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TRRL Report LR 506

**TRANSPORT and ROAD
RESEARCH LABORATORY**

DEPARTMENT of the ENVIRONMENT

**Terrain evaluation in West Malaysia
Part I. Terrain classification and
survey methods**

by
C. J. Lawrance

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TERRAIN EVALUATION IN WEST MALAYSIA
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1972

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TERRAIN EVALUATION IN WEST MALAYSIA

PART 1. TERRAIN CLASSIFICATION AND SURVEY METHODS

ABSTRACT

This report is the first of three on the application of terrain evaluation to highway engineering in the humid tropics. The study area is the south west corner of the Malay Peninsula, and this report describes the procedure for classifying its terrains, using aerial photographs. The Oxford-MEXE system of land classification is explained, and briefly compared with the work of other organisations. The procedure for classifying the terrains of south West Malaysia is then described. The dense vegetation severely hindered air photo interpretation, but in the lowlands, where most of the terrain variations occurred, there were enough gaps in the tree cover to see the land surface.

It is concluded that no modifications are required to the established system of land classification, although the complexity of the terrain (due to the intense climatic weathering) has demanded a larger mapping scale than hitherto. Under complete forest cover it is not possible to carry out a fully detailed land classification needed for site investigation, because the trees obscure the details of the land surface. But under these conditions a more general classification can be made which is useful in the preliminary stages of engineering surveys. Two appendices give an outline of the climate, geology and structural history of the Malay Peninsula, and a description of the effects of weathering upon the rocks.

1. INTRODUCTION

When the increasing traffic of a developing country outgrows the existing road network, demands for new roads become pressing. Engineers are required to build roads as quickly, cheaply and efficiently as possible, and the time allowed for planning the route and organising surveys is normally very short. West Malaysia is having to enlarge her already well-developed system of trunk roads to accommodate the growing volume of traffic, but many kilometres of new roads are also being built for her extensive development schemes. It is becoming the practice to designate large tracts of forest land for the development of agriculture, industry and settlement (the Jengka Triangle project is about 1000 km²). The scheme is started by clearing the forest and building a complete road system, eventually to include hundreds of kilometres of feeder and harvest roads. It is in these early stages that the guidance of a terrain evaluation is at its most valuable, when it can greatly speed the progress of parties in the field. This study sets out to test the effectiveness of terrain evaluation in its ability to expedite engineering surveys in West Malaysia.

For some time the Overseas Unit of the Transport and Road Research Laboratory has been developing mapping techniques to help the engineer produce soil maps quickly and efficiently, and an evaluation of the terrain based on the relationship between land form and soil type is considered to be an effective solution.

The specific aims of this terrain evaluation exercise are twofold. Firstly, to find out whether it is possible to compile an adequate classification of terrain from aerial photographs in the humid tropics, where the cover of vegetation is so dense, and where the rocks are deeply weathered. The Oxford—MEXE (Military Engineering Experimental Establishment) system of classification, that has been adopted at TRRL, was originally developed in the savanna lands of Africa, where the ground surface is visible from the air and consequently where terrain classification is easier. It is necessary to see what modifications, if any, are required to the established system of terrain classification for use in the humid tropics.

The second purpose of the study is to examine the variability of some of the land units in terms of their geometric properties and soil characteristics, and thus to assess the value of these units for predicting soil conditions from one area to another. The terrains of south West Malaysia have been classified and used to catalogue a large amount of engineering data. These data have been used in a series of statistical tests to determine the variability of each land class, and hence the predictability of its properties. The results of these tests demonstrate the validity of the terrain classes as engineering soil mapping units. The soil test information will be housed in a data store to which random access is available, for reference in subsequent engineering surveys. Later, it is hoped that the data store can be made more comprehensive by adding information on the quantity of materials (particularly earthworks) required for building roads in different types of terrain, and by providing some estimate of the cost of roads built to different standards.

The area chosen for survey forms the south west corner of the Malay Peninsula (Fig. 1). It constitutes about 18 000 km² of country, and includes lands from each of the three main physiographic provinces of West Malaysia: the vast coastal plain, the broad strip of lowland hills and the mountainous hinterland.

