9				
Oa1	86	5	9.6	0.8			92.3	89.1	-	-				
Oa2	63	4	11.5	1.1			111.6	101.2	81.8	19.4				
IIA2g	51	<1	1.2	2.3			53.1	40.3	26.4	13.9				
IIC	133	<1	1.4	1.6			54.3	46.1	25.6	20.5				

Profile No: 54 **Lab. No:** SS.6390/93

Soil Group: Organic Soil **Parent Material:** Mulu Formation slate

Family: MULU **Vegetation:** Upper Montane Rainforest

Series: Mulu

Location: Altitudinal Zonation Plot L Line 1 **Slope:** 5°, N, Crest

Latitude: 4° 2' 47" N **Altitude:** 2,370 m (7,780 f)

Longitude: 114° 55' 29" E **Rainfall:** 4,000-5,500 mm p.a.

Date Sampled: 5/8/78 **Drainage:** Poorly drained

Surface features: Lichen covered peat hummocks

Horizon	Depth (cm)	Description
O_i	0 - 30	Dark reddish brown (5YR 3/2) fibric peat; moist to wet, slightly compact; many medium coarse and fine roots;
O_e	30 - 85	Dark reddish brown (5YR 3/2) hemic peat; wet, loose; many medium and coarse roots;
O_a	85 - 100	Dark yellowish brown (10YR 4/4) sapric peat; wet, slightly compact; many medium and coarse roots; clear regular boundary;
IIA_1	100- 106	Yellowish brown (10YR 5/4) silty clay loam; moist to wet, loose to friable; weak medium crumbs; common fine to medium pores; many medium to coarse roots; common medium slightly hard weathering slate; clear regular boundary;
IIA_2	106 - 118	Light yellowish brown (10YR 6/4) silty clay, many medium faint brown and pale

brown mottles; moist to wet, firm; plastic and slightly sticky; weak medium subangular blocky to massive; weak discontinuous clayskins and weak faint humic stains; few fine pores; common medium and coarse roots; common medium slightly hard weathering slate; clear slightly wavy boundary;

IIB_2	118 - 130+	*Hard to slightly hard weathering slate; colour is grey and pale yellow above irregular iron (Fe) pan; pan is dark reddish brown to black, multiple in places at 2-5 millimetres gaps; below pan, zone of reddish yellow weathering slate fades to yellow with depth.*

Profile No : 54 Soil Group : ORGANIC SOIL Family : MULU Series : Mulu Lab. No : SS 6390-63

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1	0.05				
Oi	0-30	–	–	–	–	–	–	–	–					
Oe	30-85	–	–	–	–	–	–	–	–					
Oa	85-100	–	–	–	–	–	–	–	–					
IIA2	106-118	14.3	44.4	41.3	1.7	3.8	1.7	1.5	5.6	Sic				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B. Sat. %	Ext. by KCl (me/	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
Oi	98.8	3.2	1.8	39.89	1.14	35	0.06	0.90	0.26	0.20	81.40	1.7		
Oe	99.1	3.0	1.8	38.81	0.94	41	0.06	0.53	0.26	0.20	66.78	1.6		
Oa	54.7	3.6	2.6	25.35	0.92	28	0.06	0.08	0.05	0.13	39.18	0.8		
IIA2	19.8	3.8	3.0	6.60	0.28	24	0.11	0.02	0.19	0.07	32.77	1.2		

Horizon	"Reserve" analysis ppm				% OD	Total analysis of fine earth % OD			Free Fe_2O_3 %	Avail P ppm	P. Ret %
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3			
Oi	–	–	–	–					–	38	–
Oe	–	–	–	–					–	–	–
Oa	–	–	–	–					–	–	–
IIA2	159	T	1189	5021					0.48	6	59.4

Horizon	Available T.E. (ppm)					B	Water content (%OD)				
	Fe	Mn	Zn	Cu	Mo		1/10 bar	1/3 bar	15 bars	Avail water	
Oi	48	6	7.6	0.8			335.0	114.3	–		
Oe	64	9	12.2	0.8			268.2	91.4	–		
Oa	333	2	4.5	1.7			164.4	66.6	–		
IIA2	84	1	1.7	1.9			88.9	53.9	23.2	30.7	

Profile No: 56

Soil Group: Lithosol

Family: MELUAN

Series: Meluan

Location: FEG Limestone Ecological Plot

Latitude: 4° 8' 6" N

Longitude: 114° 53' 23" E

Date Sampled: 22/7/78

Lab. No: SS.6363/64

Parent Material: Melinau Limestone

Vegetation: Limestone Forest

Slope: 30°, N, Lower scree slope

Altitude: 200 m (660 f)

Rainfall: 4,000-5,500 mm p.a.

Drainage: Well drained

Surface features: Many hard grey sharply weathered limestones

Horizon	Depth (cm)	Description
A_{11}	0 - 5	Dark reddish brown (5YR 3/3) clay loam; moderate coarse crumb to fine crumb; moist, very firm; many medium to coarse very hard limestones; abundant medium, fine and coarse roots; patchy limestones at surface;
A_{12}	5 - 25	Dark reddish brown (5YR 3/3) clay loam; moist, very firm; moderate to weak fine crumb; many medium to coarse very hard limestones; many medium fine coarse roots;
R	25+	Hard grey limestone with occasional pockets of soil as in above horizon.

Profile No :56 Soil Group : LITHOSOL Family : MELUAN Series : Meluan Lab. No : SS 6363 – 6364

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1	0.05				
A11	0 – 5													
A12	5 – 25													

Horizon	Loss on ignition %	pH (air – dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B. Sat. %	Ext. by KCl (me/100	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
A11	37.7	5.8	5.5	11.48	2.76	4	8.97	1.67	0.27	0.19	25.40	–		
A12	26.1	6.8	6.5	3.37	1.02	3	6.73	0.50	0.13	0.15	21.80	–		

Horizon	"Reserve" analysis ppm				% OD	Total analysis of fine earth % OD			Free Fe_2O_3 %	Avail P ppm	P. Ret %			
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
A11	913	6365	1107	225	39.05	5.8	11.1	35.6	11.64	13	71.4			
A12	760	2306	1004	150	57.99	4.7	20.0	35.2	14.27	2	89.7			

Horizon	Available T.E. (ppm)						Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water				
A11	<1	1697	53.0	0.8			61.4	54.6	41.7	12.9				
A12	2	728	66.2	1.6			41.9	39.1	29.4	9.7				

Profile No: 57
Soil Group: Lithosol
Family: MELUAN
Series: Meluan
Location: Gunong Api Pinnacles path
Latitude: 4° 7' 49" N
Longitude: 114° 53' 13" E
Date Sampled: 21/8/78

Lab. No: SS.6365/66
Parent Material: Melinau Limestone
Vegetation: Limestone Forest
Slope: 30°, NW, Mid-slope
Altitude: 750 m (2,500 f)
Rainfall: 4,000-5,500 mm p.a.
Drainage: Well drained
Surface features: Many limestone boulders

Horizon	Depth (cm)	Description
A_{11}	0 - 10	Reddish brown (5YR 4/4) clay loam; moist, friable; slightly plastic; moderate medium crumb, many medium and fine pores; many medium roots; many medium hard stones of grey limestone; gradual regular boundary;
A_{12}	10 - 50+	Yellowish red (5YR 5/6) very stony clay; moist to wet, plastic and slightly sticky; common fine pores; common medium roots; abundant hard grey limestone with reddish colours (5YR 5/6) along fracture faces.

Profile No : 57 Soil Group : LITHOSOL Family : MELUAN Series : Meluan Lab. No : SS 6365-636

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2 0.05	0.002		2	1 0.5	0.25	0.1	0.05					
A11	0-10	–	–	–	–	–	–	–	–					
A12	10-50	–	–	–	–	–	–	–	–					

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B Sat %	Ext by KCl (me/	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	
A11	31.2	6.6	6.3	6.61	0.75	9	29.99	0.52	0.24	0.20	28.40	–		
A12	25.8	7.2	6.8	3.65	0.45	8	29.86	0.32	0.12	0.08	18.77	–		

Horizon	"Reserve" analysis ppm				% OD	Total analysis of fine earth % OD			Free Fe_2O_3 %	Avail P ppm	P. Ret %
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3			
A11	1392	5538	3152	3749	47.54				10.23	3	89.2
A12	933	5330	3110	3732	34.89				11.00	3	93.5

Horizon	Available T.E. (ppm)					B	Water content (%OD)			
	Fe	Mn	Zn	Cu	Mo		1/10 bar	1/3 bar	15 bars	Avail water
A11	2	1031	6.5	2.3			50.9	43.1	32.3	10.8
A12	<1	399	4.2	2.0			50.6	40.6	30.8	9.8

Profile No: 5 **Lab. No:** SS.5670/75

Soil Group: Podzol **Parent Material:** Old alluvium

Family: BUSO **Vegetation:** Primary Kerangas Forest

Series: Buso **Slope:** 7°, S, Mid-slope

Location: NE of Lobang Cina Rentis 1 tape 42 **Altitude:** 15 m (50 f)

Latitude: 4° 11' 34" N **Rainfall:** 4,000-5,500 mm p.a.