The project began in 1965 when 1150 soil samples were collected during the next two years. Although the terrain classification had not yet been compiled, the surveyors recognised what are now the Land Regions of the area (see Section 2.2.3) and sampled as many slope and geological situations as possible. In addition, to ensure a comprehensive and representative coverage, samples were taken from each land class (e.g. lowland granite) in each State where the unit occurred. In 1968 the aerial photographs became available and the land classification was produced the following year. Had the photographs been available initially, this stage of the work would normally have been completed before field work began. Discrepancies and boundary problems which arose out of the air photo study were corrected during a short second field trip in 1970.

Three reports will be issued on the Malaysian project. This first report explains the basis of terrain evaluation using Malaysian terrain conditions as an example of the method. The second report will describe the landscapes of the study area (land systems and their constituent land facets), and the third will describe the statistical methods used to test the terrain classification. (Geometric measurements of the terrain and soil test results were used to test the variations within land unit, and the difference between units.)

2. TERRAIN CLASSIFICATION AND TERRAIN EVALUATION

The earth's surface exhibits a constantly changing combination of rocks, soils and land forms, giving rise to different materials, soil moisture conditions, vegetation types and land uses. The inter-relationships between these attributes are so intimate that it is impractical to study any one of them in isolation from the rest.

There has been some confusion in the meaning of some of the basic terms used in discussions of land classification and the associations between materials and terrain. To avoid this, definitions of these terms as used in this report are given below.

The term *land* denotes an area of ground of any size, and may refer either to its surface form or to the distribution of its rocks and soils, or both. *Terrain* is also a general term to describe any piece of ground, but it implies that the ground is being assessed for some purpose. However, terrain and land may be used more or less synonymously as a general expression for ground. *Landscape* refers more specifically to the shape of the land forms making up the land surface. It also bears a connotation that suggests a fairly large piece of ground. *Classification* is the process of dividing ground into a number of classes having certain characteristics in common. A classification can be based on any attribute possessed by the ground whether superficial or at depth. For example, a classification may group together surface features such as vegetation or types of slope, or it may be based on sub-surface criteria such as geology or agricultural soil profile. *Evaluation* of a piece of ground is the assessment of its value for a particular kind of land use. Any knowledge about an area beyond its mere classification constitutes the beginnings of a terrain evaluation, which becomes more comprehensive and useful as knowledge is accumulated. A terrain evaluation must be preceded by some form of classification, otherwise information about sites cannot be extended beyond those sites.

Some surveys have used *land* (or *terrain*) *classification* to denote an analysis of land forms without reference to the rocks and soils beneath, but the term as used in this report implies the association between surface form and the underlying materials. Strictly, a *land* classification is any division of a territory into land units, such as a geology map or a slope map. In contrast, *terrain* classification suggests that the classification has been made specifically for some kind of land use. But as with "land" and "terrain", the terms are somewhat loosely applied and are frequently interchangeable.

The object of a terrain classification is to limit the seemingly infinite variations of terrain and resolve them into a manageable number of classes. Statements and properties ascribed to one site may then be extended to other sites in the same class, and the information thus becomes more useful. The type of classification chosen for mapping depends on the purpose of the survey and the proposed land use. When devising a specialised land classification it is important to know who is going to use it, and what level of detail is required. For instance, an area of low relief and deep, fine soils may be considered a single land unit to an engineer building a road, whereas a pedologist mapping the same area for an agricultural survey may recognise several soil series. Each of these soil series might be further subdivided by an agriculturalist investigating the soils for an irrigation scheme, on soil permeability or the distribution of trace elements. The question of the value of soil maps and the cost of surveys has been pursued by Beckett¹.

A specific land classification such as a soil or geology map is limited in its usefulness as an index to any information other than that for which it was compiled. On the other hand a general classification, not allying itself with any particular discipline but merely describing natural units of terrain, has the advantage that it may serve the requirements of more than one type of survey. This is particularly useful in areas where

undeveloped land is prepared for new communities by a programme of road building, agricultural development, rural settlement and urban growth. The classification used in this study is of the general type, the classes being derived from associations of geology, topography and soils without reference to their value for any particular kind of land use.

Information collected and stored within the framework of a terrain classification constitutes the beginnings of a terrain evaluation. A terrain evaluation frequently takes the form of a library or index of information accompanying a terrain classification map indicating the distribution of the terrain classes. However, a map may in itself constitute a terrain evaluation, if the land classes on it indicate something of the properties of the terrain. A simple example is a land use capability map, in which the mapping units are defined on their suitability for some specified land use. A much more sophisticated terrain evaluation is Grabau's *factor complex map*². Five factors of terrain – slope, soil grain-size distribution, soil moisture content, depth to bedrock and density of vegetation – are stored in a computer. These factors can be superimposed upon one another on a computer-drawn map to form “factor complexes”. To each factor is assigned a numerical value indicating the influence of the factor on the land use under consideration, for instance, on building an airfield. The value for each factor is incorporated in a mathematical formula which estimates a value for the factor complex as a whole. It is then possible to draw a computer map in which areas of equal constructional difficulty are shown. Thus, for each factor complex a calculation is made of the number of days it would take to construct an airfield of a specified type. The answer is superimposed on the factor complex map, and the boundaries then show the areas where the time required to build the airstrip will be the same.

2.1 Land classification and engineering surveys

At present, field work for route location and roadbuilding materials is normally confined to a particular road project. When the road is complete, all the information and experience gained during its construction are filed in reports and drawings that are relevant only to that particular road. But this information is often applicable to similar engineering situations elsewhere in the locality.

The purpose of a land classification is to provide the engineer with a group of terrain analogues so that he can recognise “similar engineering situations” in a new area. His data, catalogued under a terrain unit, will then apply to all other occurrences of that unit.

Such a classification should fulfil four conditions if it is to be useful to engineers.

- (1) It should consist of units which are easily recognisable to the engineer, both on the ground and from aerial photographs. It must therefore be of simple structure, easy to understand and easy to use.
- (2) It should allow the engineer to predict the type of ground conditions and the location of roadbuilding materials. To do this the units must be fairly well defined, but not so tightly that only detailed field survey can distinguish one unit from another. It was realized that although closely-defined units would be better for prediction purposes, they are less likely to be easily recognisable from aerial photographs. The terrain units proposed here are sufficiently uniform to be useful in preliminary surveys and all but the most detailed kinds of site investigation. At the same time they are recognisable in aerial photographs and hence can be mapped quickly and accurately.

- (3) To be useful in all types of engineering situations the classification should be of a general rather than a specific nature. (Its proposers in Oxford sought a classification which could be used by engineers, foresters, agriculturalists and economists.)
- (4) The terrain units should act as the index to the stored information, so that data is easily retrieved for future reference. The "pigeon-hole" nature of the terrain units allows the direct translation of information in the store to the location in the field.

2.2 The Oxford—MEXE system of terrain classification

The development at Oxford University of the research into methods of land classification is well summarized by Webster and Beckett³.

The Oxford—MEXE system recognizes seven categories of terrain, each defined by a combination of climate, geology and landform (Brink *et al*, p.9⁴). The units are, in decreasing order of size:

Land Zone
Land Division
Land Province
Land Region
Land System
Land Facet
Land Element

For completeness the whole classification is outlined here, although for most purposes users are only concerned with the lowest three units in the hierarchy. It is convenient to describe these three units first, as they constitute the basis of the classification from which the higher units are derived.

2.2.1 Land system, land facet and land element. The processes of weathering and erosion interact upon the rocks at the earth's surface. The resulting topography reflects both the type of climate and the nature of the geology. The rocks weather and break down to form a mantle of soil that also reflects the geology and the process of weathering. Thus topography and soils both develop in response to the same environmental factors, and a given set of environmental controls will tend to give rise to specific land and soil types.

A terrain weathering under fairly uniform geological and climatic conditions evolves into a small number of slope types or topographic units. The units are grouped into small associations, recurring over a wide area in a distinctive arrangement or pattern (Plates 1 and 2). This pattern of land forms is called a *land system*. It is defined by the geology and climate and by its complement of small topographic units, called *land facets*. The pattern persists to the limits of the geological formation upon which it is developed, or until the prevailing land forming process gives way to another. At this point a new land system is developed. Land systems can often be recognised on print laydowns at scales of about 1:100 000 by the distinctive appearance of their dissection, vegetation and land use patterns. By this means they may be tentatively outlined but they can only be properly mapped by delineating the limits of their complement of land facets. The recurrent association of groups of facets defines the extent of the land system: at the land system boundary all (or most) of the facets

give way to a new association, in a different land system. A land system is named after a town or other geographical location, partly to aid its recall but more importantly to stress its restriction to a particular locality. Two landscapes that are apparently identical but distantly separated are initially given separate names, until it can be shown by more detailed soil mapping and test results that the landscapes may be considered identical. They will then both receive the name of the type locality. This avoids the possibility of grouping together two landscapes of different properties with insufficient evidence for their similarity.