Longitude: 114° 54' 11" E **Drainage:** Moderately well drained

Date Sampled: 25/4/78 **Surface features:** Thickly littered

Horizon	Depth (cm)	Description
	3 - 0	Thin mor layer (not sampled);
A_1	0 - 9	Very dark greyish brown (10YR 3/2) medium sandy loam; moist, loose; weak granular; abundant medium roots; abrupt wavy boundary to;
A_2	9 - 30	Light grey (10YR 7/2) sand; moist, loose and structureless; few fine roots; humus staining; diffuse wavy change to;
B_{21h}	30 - 40	Dark brown (10YR 3/3) loamy sand; moist, friable and structureless; few fine roots; diffuse wavy change to;
B_{22h}	40 - 54	Yellow brown (10YR 5/6) medium sand, many fine distinct light grey (10YR 7/2) mottles; moist, friable and structureless; quartz grits; diffuse wavy boundary to;

B_{23}	54 - 137	Yellow (10YR 7/6) loamy sand, few to many fine to medium faint to distinct greyish brown mottles; moist, friable; structureless;
B_3	137+	Very pale brown (10YR 7/4) medium sandy loam (auger sample).

Profile No : 5 Soil Group : PODZOL Family : BUSO Series : Buso Lab. No : SS. 5670 - 5

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2 0.05	0.05 0.002		2	1 0.5	0.5 0.25	0.25 0.1	0.1 0.05					
A1	0-9	–	–	–	–	–	–	–	–	–				
A2	9-30	89.2	8.2	2.6	2.0	6.1	20.0	34.1	27.0	S				
B21h	30-40	85.5	8.5	6.0	1.8	5.8	20.6	33.1	24.2	L S				
B22h	40-54	–	–	–	–	–	–	–	–	–				
B23h	54-137	81.8	7.4	10.8	1.7	6.2	22.0	31.3	20.6	L S				
B3	137+	–	–	–	–	–	–	–	–	–				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100g	B. Sat. %	Ext. by KCl (m	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	
A1	4.4			1.36	0.12	11	0.50	0.08	0.10	0.27	12.01	7.9		
A2	0.8			0.32	0.04	8	0.50	0.02	0.04	0.26	4.03	20.3	0.15	C
B21h	2.4			1.07	0.03	36	0.50	<0.01	0.04	0.28	4.83	17.0		
B22h	2.7			0.79	0.04	20	0.50	<0.01	0.04	0.24	5.65	13.8		
B23h	2.3			0.42	0.01	42	0.55	0.02	0.03	0.23	3.83	21.7		
B3	2.8			0.35	0.01	35	0.59	<0.01	0.05	0.33	5.08	19.1		

Horizon	"Reserve" analysis					Total analysis of Clay			Free Fe_2O_3 %	Avail P ppm	P. Ret %	PYROPHOSPHATE EXT.	
	ppm				% OD	% OD							
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3				Fe(ppm)	C(%)
A1	58	126	76	89	0.00	–	–	–	0.02	6	1.5	81	0.26
A2	18	63	75	25	0.18	61.4	1.1	9.2	0.01	<1	1.4	10	0.12
B21h	40	T	252	629	0.91	44.6	2.0	29.3	0.02	40	14.5	101	0.73
B22h	40	25	316	757	1.80	43.4	2.8	31.6	0.02	<1	23.2	121	0.73
B23h	47	13	580	1462	3.51	40.3	5.2	32.7	0.22	<1	30.5	1290	0.50
B3	–	–	–	–	–	–	–	–	0.12	4	20.3	1230	0.38

Horizon	Available T.E. (ppm)						Water content (%OD)				PH(Moist)			
	Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water	H2O (1:2.5)			
A1	33	2	1.7	1.5	0.5	0.07	30.1	8.7	–	–	4.9			
A2	23	1	0.9	1.0	0.1	0.03	17.9	7.4	1.8	5.6	4.6			
B21h	43	1	1.4	1.3	1.0	0.06	23.4	11.8	4.2	7.6	4.3			
B22h	28	1	1.3	1.3	0.11	0.06	21.6	12.7	6.0	6.7	4.1			
B23h	26	1	0.6	2.3	0.3	0.02	24.7	14.6	7.7	6.9	4.4			
B3	55	1	2.6	1.9	0.3	0.03	14.0	–	–	–	4.3			

Profile No: 71 **Lab. No:** SS.6252/56

Soil Group: Podzol **Parent Material:** Alluvial sandstone

Family: BUSO

Series: Buso **Vegetation:** Kerangas Forest

Location: Kerangas Plot at A_2 **Slope:** Relatively flat

Latitude: 4° 9' 6" N **Altitude:** 50 m (165 f)

Longitude: 114° 53' 4" E **Rainfall:** 4,000-5,500 mm p.a.

Date Sampled: 21/7/78 **Drainage:** Imperfectly drained

Surface features: Well littered, uneven surface

Horizon	Depth (cm)	Description
O_1	4 - 0	Abundant fine and medium roots;
A_1	0 - 4	Dark reddish brown (5YR 3/2) silt loam, many medium distinct reddish grey (5YR 5/2) mottles; moist, friable; weak medium subangular blocky; many fine and medium roots; clear wavy boundary;
A_{21}	4 - 24	Reddish grey (5YR 5/2) loamy fine sand, few fine distinct reddish brown mottles; moist, wet, friable; weak medium subangular blocky; can be broken to single grain; many fine and medium roots; clear irregular boundary;
A_{22}	24 - 38	Light grey (2.5Y 7/2) fine sandy loam, many fine distinct brown (10YR 5/3) mottles; moist, friable; structureless; bouldery, few fine roots; clear wavy boundary;

B_{2h}	38 - 63	*Dark reddish brown (5YR 2.5/2) sandy clay loam, many coarse faint brown mottles; weak medium and coarse angular blocky; few fine and medium roots; clear wavy boundary;*
C	*63+*	*Mainly unweathered boulders coated with black humic material.*

Profile No : 71 Soil Group : PODZOL Family : BUSO Series : Buso Lab. No : SS6252-6256

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1	0.05				
01	4-0	-	-	-	-	-	-	-	-	-				
A1	0-4	-	-	-	-	-	-	-	-	-				
A21	4-24	77.5	15.4	7.1	0.4	2.7	13.6	29.9	30.9	LFS				
A22	24-38	76.2	17.1	6.7	0.5	2.9	15.9	29.2	27.7	FSL				
B2h	38-63	55.7	19.8	24.5	0.8	3.1	12.3	20.5	19.0	SCL				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B Sat %	Ext. by KCl (me/l	
		H_2O (1:1)	1ON KCl (1:1)				Ca	Mg	K	Na			Al	H
01		3.3	3.1	35.41	0.35	101	1.44	<0.01	1.72	0.10	75.11	4.3	0.55	6.8
A1		3.9	3.2	6.65	0.27	25	0.98	1.61	0.43	0.07	44.73	6.9	0.03	0.9
A21		4.0	2.6	1.93	0.07	28	<0.01	0.08	0.04	<0.01	37.11	0.3	0.21	0.7
A22		4.3	2.9	1.67	0.01	167	<0.01	0.01	0.02	<0.01	4.77	0.6	0.18	0.2
B2h		3.9	3.3	7.81	0.13	60	<0.01	0.01	0.02	<0.01	2.41	1.2	9.59	0.0

Horizon	"Reserve" analysis ppm				% OD	Total analysis of fine earth %OD			Free Fe_2O_3 % pmm	Avail P ppm	P. Ret %	PYROPHOSPHATE EXT.	
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3				Fe(ppm)	C(%)
01	332	628	434	464	0.28				203	126	1.9	12	2.36
A1	177	2320	353	421	0.38				450	18	1.8	396	1.03
A21	23	75	50	8	0.00				27	5	0.8	18	0.25
A22	13	25	50	1904	0.00				13	<1	1.6	10	0.22
B2h	43	T	294	1789	1.31				57	<1	54.3	48	5.07

Horizon	Available T.E. (ppm)						Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water				
01	22	22	10.2	0.6		0.61								
A1	310	23	6.4	0.8		0.24								
A21	2	<1	1.4	0.2		0.07								
A22	1	<1	1.1	0.9		0.11								
B2h	1	<1	1.5	0.2		0.12								

Profile No: 45

Soil Group: Gley Soil

Family: TUMAU

Series: Tumau

Location: Altitudinal Zonation Plot H Line 3

Latitude: 4° 2' 31" N

Longitude: 114° 54' 24" E

Date Sampled: 6/8/78

Lab. No: SS.6300/03

Parent Material: Mulu Formation siltstone

Vegetation: Lower Montane Rainforest

Slope: 30°, NE, Upper slope

Altitude: 1,650 m (5,560 f)

Rainfall: 4,000-5,500 mm p.a.