Land systems have been mapped elsewhere at scales of 1:500 000 to 1:1 million but in West Malaysia a scale of 1:250 000 is more appropriate for the complex terrain (see map in the back pocket of the second report).

The land facet is the basic unit of mapping. It too is defined on its geology, water regime and topography, but in a much more restricted way than the parent land system. A land facet has a simple form (it would fit into one slope class in a slope map), a fairly homogeneous parent material and a single water regime (both surface water and ground water). The materials developed on it are naturally fairly uniform, such that a pedologist would map its soils at approximately association level, and an engineer would accept a single design specification for a section of road built on it. Plate 3 illustrates the association of land facets in the Labu land system.

Land facets are normally mappable at scales up to about 1:50 000, but in West Malaysia a larger scale (1:20 000 – 1:30 000) is necessary as the facets tend to be rather small.

It frequently happens that a very small feature of the landscape is of particular significance to a proposed scheme. The feature is too small to be mapped, but is nonetheless important enough to warrant a special category. In this case a *land element* is recognised, the smallest unit of landscape that is normally significant in preliminary and perhaps detailed surveys. For example, a hill slope may consist of two land elements, a steep upper slope and a gentle lower slope. To an engineer each slope element is important when considering slope stability and amounts of cut and fill. Other examples of land elements are very small river terraces, gully slopes and small rock outcrops.

The occurrence of one or more land elements in a particular facet is predictable, although they are not necessarily always present. The relationship between the land system, land facet and land element is illustrated in Fig. 2.

2.2.2 Variants, included facets and compound land systems. The land system, land facet and land element are the main units of the terrain classification. Three additional categories, briefly described here, are designed to accommodate the minor variations in landscapes and materials that inevitably occur.

Variants. In contrast to the land element, a *variant* is a part of the landscape whose occurrence or properties are not predictable. It has little or no surface expression and therefore its frequency and extent cannot be predicted. Its presence may be forecast from a knowledge of the physiography, but it can only be mapped on the ground. The term variant is also used for features which have surface expression but whose distribution in the landscape is not predictable. An example of a variant is found in the Muar land system, where riverine alluvium and marine alluvium are indistinguishable except by augering. The riverine alluvium is very widespread and not restricted to present-day river channels, and it is significant to engineers and agriculturalists

in being heavier and wetter than the marine alluvium. The presence of peat in the Muar land system is also very difficult to detect by any means other than ground survey; it too has been given variant status.

Included facets. The facets of a land system are normally genetically linked, and therefore occur in a specific relationship to each other. Occasionally a facet appears whose origin is not connected with the geomorphic evolution of the landscape around it. Such a facet is called an *included facet* because its occurrence and location are not influenced by the surrounding facets. Of more importance to the engineer is the fact that included facets are often strikingly different in form and materials from the normal facets. For example, the "islands" of exposed older rock protruding through the Recent Alluvium at the fringes of the coastal plain are included facets in the Muar land system. Their form and materials are related to the lowland hills land systems rather than the marine alluvium but they are too small to be mapped as lowland hills land systems.

Compound land systems. A land system is normally developed under a single morphogenic (land forming) process, and its facets are all interrelated. However two processes sometimes overlap to produce two landscapes which for reasons of scale cannot be mapped separately. The resulting *compound land system* consists of two groups of land facets. Within each group facets are genetically related but between the groups there is no genetic link and cross-prediction is not possible.

Although there is a certain overlap of some land systems in West Malaysia (for example where a small group of facets exists as an "outlier" of one land system within another) it was considered unnecessary to complicate the classification by recognising compound land systems.

2.2.3 Higher land units

Land region. A *land region* is made up of a group of land systems having the same basic geological composition and an overall similarity of land forms. The lowland granite land region and the lowland sediments land region of West Malaysia are examples. They may be mapped at scales between 1:1 million and 1:5 million. It has been found convenient to group the land systems of south West Malaysia into land regions on the basis of the soil test results (see the third report), and the land regions are indicated on the map in the second report by the areas of colour.

Land province. A *land province* is a group of land regions belonging to a major structural, geomorphic or sometimes lithological unit. There may be a similarity in the gross morphology owing to strong structural or erosional influences, but morphological consistency is not essential to the definition of the unit. The lowlands land province of West Malaysia comprises all the landscapes developed between sea level and 150m, except the coastal plain. An appropriate mapping scale for this unit would be up to 1:10 million.