Drainage: Imperfectly drained

Surface features: Moss, leaf and log litter

Horizon	Depth (cm)	Description
A_1	0 - 14/22	Brown to dark brown (7.5YR 4/4) humic silty clay; moist to wet, loose to friable; weak fine crumbly; common fine pores; abundant fine medium and coarse roots; clear wavy boundary;
A_{2g}	14/22 - 44/60	Light grey (10YR 7/2) silty clay; common medium prominent reddish yellow and reddish brown mottles; wet, sticky, very plastic; massive structure; weak discontinuous faint humic stain in cracks; many medium pores; many fine to medium live and dead roots; clear wavy boundary;
B_{21}	44/60 - 60/70	Greyish brown (10YR 5/2) humic silty clay loam, common medium faint greyish brown and pale brown mottles; wet, slightly sticky and very plastic; weak medium subangular blocky; weak

			discontinuous faint humic stain in cracks; few medium pores; many to common fine to medium live and dead roots; many fragments of leaves, in places quite peaty dark greyish brown (10YR 4/2); clear wavy boundary;
B_{22}	60/70	- 70/90	*Pale brown (10YR 6/3) silty clay, few medium distinct reddish yellow and reddish brown mottles; wet, plastic and sticky; massive structure; common medium pores; common medium roots; few medium slightly hard grey weathered siltstones and slate; clear wavy boundary;*
C	70/90	- 110+	*Olive brown, weathered siltstones and sandstones with patches of brownish yellow (10YR 6/6) sandy clay loam; mottles are of sandstones colours of red and yellow; moist to wet; slightly hard to hard siltstones dominant.*

Profile No : 45 Soil Group : GLEY SOIL Family : TUMAU Series : Tumau Lab. No : SS 6300 - 63

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1 0.05					
A1	0-14/22	7.7	51.8	40.5	1.3	1.5	1.0	0.8	3.1	SiC				
A2g	14/44/22-60	14.0	42.9	43.1	0.4	0.7	0.5	1.0	11.4	SiC				
B21	44/60/60-70	13.6	51.8	34.6	0.2	0.5	0.4	0.7	11.8	SiCL				
B22	60/70/70-90	12.9	44.2	42.9	0.6	0.9	0.7	1.2	9.5	SiC				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B. Sat. %	Ext by KCl (me	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	
A1	31.1	4.2	3.6	11.89	0.78	15	0.11	0.19	0.36	0.03	27.18	2.5		
A2g	8.2	4.2	3.5	2.17	0.17	13	0.51	<0.01	0.07	0.02	18.56	3.3		
B21	12.6	4.2	3.8	3.52	0.23	15	0.52	<0.01	0.06	0.01	14.02	4.3		
B22	8.1	4.2	3.8	1.80	0.15	12	0.67	<0.01	0.09	0.03	8.27	9.7		

Horizon	"Reserve" analysis					Total analysis of fine earth			Free Fe_2O_3 %	Avail P ppm	P. Ret %			
	ppm				% OD	% OD								
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
A1	217	T	1043	5671	11.24				5.51	2	79.6			
A2g	29	25	1197	6776	7.32				0.99	1	36.2			
B21	60	26	1173	6392	7.04				0.64	1	62.2			
B22	37	76	1654	7431	9.50				1.56	1	38.7			

Horizon	Available T.E. (ppm)						Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water				
A1	973	10	3.4	3.2			95.4	72.9	36.3	36.6				
A2g	185	<1	1.9	1.8			71.0	51.3	16.0	35.3				
B21	405	4	1.7	3.7			79.4	59.1	15.4	43.7				
B22	611	36	2.4	3.4			67.7	49.8	17.2	32.6				

Profile No: 46

Soil Group: Gley Soil

Family: TUMAU

Series: Tumau

Location: Altitudinal Zonation Plot T Line 1

Latitude: 4° 2' 47" N

Longitude: 114° 54' 55" E

Date Sampled: 10/7/78

Lab. No: SS.6304/08

Parent Material: Mulu Formation slate

Vegetation: Primary Lower Montane Forest

Slope: 39°, N, Upper slope

Altitude: 1,860 m (6,200 f)

Rainfall: 4,000-5,500 mm p.a.

Drainage: Poorly drained

Surface features: Mossy peat hummocks about 3-5 m apart up to 70-100 cm high

Horizon	Depth (cm)	Description
O_1	45 - 30	Dark reddish brown (5YR 2/2) fibric leaf peat; very wet; abundant medium and coarse roots; gradual boundary;
O_2	30 - 0	Dark reddish brown (5YR 2/2) fibric-hemic peat; very wet; abundant medium coarse roots; clear regular boundary;
A_1	0 - 10/15	Light yellowish brown (10YR 6/4) silty clay loam, common medium faint brown and grey mottles; very wet, plastic and slightly sticky; very weak to structureless fine subangular to angular blocky; moisture skins; very few coarse pores; common medium to coarse roots; clear slightly wavy boundary;
A_{2g}	10/15 - 20/30	Light grey (10YR 7/2) silty clay, many medium prominent reddish yellow, reddish brown mottles; very wet, very plastic and very sticky; massive to very weak

fine subangular blocky; few weak organic stains and very weak moisture clayskins; rare coarse pores; few medium roots; clear wavy boundary;

B_{1-3}	20/30 - 60/85+	Reddish yellow (7.5YR 6/8) silty clay; common increasing to many patches of reddish yellow and strong weathering slate, with black cleavage planes; moist to wet, plastic and sticky; moderate coarse subangular blocky; few medium and fine roots; gradual very wavy boundary;
R	60/85+	Hard grey slate, black cleavage planes; dipping about 45° to east.

Profile No : 46 Soil Group : GLEY SOIL Family : TUMAU Series : Tumau Lab. No : SS 6304 - 6308

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density	Fiber content		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2 0.05	0.05 0.002		2	1 0.5	0.5 0.25	0.25 0.1	0.1 0.05		g/cc	%		
01	45-30	-	-	-	-	-	-	-	-			32.1		
02	30-0	-	-	-	-	-	-	-	-			38.4		
A1	0-10	12.7	47.7	39.6	0.1	0.6	0.7	1.1	10.2	SiCL				
A2g	10-20	14.9	41.3	43.8	0.6	1.6	1.2	1.6	9.9	SiC				
B1-3	20-60	15.9	40.4	43.7	0.6	1.4	1.7	2.6	9.6	SiC				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B. Sat. %	Ext. by KCl (me/100	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
01	95.3	3.4	2.2	40.92	1.78	23	0.05	2.06	1.54	0.23	51.60	7.5		
02	92.5	3.4	2.1	39.89	1.72	23	0.12	0.67	1.11	0.25	72.00	3.0		
A1	14.6	4.1	3.1	4.56	0.34	13	0.05	0.19	0.11	0.05	19.00	2.1		
A2g	10.3	4.2	3.2	2.64	0.22	12	0.41	0.10	0.04	0.03	12.60	4.6		
B1-3	8.5	4.5	3.4	0.83	0.13	6	0.62	0.08	0.03	0.02	13.60	5.5		

Horizon	"Reserve" analysis					Total analysis of fine earth			Free Fe_2O_3 %	Avail P ppm	P. Ret %			
	ppm				% OD	% OD								
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
01	371	30	419	897	0.69	-	-	-	-	89	-			
02		89	417	476	1.43	-	-	-	-	92	10.8			
A1	99	T	912	3855	5.55	68.5	3.2	13.1	2.22	4	76.6			
A2g	51	T	951	4163	4.25	62.3	4.0	17.8	3.50	<1	60.3			
B1-3	80	T	1336	5654	13.65	59.6	7.9	20.4	5.98	<1	51.8			

Horizon	Available T.E. (ppm)						Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water				
01	64	19	15.7	2.5			136.8	122.9	-					
02	155	15	14.8	2.1			129.1	118.0	-					
A1	2560	<1	1.8	1.6			75.8	61.4	32.5	28.9				
A2g	450	<1	1.2	1.5			72.4	60.1	35.0	25.1				
B1-3	330	2	1.1	1.1			59.1	57.4	27.9	29.5				

Repeated pages

Profile No: 46 **Lab. No:** SS.6304/08

Soil Group: Gley Soil **Parent Material:** Mulu Formation slate

Family: TUMAU

Series: Tumau **Vegetation:** Primary Lower Montane Forest

Location: Altitudinal Zonation Plot T Line 1 **Slope:** 39°, N, Upper slope

Latitude: 4° 2' 47" N **Altitude:** 1,860 m (6,200 f)

Longitude: 114° 54' 55" E **Rainfall:** 4,000-5,500 mm p.a.

Date Sampled: 10/7/78 **Drainage:** Poorly drained

Surface features: Mossy peat hummocks about 3-5 m apart up to 70-100 cm high

Horizon	Depth (cm)	Description
O_1	45 - 30	Dark reddish brown (5YR 2/2) fibric leaf peat; very wet; abundant medium and coarse roots; gradual boundary;
O_2	30 - 0	Dark reddish brown (5YR 2/2) fibric-hemic peat; very wet; abundant medium coarse roots; clear regular boundary;
A_1	0 - 10/15	Light yellowish brown (10YR 6/4) silty clay loam, common medium faint brown and grey mottles; very wet, plastic and slightly sticky; very weak to structureless fine subangular to angular blocky; moisture skins; very few coarse pores; common medium to coarse roots; clear slightly wavy boundary;
A_{2g}	10/15 - 20/30	Light grey (10YR 7/2) silty clay, many medium prominent reddish yellow, reddish brown mottles; very wet, very plastic and very sticky; massive to very weak

		fine subangular blocky; few weak organic stains and very weak moisture clayskins; rare coarse pores; few medium roots; clear wavy boundary;
B_{1-3}	20/30 - 60/85+	Reddish yellow (7.5YR 6/8) silty clay; common increasing to many patches of reddish yellow and strong weathering slate, with black cleavage planes; moist to wet, plastic and sticky; moderate coarse subangular blocky; few medium and fine roots; gradual very wavy boundary;
R	60/85+	Hard grey slate, black cleavage planes; dipping about 45° to east.

Profile No : 46 Soil Group : GLEY SOIL Family : TUMAU Series : Tumau Lab. No : SS 6304 - 6308

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1 0.05					
01	45-30	–	–	–	–	–	–	–	–					
02	30-0	–	–	–	–	–	–	–	–			32.1		
A1	0-10	12.7	47.7	39.6	0.1	0.6	0.7	1.1	10.2	SiCL		38.4		
A2g	10-20	14.9	41.3	43.8	0.6	1.6	1.2	1.6	9.9	SiC				
B1-3	20-60	15.9	40.4	43.7	0.6	1.4	1.7	2.6	9.6	SiC				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B. Sat. %	Ext. by KCl (me/100g)	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
01	95.3	3.4	2.2	40.92	1.78	23	0.05	2.06	1.54	0.23	51.60	7.5		
02	92.5	3.4	2.1	39.89	1.72	23	0.12	0.67	1.11	0.25	72.00	3.0		
A1	14.6	4.1	3.1	4.56	0.34	13	0.05	0.19	0.11	0.05	19.00	2.1		
A2g	10.3	4.2	3.2	2.64	0.22	12	0.41	0.10	0.04	0.03	12.60	4.6		
B1-3	8.5	4.5	3.4	0.83	0.13	6	0.62	0.08	0.03	0.02	13.60	5.5		

Horizon	"Reserve" analysis ppm				% OD	Total analysis of fine earth % OD			Free Fe_2O_3 %	Avail P ppm	P. Ret %
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3			
01	371	30	419	897	0.69	–	–	–	–	89	–
02		89	417	476	1.43	–	–	–	–	92	10.8
A1	99	T	912	3855	5.55	68.5	3.2	13.1	2.22	4	76.6
A2g	51	T	951	4163	4.25	62.3	4.0	17.8	3.50	<1	60.3
B1-3	80	T	1336	5654	13.65	59.6	7.9	20.4	5.98	<1	51.8

Horizon	Available T.E. (ppm)					B	Water content (%OD)			
	Fe	Mn	Zn	Cu	Mo		1/10 bar	1/3 bar	15 bars	Avail. water
	64	19	15.7	2.5			136.8	122.9	–	
	155	15	14.8	2.1			129.1	118.0	–	
	2560	<1	1.8	1.6			75.8	61.4	32.5	28.9
	450	<1	1.2	1.5			72.4	60.1	35.0	25.1
	330	2	1.1	1.1			59.1	57.4	27.9	29.5

Profile No: 9 **Lab. No:** SS.5638/41

Soil Group: Alluvial Soil **Parent Material:** Alluvium

Family: BEMANG **Vegetation:** Primary Forest

Series: Bemang **Slope:** Flat

Location: NW of Sg. Berar Camp Rentis 10 tape 9 **Rainfall:** 4,000-5,500 mm p.a.

Latitude: 4° 10' 4" N **Drainage:** Imperfectly drained

Longitude: 114° 51' 13" E **Surface features:** Common low limestone outcrops, roots and dead leaves

Date Sampled: 4/5/78

Horizon	Depth (cm)	Description
O_1	2 - 0	Root mat and fallen leaves (not sampled);
A_1	0 - 10	Dark greyish brown (10YR 4/2) very fine sandy clay loam, many fine distinct rusty mottles; moist, friable to slightly wet, slightly sticky and slightly plastic; moderately strong fine subangular blocky; many medium roots; iron coating along root channels; gradual to diffuse wavy change to;
AC	10 - 20	Brown (10YR 5/3) clay loam, many fine distinct strong brown (7.5YR 5/6) mottles; moist to slightly wet, firm slightly sticky and plastic; moderately strong medium subangular blocky; few fine roots; iron staining along root-channels and cracks; diffuse wavy boundary to;
C_1	20 - 85	Yellowish brown (10YR 5/8) clay loam, many fine faint red (2.5YR 5/8) mottles;

		moist to slightly wet, firm to slightly sticky; massive; few fine roots; iron staining along root-channels and cracks; diffuse boundary to;
IIC_2	85 - 130	*Brownish yellow (10YR 6/6) fine sandy clay loam, many fine distinct strong brown (7.5YR 5/6) mottles; moist, friable to wet slightly plastic and slightly sticky; structureless; more sandy at depth.*

Profile No : 9 Soil Group : ALLUVIAL SOIL Family : BEMANG Series : Bemang Lab. No : SS 5638-5641

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1 0.05					
A1	0-10	45.0	25.6	29.4	0.1	0.2	2.4	12.1	30.3	SCL				
AC	10-20	44.2	25.7	30.1	0.2	0.3	2.2	11.4	30.1	CL				
C1	20-85	41.0	27.0	32.0	0.2	0.1	1.5	9.0	30.2	CL				
IIC2	85-130	67.1	11.0	21.9	0.0	0.2	6.1	40.1	20.7	SCL				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100g	B. Sat. %	Ext. by KCl (me/10	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
A1				1.63	0.16	10	11.30	0.39	0.14	0.14	14.80	–	T	0.08
AC				1.10	0.12	9	10.48	0.32	0.15	0.12	12.32	–	T	0.05
C1				0.39	0.06	7	9.41	0.13	0.12	0.09	6.55	–	T	T
IIC2				0.23	0.03	8	8.10	0.10	0.10	0.07	5.67	–	0.03	T

Horizon	"Reserve" analysis ppm				% OD	Total analysis of Clay %OD			Free Fe_2O_3 %	Avail P ppm	P. Ret %	PH (Moist)	
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3				H2O (1:2.5)	
A1	265	2210	2038	3701	7.09	47.9	7.6	27.4	3.45	< 1	27.4	5.8	
AC	246	2028	2100	3800	7.81	47.3	7.6	28.2	3.76	< 1	28.8	5.9	
C1	184	1407	2350	2762	9.10	46.7	7.9	28.5	3.91	< 1	27.2	5.9	
IIC2	137	785	1375	2634	4.44	47.3	8.4	28.0	2.77	< 1	14.6	5.9	

Horizon	Available T.E. (ppm)						Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water				
A1	144	101	0.8	2.2	14.0	0.16	48.9	35.2	16.4	18.8				
AC	128	102	0.6	2.2	22.6	0.20	46.4	32.8	15.6	17.2				
C1	59	37	0.2	2.4	8.4	0.06	40.3	30.7	18.1	12.6				
IIC2	38	27	0.1	1.9	4.5	0.08	38.5	19.6	9.6	10.0				

Profile No: 4

Soil Group: Alluvial Soil

Family: BEMANG

Series: Semilajau

Location: SW of Lobang Cina
Rentis 4 tape 20

Latitude: 4° 11' 0" N

Longitude: 114° 53' 42" E

Date Sampled: 25/4/78

Lab. No: SS.5642/49

Parent Material: Sedimentary alluvium

Vegetation: Primary forest

Slope: Flat

Rainfall: 4,000-5,500 mm p.a.

Drainage: Moderately well drained

Surface features: Thinly littered

Horizon	Depth (cm)	Description
A_1	0 - 3	Dark brown to brown (10YR 4/3) loam; moist, friable; medium granular; many medium roots; abrupt smooth boundary to;
C_1	3 - 8	Brownish yellow (10YR 6/8) very fine sandy loam, few medium faint dark brown mottles; moist, friable; weak medium subangular blocky to structureless; few fine roots; diffuse wavy boundary to;
C_2	8 - 20	Yellow (10YR 7/8) sandy clay loam; moist, friable; structureless; many fine roots; gradual wavy boundary to;
C_3	20 - 40	Brownish yellow (10YR 6/6) very fine sandy loam; moist, friable; structureless; few fine roots; gradual wavy boundary to;
C_4	40 - 75	Yellow (10YR 8/8) fine sandy loam, few medium to coarse faint to distinct greyish brown mottles; moist, friable;

		structureless; few fine roots; few quartz grits; gradual wavy boundary to;
C_5	75 - 95	*Yellow (10YR 8/6) very fine sandy loam, many medium distinct brownish yellow mottles; moist, slightly firm; structureless; few quartz grits; few fine roots; distinct wavy boundary to;*
C_{6g}	95 - 110	*Grey (10YR 6/1) very fine sandy loam, many medium distinct yellowish brown mottles; moist, firm; structureless.*

Profile No : 4 Soil Group : ALLUVIAL SOIL Family : BEMANG Series : Semilajau Lab. No : SS 5642 – 5