Land division and land zone. The two highest units of the classification represent the two most general agencies producing natural regions. The first agency is morphotectonic activity and the second is climate. Tectonic forces create the world's major land forms, and climate influences soils and vegetation, and modifies land forms.

The *land division* is a major morphotectonic structural unit such as a fold mountain belt or continental shield area. The entire Malay Peninsula is part of a land division extending north into Thailand, comprising a fold mountain belt with granitic intrusions. Land divisions are mapped at scales smaller than 1:5 million, that is at continental or world scale.

The *land zone* is a major climatic region of the world. Its boundaries are diffuse and it may extend across the natural morphological boundaries of the other land units. Perrin and Mitchell⁵ have investigated the extent to which analogous land systems occur within a well-defined world climatic regime, the hot deserts. The extreme rigour of this climate has had a major controlling influence on the resulting landforms. No investigation has yet been made into the topographic effects of other extreme climates such as glacial or tundra conditions. However, it seems likely that the severity of such climates may produce a characteristic set of landforms regardless of geographical location or geology. It is not known to what extent analogous land forms occur between areas where the climate is less extreme.

2.3 Other studies of land classification

Discussions of the rationale and growth of terrain classification studies are to be found in Thomas and Whittington (Chapter 6)⁶, Mabbutt⁷ and Beckett and Webster⁸.

Towards the end of the 1940's, planning and development organisations in different parts of the world began to investigate methods of speeding up mapping techniques for reconnaissance surveys. Among the first were the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Division of Land Research, who mapped large areas of north and central Australia at a general (land system) level, using aerial photographs. Land Resources Division of the Overseas Development Administration (ODA) first employed terrain mapping in West Cameroun and Botswana in the early 1960's, and the National Institute for Road Research (NIRR, South Africa) and TRRL used similar techniques for engineering soils mapping, again using aerial photographs.

It became clear that the separate institutions were all arriving at the same conclusions regarding the nature and size of terrain units mapped from aerial photographs. A meeting was therefore convened at Oxford University between the Oxford-MEXE terrain group and representatives from TRRL, ODA, NIRR and CSIRO. At this meeting all the current classifications were discussed and moulded into a single agreed system with a standard nomenclature⁴.

The Oxford-MEXE group began a research programme to test the uniformity of the land facet (the smallest unit of mapping). They recorded the soil moisture movements and described the soil profiles of all the facets within a study area round Oxford. Hitherto the uniformity of the facet had been tacitly accepted without rigorous testing. Satisfied as to its validity as a mapping unit, they went on to classify and map the terrain units of the whole of Uganda⁹ and Swaziland¹⁰, about 200 000km² in Western Kenya¹¹ and smaller areas in parts of Southern Africa^{12, 13}.

In parallel with this programme a team from Cambridge University, in collaboration with MEXE, studied the landscapes of the world's hot deserts⁵. Their aim was to see to what extent the development of landscapes is influenced by a harsh climatic regime, regardless of the continent in which they occur.

In the early 1960's a system of terrain classification specially for use by engineers was introduced by Aitchison and Grant at the CSIRO Division of Soil Mechanics¹⁴. The structure of the new classification was identical to that agreed at the convention in Oxford except in two major respects. It had a different nomenclature for its land units, but, more important, its land classes were defined in abstract as a series of pre-determined land forms, any of which could theoretically occur in association with any other. The precise combination of *terrain units* within a *terrain pattern* defined a landscape equivalent to the land facet and land system. However, because of its abstract nature that terrain pattern was not necessarily restricted to a particular locality, as is a land system. The possible limitations of the PUCE programme are discussed in Brink *et al*¹⁵

(p. 1627) but the programme has not yet been fully developed, nor yet fully tested in the field. The application of terrain classification to engineering was studied at TRRL, using the standard Oxford-MEXE nomenclature, and land systems of parts of Northern Nigeria were described in engineering terms^{16, 17}.

Geographers in the USSR have been working independently on land classification for economic planning. Their conclusions about the breakdown of terrain into successively smaller genetically-related units are similar but not analogous to those outlined above. An indication of the scope of their work is given in the references¹⁸.

3. PROBLEMS OF MAPPING AND LAND CLASSIFICATION IN SOUTH WEST MALAYSIA

In this section reference is made to the main physiographic divisions of West Malaysia. To clarify the discussion a brief description of these is given in Appendix 1 (Section 8). The effects of climatic weathering are also discussed, and therefore an outline of weathering processes in West Malaysia appears in Appendix 2 (Section 9).