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1	0.05				
A1	0-3	–	–	–	–	–	–	–	–					
C1	3-8	65.5	17.1	17.4	0.0	0.4	10.1	26.8	28.2	VFSL				
C2	8-20	59.5	19.1	21.4	0.0	0.7	9.7	24.1	25.0	SCL				
C3	20-40	63.4	17.0	19.6	0.0	1.0	10.7	27.6	24.1	VFSL				
C4	40-75	76.9	10.7	12.4	1.3	3.8	18.7	33.5	19.6	FSL				
C5	75-95	68.2	16.1	15.7	0.5	3.0	13.6	25.1	26.0	VFSL				
C6g	95-110	61.4	20.3	18.3	0.1	0.5	6.2	21.1	33.5	VFSL				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100g	B. Sat. %	Ext. by KCl (me	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	
A1				4.77	0.42	11	3.94	0.31	0.43	0.07	23.64	20.1		
C1				1.16	0.12	10	0.81	<0.01	0.12	0.08	10.37	9.8		
C2				0.68	0.06	11	0.41	<0.01	0.09	0.03	9.15	5.9		
C3				0.42	0.04	11	0.61	<0.01	0.08	0.03	4.87	14.9	1.91	0.(
C4				0.20	0.02	10	0.75	<0.01	0.09	0.03	3.40	25.6		
C5				0.10	0.02	5	0.81	<0.01	0.06	0.01	3.85	41.8		
C6g				0.07	0.01	7	1.21	<0.01	0.31	0.28	4.23	42.8		

Horizon	"Reserve" analysis ppm				% OD	Total analysis of Clay %OD			Free Fe_2O_3 %	Avail P ppm	P. Ret %	PH(Moist) H2O 1:2.5		
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
A1	290	311	713	3215	2.28	–	–	–	0.90	21	35.8	3.8		
C1	132	64	875	3458	3.74	43.7	6.5	29.0	1.41	3	47.6	4.5		
C2	110	64	1275	4475	4.86	42.9	7.1	31.1	1.81	<1	45.4	4.6		
C3	95	25	1513	5324	6.27	42.4	6.5	31.8	1.86	<1	40.1	5.1		
C4	81	25	1354	4220	4.11	42.0	7.1	32.0	1.32	<1	24.9	5.0		
C5	60	25	1259	4632	4.66	46.0	5.1	32.7	0.75	<1	23.2	5.7		
C6g	38	T	1512	5342	5.09	45.0	3.4	32.5	0.30	<1	17.4	5.2		

rizon	Available T.E. (ppm)						Water content (%OD)								
	Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water					
A1	240	4	2.1	1.3	3.3	0.19	–	–	–	–					
C1	357	2	0.2	1.1	3.4	0.12	57.1	27.5	8.1	19.4					
C2	221	2	0.5	1.7	8.5	0.09	57.2	29.2	9.0	20.2					
C3	202	2	1.7	1.4	6.7	0.09	45.1	25.6	7.7	19.9					
C4	149	2	0.9	1.6	7.3	0.05	34.0	17.6	6.7	10.9					
C5	105	2	0.5	1.1	4.6	0.06	35.2	20.7	8.9	11.8					
6g	112	2	1.2	1.9	2.1	0.16	35.8	21.6	10.0	10.6					

Profile No: 19 **Lab. No:** SS.6265/67

Soil Group: Regosol **Parent Material:** Colluvium from Mulu Formation

Family: TUTOH

Series: Tutoh **Vegetation:** Mixed Dipterocarp Forest

Location: Altitudinal Zonation, Plot B Line 1 **Slope:** 10°, N, Upper slope

Latitude: 4° 3' 6" N **Altitude:** 130 m (430 f)

Longitude: 114° 51' 0" E **Rainfall:** 4,000-5,500 mm p.a.

Date Sampled: 17/7/78 **Drainage:** Well drained

Surface features: Few hard grey fine sandstone or siltstone boulders

Horizon	Depth (cm)	Description
O	2 - 0	Very dark brown; leaf and root litter; fibrous-amorphous; abundant medium to fine roots; clear regular boundary;
A_1	0 - 12	Brownish yellow (10YR 6/6) silt loam, common medium distinct grey, reddish brown and brown mottles; moist, slightly firm; moderate medium to fine subangular blocky; few medium soft charcoals; few fine pores; common to few fine, medium and coarse roots; gradual slightly wavy boundary;
B_2	12 - 42	Yellow (10YR 7/8) silty clay loam; moist, slightly firm; moderate medium subangular blocky; few medium pores; common medium and coarse roots; clear regular boundary;

C	42 - 65+	*Yellow (10YR 7/8) stony, silty clay, common medium faint yellow and reddish yellow mottles; moist, firm; moderate medium subangular blocky; many to abundant medium to coarse hard subrounded grey siltstones and sandstones; very few medium pores; few coarse roots.*

Profile No : 19 Soil Group : REGOSOL Family : TUTOH Series : Tutoh Lab. No : SS 6265 –

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %	
		Total (% of < 2 mm)			Sand (% of < 2 mm)								
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F				
		2 – 0.05	0.05 – 0.002		2 – 1	1 – 0.5	0.5 – 0.25	0.25 – 0.1	0.1 – 0.05				
A1	0–12	36.1	32.3	31.6	0.2	0.7	0.6	3.7	30.9	CL			
B2	12–42	36.6	29.1	34.3	0.1	0.6	0.7	3.1	32.1	CL			
C	42–65	35.7	28.9	35.4	0.1	0.7	1.1	3.6	30.2	CL			

Horizon	Loss on ignition %	pH (air – dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B. Sat %	Ext. by KCl (n	
		H_2O (1:1)	ION KCl (1:1)				Ca	Mg	K	Na			Al	
A1		4.0	3.4	2.77	0.24	12	0.52	0.08	0.10	0.04	16.40	4.5	–	
B2		4.4	3.7	0.93	0.10	9	0.21	0.08	0.09	0.10	8.40	5.7	5.02	
C		4.5	3.6	0.40	0.07	6	0.26	0.08	0.12	0.09	10.20	5.4	4.20	

Horizon	"Reserve" analysis ppm				% OD	Total analysis of fine earth % OD			Free Fe_2O_3 %	Avail P ppm	P. Ret %			
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
A1	120	T	1569	3870	7.77				1.82	6	68.3			
B2	77	T	2034	4223	9.53				2.27	< 1	63.0			
C	51	T	2223	5110	10.02				2.28	< 1	43.1			

Horizon	Available T.E. (ppm)					B	Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo		1/10 bar	1/3 bar	15 bars	Avail water				
A1	317	2	5.8	1.3			62.4	42.5	19.1	23.4				
B2	210	1	12.4	1.1			58.2	40.9	20.2	20.7				
C	138	1	1.5	1.5			50.6	37.6	18.6	19.0				

Profile No: 7 **Lab. No:** SS.5679/83

Soil Group: Red-Yellow Podzolic

Family: MERIT **Parent Material:** Sandstone and shale

Series: Merit

Location: NW of Sg. Berar Camp Rentis 10 tape 56 **Vegetation:** Mixed Dipterocarp Forest

Latitude: 4° 10' 20" N **Slope:** 25°, SE, Lower - mid slope

Longitude: 114° 50' 45" E **Altitude:** 170 m (560 f)

Date Sampled: 2/5/78 **Rainfall:** 4,000-5,500 mm p.a.

Drainage: Imperfectly drained

Surface features: Thinly littered with dead leaves and twigs

Horizon	Depth (cm)	Description
	2 - 0	Root mat (not sampled);
A_1	0 - 5	Yellowish brown (10YR 5/4) sandy clay loam; moist, friable; medium granular; many medium roots; diffuse wavy boundary to;
B_1	5 - 30	Brownish yellow (10YR 6/8) clay loam, few medium distinct grey and rusty mottles; medium subangular blocky; few coarse roots; gradual wavy boundary to;
B_{21t}	30 - 60	Yellow (10YR 7/8) clay loam, many medium distinct brownish yellow mottles; moist, firm; weak medium subangular blocky; few soft shale and sandstone fragments; few medium roots; patchy clayskin; organic stain along root channels; gradual boundary to;

Profile No: 7 Lab. No: 56.5529/93

Soil Group: Red-Yellow Podzolic

Family: MERIT

Series: Merit

Location: NW of Sp. Berar Camp

Rentis 10 tape 56

Latitude: 4° 10' 20" N

Longitude: 114° 50' 45" E

Date Sampled: 2/5/78

Parent Material: Sandstone and shale

Vegetation: Mixed Dipterocarp Forest

Slope: 25°, SE, lower - mid slope

Altitude: 170 m (560 ft)

Rainfall: 4,000-5,500 mm p.a.

Drainage: Imperfectly drained

Surface features: Thinly littered with dead leaves and twigs

Horizon	Depth (cm)	Description
	2 - 0	Root mat (not sampled)
A_1	0 - 5	Yellowish brown (10YR 5/4) sandy clay loam, moist, friable, medium granular; many medium roots; diffuse wavy boundary to:
B_1	5 - 30	Brownish yellow (10YR 6/8) clay loam; few medium distinct grey and ruddy mottles; medium subangular blocky; few coarse roots; gradual wavy boundary to:
B_{21t}	30 - 60	Yellow (10YR 7/8) clay loam, many medium distinct brownish yellow mottles moist, firm; weak medium subangular blocky; few soft shale and sandstone fragments; few medium roots; patchy clayskin; organic stain along root channels; gradual boundary to:

B_{22t}	60 - 80	Reddish yellow (7.5YR 6/8) clay, abundant fine to medium distinct grey and strong brown mottles; moist, very firm to slightly wet, slightly sticky and slightly plastic; weak medium blocky; many grits of soft shale, sandstone and iron concretion; few fine roots; diffuse change to;
B_{23t}	80 - 120	Reddish yellow (7.5YR 6/8) clay, abundant medium distinct yellowish brown and yellowish red mottles; moist, firm; slightly sticky and plastic; weak medium blocky to almost structureless; many platy soft iron concretions.

Profile No : 7 Soil Group : RED-YELLOW PODZOLIC SOIL Family : MERIT Series : Merit Lab. No : SS 5679 – 5

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1 0.05					
A1	0 – 5	48.1	26.9	25.0	0.2	0.4	2.8	11.0	33.7	SCL				
B1	5 – 30	39.6	27.2	33.2	0.3	0.3	1.0	8.0	30.0	CL				
B21t	30 – 60	39.9	26.4	33.7	0.6	0.9	2.0	8.3	28.1	CL				
B22t	60 – 80	33.5	25.9	40.6	0.4	0.5	1.2	5.0	26.4	C				
B23t	80 – 120	29.9	25.4	44.7	0.5	1.4	2.1	5.0	20.9	C				

Horizon	Loss on ignition %	pH (air – dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B Sat %	Ext. by KCl (me	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	
A1				2.51	0.19	13	–	–	–	–	–	–		
B1				0.53	0.06	9	0.56	<0.01	0.08	0.27	9.81	9.4	7.18	0
B21t				0.40	0.05	8	0.51	<0.01	0.08	0.27	–	–	6.71	0
B22t				0.23	0.04	6	0.56	0.08	0.08	0.27	8.79	11.3	7.39	0
B23t				0.26	0.05	5	0.51	0.09	0.09	0.30	10.04	9.4	7.98	0

Horizon	"Reserve" analysis ppm				% OD	Total analysis of Clay % OD			Free Fe_2O_3 %	Avail P ppm	P Ret %	PH(Moist) H2O 1:2.5		
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
A1	121	26	1261	2675	3.76	45.0	6.9	25.9	2.18	<1	49.6	4.2		
B1	92	T	1840	3935	6.83	46.7	8.6	29.6	2.86	<1	47.1	4.1		
B21t	82	26	2068	5411	8.30	45.9	7.9	29.2	3.32	<1	40.4	4.2		
B22t	92	T	2070	3781	7.87	46.3	8.7	30.1	4.03	<1	39.0	4.2		
B23t	97	T	2406	5427	10.19	46.0	9.2	29.7	5.04	<1	39.1	4.4		

Available T.E. (ppm)						Water content (%OD)							
Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail water				
330	4	0.5	2.0	22.6		62.5	39.0	19.5	19.5				
164	2	1.7	2.2	27.1		41.8	34.4	17.8	16.6				
106	1	1.3	2.0	30.6		47.5	31.8	21.4	10.4				
75	1	1.2	1.9	9.0		53.9	35.5	25.4	10.1				
60	1	0.2	2.4	15.1		53.5	37.7	26.9	10.8				

Profile No: 27 **Lab. No:** SS.6344/47

Soil Group: Red-Yellow Podzolic

Family: MERIT

Series: Merit

Parent Material: Colluvium from Mulu Formation siltstone and sandstone

Location: Altitudinal Zonation Plot D Line 1

Vegetation: Mixed Dipterocarp Forest

Latitude: 4^{o} 2' 42" N

Slope: 26^{o}, N, Upper mid-slope

Longitude: 114^{o} 52' 11" E

Altitude: 500 m (1,640 f)

Date Sampled: 15/7/78

Rainfall: 4,000-5,500 mm p.a.

Drainage: Well drained

Surface features: Rare hard grey sandstones, moderate tree root stepping

Horizon	Depth (cm)	Description
O_1	1 - 0	Dark brown litter and roots; moist, fibrous; abundant fine, medium and coarse roots; clear regular boundary;
A_1	0 - 6/9	Brown to dark brown (7.5YR 4/4) loam, few medium faint brownish grey mottles; moist, friable; weak fine crumb; many fine pores; many fine to medium roots; clear wavy boundary
A_3	6/9 - 7/13	Yellowish brown (10YR 5/6) very fine sandy loam, many medium distinct grey and reddish brown mottles; moist, friable; weak fine subangular blocky; many fine pores; many fine medium roots; clear wavy boundary;
B_{21t}	7/13 - 30	Yellow (10YR 7/8) silty clay loam; moist, firm; moderate medium subangular blocky;

		weak discontinuous clayskin with some brown humic staining; common medium pores; few fine to medium roots; rare medium to fine soft red weathered sandstones; diffuse boundary;
B_{22t}	30 - 70	*Yellow (10YR 7/8) silty clay, common fine faint yellowish and red mottles; moist, very firm; moderate medium subangular blocky; moderate discontinuous clayskins; common medium pores; rare medium roots; few medium soft to slightly hard red, yellow, grey sandstones; gradual slightly wavy boundary;*
B_{23t}	70 - 155	*Reddish yellow (7.5YR 7/8) fine sandy clay, many medium distinct red, yellow and white mottles; moist, firm; weak coarse platy breaking to moderate medium subangular blocky; moderate continuous clayskins; few medium pores; common medium soft to slightly hard red, yellow, grey sandstones; diffuse boundary;*
B_3	155 - 175+	*Reddish yellow (7.5YR 7/8) fine sandy loam mixed with white, red and yellow weathered rock; moist, friable-crumbly; weak medium platy structure; abundant medium soft to slightly hard red, yellow and grey sandstones.*

Profile No : 27 Soil Group : RED-YELLOW PODZOLIC SOIL Family : MERIT Series : Merit Lab. No : SS6344-6347

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1 0.05					
A1	0-6	47.1	22.9	30.0	0.1	0.3	0.5	3.6	42.6	L				
A3	6-13	49.3	23.4	27.3	0.1	0.2	0.3	3.4	45.3	SCL				
B21	13-30	40.5	23.9	35.6	0.3	0.3	0.3	2.2	37.4	CL				
B221	30-70	42.0	23.4	34.6	0.1	0.1	0.3	2.2	39.2	CL				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100g	B. Sat. %	Ext by KCl (me/100g)	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
A1		4.8	3.3	3.90	0.27	14	0.52	0.07	0.10	0.05	14.00	5.3		
A3		4.3	3.2	2.04	0.12	17	0.52	0.07	0.05	0.05	13.20	5.2		
B21		4.6	3.3	0.28	0.05	6	0.51	0.02	0.08	0.05	5.40	12.2		
B221		3.9	3.2	–	0.02	–	0.51	0.02	0.08	0.05	9.20	7.2		

"Reserve" analysis					Total analysis of fine earth			Free Fe_2O_3 %	Avail P ppm	P. Ret %
ppm				% OD	% OD					
P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3			
109	T	781	2082	4.94				0.86	10	65.4
86	T	1222	2704	8.61				1.27	< 1	69.6
77	T	1737	–	11.34				2.14	< 1	43.9
51	T	1748	4061	10.60				2.14	< 1	53.5

Available T.E. (ppm)						Water content (%OD)			
Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water
375	2	2.2	0.4			61.2	47.5	–	–
387	2	2.1	0.7			66.2	40.5	20.5	20.0
220	< 1	1.4	0.4			48.8	39.1	27.8	11.3
191	< 1	1.2	0.5			54.6	40.2	26.1	14.1

Profile No: 31 Lab. No: SS.6352/54

Soil Group: Red-Yellow Podzolic

Family: BEKENU

Series: Bekenu

Location: Altitudinal Zonation Plot E Line 3

Latitude: 4° 2' 31" N

Longitude: 114° 52' 41" E

Date Sampled: 14/7/78

Parent Material: Mulu Formation sandstones (colluvial)

Vegetation: Lower Montane Forest - Mixed Dipterocarp Forest

Slope: 44°, N, Upper slope

Altitude: 830 m (2,700 f)

Rainfall: 4,000-5,500 mm p.a.

Drainage: Well drained

Surface features: Common sandstones boulders up to 2 metres across; much surface stepping

Horizon	Depth (cm)	Description
O_1	1 - 0	Dark brown; leaf and root litters; fibrous abundant fine and medium roots; clear regular boundary;
A_1	0 - 4	Dark brown (7.5YR 3/2) silt loam (organic); moist to wet, friable; weak fine crumb; many fine to medium pores; many fine and medium roots; rare fine slightly hard sandstones; abrupt regular boundary;
B_1	4 - 19	Yellowish brown (10YR 5/8) silty clay loam, few medium faint grey, yellow, reddish brown mottles; moist, wet, friable; moderate fine to medium crumb structure; rare fine slightly hard sandstones; many fine medium pores; many fine medium roots; clear slightly wavy boundary;

B_{2t}	19 - 70	*Reddish yellow (7.5YR 7/8) silty to very fine sandy clay, few medium distinct reddish yellow mottles; moist, firm; moderate medium subangular blocky; few medium hard sandstones; rare medium pores; few medium to coarse roots; moderate discontinuous clayskins; diffuse boundary;*
C	70 - 200+	*Reddish yellow (7.5YR 7/8) stony very fine sandy to silty clay, many medium distinct reddish yellow and grey mottles of weathering rock; moist, firm; moderate medium subangular blocky; rare medium pores; rare coarse roots; many medium hard grey sandstones.*

ofile No : 31 Soil Group : RED-YELLOW PODZOLIC SOIL Family : BEKENU Series : Bekenu Lab. No : SS 6352 – 6354

on	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2 0.05	0.002		2	1 0.5	0.25	0.1	0.05					
	0-4	20.0	20.4	35.7	0.1	0.3	0.6	1.1	17.9	CL				
	4-19	38.5	27.8	32.2	0.3	0.4	0.8	2.1	35.1	CL				
	19-70	38.4	27.9	33.7	0.4	0.4	0.9	2.1	34.6	CL				

n	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100g	B. Sat. %	Ext. by KCl (me/100g)	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
		4.0	3.0	7.83	0.55	14	0.22	0.01	0.41	0.05	13.40	5.1		
		4.2	3.3	1.98	0.15	13	0.47	0.08	0.05	0.07	15.00	4.5		
		4.8	3.5	0.20	0.03	7	0.46	0.01	0.10	0.02	7.20	8.2		

"Reserve" analysis					Total analysis of fine earth			Free Fe_2O_3 %	Avail P ppm	P. Ret %			
ppm				% OD	% OD								
P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
290	T	1288	2466	6.49				1.44	34	73.4			
97	T	1797	2605	10.82				2.03	4	74.1			
36	T	1883	5497	12.07				2.47	<1	31.1			

Available T.E. (ppm)						Water content (%OD)							
Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail. water				
977	7	3.2	0.8			72.6	65.0	46.8	18.2				
344	3	1.7	0.3			60.3	42.5	23.4	19.1				
32	<1	0.7	0.8			42.9	36.1	18.8	16.3				

Profile No: 34 Lab. No: SS.6279/82

Soil Group: Red-Yellow Podzolic

Family: BEKENU

Series: Bekenu

Location: Altitudinal Zonation
Plot F Line 1

Latitude: 4° 2' 23" N

Longitude: 114° 53' 2" E

Date Sampled: 13/7/78

Parent Material: Colluvium from Mulu Formation fine sandstone

Vegetation: Lower Montane Forest

Slope: 34°, W, Mid-upper slope

Altitude: 1,130 m (3,600 f)

Rainfall: 4,000-5,500 mm p.a.

Drainage: Well drained

Surface features: Rare sandstone boulders, common marked tree root stepping

Horizon	Depth (cm)	Description
O_1	2 - 0	Dark brown; leaf and root mor litter; fibrous; abundant medium fine roots; clear regular boundary;
A_1	0 - 7	Dark yellowish brown (10YR 4/4) loam; moist, firm; weak fine crumbly; few fine to coarse hard yellow and grey sandstones, many fine pores; many fine medium and coarse roots; clear regular boundary;
A_3	7 - 12	Light yellowish brown (10YR 6/4) fine sandy clay loam, many medium and fine distinct reddish yellow and grey mottles; moist, slightly firm; weak fine subangular blocky; few fine to coarse hard yellow and grey sandstones; many medium to fine pores; many fine, medium and coarse roots; gradual slightly wavy boundary;

B_1	12 - 30	Yellow (10YR 7/8) very fine sandy clay loam, many medium distinct light grey, reddish brown mottles; moist, firm; moderate medium subangular blocky; common fine and coarse hard yellow, grey and red sandstones; few coarse pores; common coarse and medium roots; gradual regular boundary;
B_{21t}	30 - 75	Reddish yellow (7.5YR 7/8) clay loam, common medium and coarse distinct yellow, brown and red mottles, mainly from weathered rock; moist, very firm; moderate coarse subangular blocky; many coarse and medium hard reddish brown, red, yellow randomly oriented sandstones; strong discontinuous clayskins; few medium pores; few medium roots;
B_{22t}	75 - 120	Reddish yellow (7.5YR 7/8) clay loam, few medium and coarse distinct yellow and red mottles; moist, slightly sticky and very plastic; moderate coarse subangular blocky; few fine hard reddish brown, red and yellow horizontally bedded sandstones; strong continuous clayskins, very few fine pores; rare medium roots; clear regular boundary;
C	120 - 190+	In situ yellow slightly hard weathering sandstones, with reddish colour along horizontal bedding planes.

Profile No : 34 Soil Group : RED-YELLOW PODZOLIC SOIL Family : BEKENU Series : Bekenu Lab. No : SS 6279 - 6282

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1 0.05					
A1	0-7	43.7	28.2	28.1	0.2	0.5	0.6	3.8	38.6	L				
B1	12-30	47.4	26.1	26.5	0.1	0.3	0.4	5.3	41.3	SCL				
B21t	30-75	37.3	28.8	33.9	0.3	0.4	0.3	3.2	33.1	CL				
B22t	75-120	38.6	29.2	32.2	0.1	0.2	0.3	4.3	33.7	CL				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100g	B. Sat %	Ext by KCl (me/100g)	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
A1		4.2	3.3	4.98	0.32	16	0.21	0.31	0.08	0.09	13.00	5.3	-	-
B1		4.2	3.2	0.89	0.07	13	0.51	0.10	0.08	0.09	8.00	9.8	10.28	0.34
B21t		4.6	3.4	0.30	0.03	10	0.51	0.07	0.12	0.10	7.00	11.1	5.22	0.15
B22t		4.5	3.4	0.16	0.02	8	0.50	0.03	0.08	0.07	6.40	10.6	-	-

Horizon	"Reserve" analysis					Total analysis of fine earth			Free Fe_2O_3 %	Avail P ppm	P. Ret %
	ppm				% OD	% OD					
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3			
A1	136	T	954	3658	4.57				0.46	2.0	44.9
B1	41	T	1149	3367	5.60				1.05	<1	50.6
B21t	41	25	2011	4836	9.93				2.43	<1	41.2
B22t	-	T	1622	5070	9.56				1.93	<1	33.5

Horizon	Available T.E. (ppm)					B	Water content (%OD)			
	Fe	Mn	Zn	Cu	Mo		1/10 bar	1/3 bar	15 bars	Avail. water
A1	1220	8	3.5	1.1			81.7	50.2	27.0	23.2
B1	291	2	1.2	0.7			54.1	38.2	12.8	25.4
B21t	97	1	1.1	0.5			50.7	39.9	16.6	23.3
B22t	34	<1	1.1	0.7			45.9	36.7	15.4	21.3

Profile No: 8 **Lab. No:** SS.5684/87

Soil Group: Red-Yellow Podzolic

Family: NYALAU **Parent Material:** Sandstone

Series: Nyalau **Vegetation:** Mixed Dipterocarp Forest

Location: NW of Sg. Berar Camp Rentis 10 tape 31 **Slope:** 30°, NNW, Upper slope

Latitude: 4° 10' 11" N **Altitude:** 170 m (560 f)

Longitude: 114° 51' 2" E **Rainfall.** 4,000-5,500 mm p.a.

Date Sampled: 2/5/78 **Drainage:** Well drained

Surface features: Thickly littered with dead leaves and twigs

Horizon	Depth (cm)	Description
	5 - 0	Root mat (not sampled);
A_1	0 - 5	Dark yellowish brown (10YR 4/4) loamy fine sand; moist, very friable; weak fine subangular blocky; many fine, medium and coarse roots; diffuse wavy change to;
A_3	5 - 25	Yellowish (10YR 7/6) loamy fine sand; moist, very friable; weak fine sub-angular blocky; many fine roots; dark brown humus stain along channels; gradual wavy boundary to;
B_{21}	25 - 85	Yellow (10YR 8/8) very fine sandy loam, few fine distinct dark brown mottles; moist, friable to slightly firm; weak medium subangular blocky; few fine roots; humus coatings along roots channels; diffuse wavy change to;

B_{22}	85 - 125	*Yellow (10YR 7/8) fine sandy loam, few fine faint light grey mottles; moist, friable; weak medium subangular blocky; many soft strong brown sandstone fragments; patchy humus coating along root channels and cracks.*

Profile No : 8 Soil Group : RED-YELLOW PODZOLIC SOIL Family : NYALAU Series : Nyalau Lab. No : SS 5684-5687

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C.	M.	F.	V. F.					
		2	0.05	0.002	2	1	0.5	0.25	0.1 0.05					
A1	0-5	82.4	10.3	7.3	-	0.5	17.1	34.5	30.3	LFS				
A3	5-25	79.4	12.3	8.3	-	0.3	14.9	33.0	31.2	LFS				
B21	25-85	77.5	11.3	11.2	0.1	0.4	14.0	34.0	29.0	VFSL				
B22	85-125	72.7	12.5	14.8	0.1	0.5	17.1	30.0	25.0	FSL				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100 g	B. Sat. %	Ext. by KCl (me/10	
		H_2O (1:1)	1.0N KCl (1:1)				Ca	Mg	K	Na			Al	H
A1				1.17	0.07	17	0.35	0.04	0.09	0.31	-	-	3.20	0.3
A3				0.46	0.02	23	0.30	0.07	0.09	0.31	3.42	22.5	-	-
B21				0.13	0.06	2	0.55	0.04	0.05	0.31	2.22	42.8	1.89	0.05
B22				0.09	0.01	9	0.20	0.07	0.04	0.29	3.23	18.6	2.51	0.03

orizon	"Reserve" analysis					Total analysis of Clay			Free Fe_2O_3 %	Avail P ppm	P. Ret %	PH (Moist)		
	ppm				% OD	% OD								
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3				H2O 1:2.5		
A1	69	T	278	606	1.19	44.7	6.7	25.6	0.35	<1	18.9	4.2		
A3	50	T	378	705	1.41	34.7	5.7	30.9	0.44	<1	21.7	4.6		
321	50	T	629	1416	2.67	46.5	5.5	31.8	0.69	<1	26.8	4.6		
322	66	176	983	2722	5.19	45.1	6.5	32.2	1.22	<1	23.7	4.3		

rizon	Available T.E. (ppm)						Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo	B	1/10 bar	1/3 bar	15 bars	Avail water				
A1	190	1	0.5	1.6	3.3	0.13	44.5	15.9	6.3	9.6				
A3	93	1	0.1	1.7	6.6	0.05	37.9	15.4	4.6	10.8				
21	93	1	0.6	1.4	3.2	0.01	31.3	16.9	6.3	10.6				
22	60	1	0.9	1.9	4.4	0.03	34.2	18.2	8.6	9.6				

Profile No: 10 **Lab. No:** SS.5688/92

Soil Group: Red-Yellow Podzolic

Family: NYALAU **Parent Material:** Sandstone

Series: Nyalau **Vegetation:** Poor primary forest

Location: S of Sg. Berar Camp Rentis 18 tape 13 **Slope:** 10°, W, Mid-slope

Latitude: 4° 9' 50" N **Altitude:** 90 m (295 f)

Longitude: 114° 51' 17" E **Drainage:** Well-drained

Date Sampled: 4/5/78 **Surface features:** Well littered with dead leaves and twigs

Horizon	Depth (cm)	Description
O_1	2 - 0	Layer of root mat (not sampled);
A_{11}	0 - 8	Dark brown (7.5YR 4/2) very fine sandy loam; moist, very friable; subangular blocky to granular; few coarse roots; diffuse wavy boundary to;
A_{12}	8 - 12	Dark yellowish brown (10YR 4/4) very fine sandy loam, few fine faint grey and yellowish brown mottles; moist, very friable; fine subangular blocky to granular; few medium roots; diffuse wavy change to;
A_2	12 - 55	Brownish yellow (10YR 6/6) very fine sandy loam, few fine distinct yellowish red (2.5YR 5/8) mottles; moist, friable; medium subangular blocky; few fine roots; few quartz and rusty weathered sandstone fragments; texturally diffuse change to;

B_{21t}	55 - 85	*Brownish yellow (10YR 6/6) sandy clay loam, few fine distinct strong brown mottles; moist, firm to slightly wet and plastic; medium subangular blocky; few fine roots; many quartz grits; gradual wavy change to;*
B_{22t}	85 - 125	*Reddish yellow (7.5YR 6/8) clay loam, many fine to medium distinct yellowish brown and strong brown mottles; moist, firm to slightly wet, plastic and non-sticky; strong coarse sub-angular blocky; few fine roots; faint argillans on ped faces.*

Profile No : 10 Soil Group RED — YELLOW PODZOLIC SOIL Family : NYALAU Series : Nyalau Lab. No : 5688 - 5692

Horizon	Depth cm	Size Class and Particle diameter (mm)								Textural class	Bulk density g/cc	Fiber content %		
		Total (% of < 2 mm)			Sand (% of < 2 mm)									
		Sand	Silt	Clay	V. C.	C	M.	F.	V. F.					
		2 0.05	0.05 0.002		2	1 0.5	0.5 0.25	0.25 0.1	0.1 0.05					
A11	0-8	72.7	14.0	13.3	0.4	3.0	13.5	27.9	27.9	VFSL				
A12	8-12	70.8	16.1	13.1	0.7	2.8	14.6	24.9	27.8	VFSL				
A2	12-55	64.0	17.2	18.8	1.4	2.9	13.3	21.4	25.0	VFSL				
B21t	55-85	48.5	22.5	29.0	0.7	2.0	8.2	14.9	22.7	SCL				
B22t	85-125	37.3	30.5	32.2	0.5	1.1	7.0	8.6	20.1	CL				

Horizon	Loss on ignition %	pH (air-dry)		C %	N %	C/N	Extractable bases (me/100g)				CEC me/100g	B. Sat %	Ext. by KCl (me/100	
		H_2O (1:1)	1ON KCl (1:1)				Ca	Mg	K	Na			Al	H
A11				2.58	0.20	13	0.31	0.20	0.14	0.32	–	–	–	–
A12				1.49	0.11	14	0.57	0.15	0.09	0.35	11.80	9.8	0.34	5.24
A2				0.27	0.03	9	–	0.08	0.06	0.30	4.45	–	0.15	3.86
B21t				0.28	0.04	7	0.31	0.09	0.03	0.31	9.77	7.6	0.05	4.72
B22t				0.23	0.05	5	0.36	0.08	0.05	0.32	6.74	12.0	0.04	6.33

Horizon	"Reserve" analysis ppm				% OD	Total analysis of fine earth % OD			Free Fe_2O_3 %	Avail P ppm	P. Ret %			
	P	Ca	Mg	K	Gp III	SiO_2	Fe_2O_3	Al_2O_3						
A11	138	26	561	1326	2.94				1.23	7	52.8			
A12	106	T	738	1703	4.03				1.56	5	56.3			
A2	51	T	886	2226	1.11				1.00	<1	34.9			
B21t	74	T	1985	4683	11.28				3.89	<1	40.3			
B22t	77	T	2757	4952	12.00				4.86	<1	38.9			

Horizon	Available TE (ppm)					B	Water content (%OD)							
	Fe	Mn	Zn	Cu	Mo		1/10 bar	1/3 bar	15 bars	Avail. water				
A11	1463	2	2.2	2.2	0.12		53.9	22.0	12.3	9.7				
A12	1321	2	0.9	2.4	0.02		47.1	20.3	8.5	11.8				
A2	176	1	0.5	2.0	0.01		39.6	23.9	11.8	12.1				
B21t	98	1	1.3	2.7	0.01		49.1	32.9	19.2	13.7				
B22t	99	1	0.5	2.4	0.01		54.9	36.9	23.5	13.4				

APPENDIX IV

TENTATIVE CORRELATION OF SOIL FAMILIES WITH SOIL TAXONOMY (USDA) AND WORLD SOIL MAP LEGEND (FAO-UNESCO)

Soil Group	Family	Soil Taxonomy	World Soil Map Legend
Organic Soil	MUKAH	Terric Tropofibrist Terric Tropohemist	Dystric Histosol
	ANDERSON	Typic Tropofibrist Fluvaquentic Tropofibrist	Dystric Histosol
	MULU	Hemic Sphagnofibrist Sapric Sphagnofibrist	Dystric Histosol
Lithosol	MELUAN	Lithic Troporthent Lithic Tropofolist	Lithosol
Podzol	MIRI	Tropohumod* Histic Tropaquod	Humic Podzol Gleyic Podzol
	BUSO	Tropohumod*	Humic Podzol
Gley Soil	BIJAT	Tropaquent* Tropic Fluvaquent	Humic Gleysol Calcaric Gleysol Dystric Gleysol
	TUMAU	Tropaquent*	Humic Gleysol Dystric Gleysol
Alluvial Soil	SEDUAU	Tropofluvent*	Dystric Fluvisol Calcaric Fluvisol
	BEMANG	Tropofluvent*	Dystric Fluvisol
Regosol	TIKA	Typic Quartzipsamment	Albic Arenosol Ferralic Arenosol
	TUTOH	Typic Troporthent	Dystric Regosol

Soil Group	Family	Soil Taxonomy	World Soil Map Legend
Red-Yellow Podzolic Soil	MERIT	Typic (Oxic) Paleudult Orthoxic Tropudult Oxic Dystropept	Dystric Nitosol Ferric Acrisol Dystric Cambisol
	BEKENU	Typic (Oxic) Paleudult Orthoxic Tropudult Oxic Dystropept	Dystric Nitosol Ferric Acrisol Dystric Cambisol
	NYALAU	Typic (Oxic) Paleudult Orthoxic Tropudult Oxic Dystropept	Dystric Nitosol Ferric Acrisol Dystric Cambisol
Grey-White Podzolic Soil	SARATOK	Typic (Oxic) Paleudult Orthoxic Tropudult Oxic Dystropept	Dystric Nitosol Ferric Acrisol Dystric Cambisol

* Classification at sub-group level undeveloped.

REFERENCE:

1. FAO, 1974. Soil Map of the World. Vol.1, Legend, FAO-UNESCO, Paris.

2. Soil Survey Staff, 1975. Soil Taxonomy - A Basic System of Soil Classification for Making and Interpreting Soil Surveys. USDA, Agriculture Handbook No.436.

/lke.

Produced by the Department of Agriculture, Kuching, Sarawak, Malaysia.