Land systems are normally distinguishable at a small scale by their pattern in air photo print laydowns. These patterns are the result of the regular arrangement of surface features such as drainage, geology, vegetation and land use. The delineation of the patterns is usually the first stage in a land system survey, to establish tentative land system boundaries. Later the photographs are examined in detail to describe the land facets present and hence to define the land systems.

This traditional approach was found to be impractical in West Malaysia for the following reasons:

- (1) The dense tree cover blanketing the landscape obscured all but the gross morphology of the terrain. The vegetation is of two main types: jungle and tree crops in plantations. The mountains and very steep hills have not been cultivated and remain under primary jungle. Elsewhere, on the lowlands and coastal plain the land is almost entirely given over to rubber and other plantations. This cover of vegetation hides the drainage patterns and precludes the development of sensitive changes of natural vegetation that form patterns in print laydowns.
- (2) Changes of landscape in West Malaysia are frequent and only mappable at a fairly large scale. It was not possible to recognise all the subtle changes of landscape in the print laydowns at 1:100 000 scale, so it was necessary to look at the individual stereopairs from the outset.

Only two major changes in landscape can be detected in the print laydowns reliably and with reasonable accuracy, the change from the flat coastal plain to the gently undulating lowlands and the junction between the lowlands and the mountains. Both boundaries are marked by a distinct change in land use (Plate 4). The coastal plain, being reclaimed land of peaty and heavy soils, is intensively cultivated for rice, coconuts and pineapples. The rectangular arrangement of the myriad tiny drainage channels gives a distinct regularity to the air photo pattern. The low hills, on granite or sedimentary rocks, mostly support rubber estates. The plots bear trees in all stages of growth and appear in the photographs as a broad, irregular patchwork, quite different from the regimented fields of the coastal plain. The junction of those two patterns represents on the ground a change in (a) land form, from perfectly flat land to gently rolling country of 3–7° slopes; (b) geology, from Recent Alluvium to granite or Palaeozoic sediments; (c) soils, from organic fine soils to mineral soils; (d) materials, from soft unconsolidated profiles to deeply weathered, firmer and more stable materials, and (e) drainage conditions, from waterlogged, often inundated ground to drier, more or less freely-draining ground.

The second major change in air photo pattern is seen at the junction between the low hills and the mountains. The jungle gives an even, speckled effect on the photos, easily distinguished from the bold pattern of the rubber plantations. On the ground, the junction between the two is marked by a sudden change of slope from less than 15° to 25° or more, as well as attendant changes of dissection pattern, weathering profile and water regime.

Since it is necessary to use a stereoscope to map the terrains of West Malaysia, a general view of the ground may first be obtained using the photographic cover at 1:60 000. The photography at 1:25 000 may then be used for detailed examination and the definition of land facets.

Of the total 42 land systems recognised in south West Malaysia, two have been recognised in the coastal plain and nine in the steep hills and mountains. The remaining 31 land systems are developed in the intermediate zone of lowland hills, which comprises 62 per cent of the study area. The mountains and coastal plain account for 13 per cent and 25 per cent respectively. The lowland hills lie between sea level and about 100m, with a relief of 20–60m. This topographic range is very small compared with the proportional size of the mapping area, and it is the complexity of the terrain which has given the relatively large number of land systems.

The main morphological variables contributing to a landscape are:

- (1) Relief
- (2) Angle of slope (including valleys)
- (3) Shape of slope (including valleys)
- (4) Drainage density
- (5) Drainage pattern
- (6) Relative proportions and combinations of land facets.

The sixth variable requires some explanation. A land system normally comprises about half a dozen land facets and occupies a discrete area of at least several square kilometres, and the boundary between one land system and another is usually marked by a change in all or most of the land facets. In the lowland hills area of West Malaysia the deep weathering has produced rather few facet types, mostly hill and valley forms. However the lowland hills comprise 31 of the 42 land systems defined. The differences between the land systems is therefore sometimes subtle, particularly when the change from one to another is gradual, as it frequently is. Gradations of slope form and in the size and proportion of facets are common.

Most of the land systems defined for south West Malaysia are sound in concept but contain a few odd facets that are not typical of the landscape. Such impurities may be ignored for the purposes of the classification. Others unfortunately are less consistent, and contain a higher proportion of aberrant facets. The possibility of defining *compound land systems* was considered (see Section 2.2.2), but rejected on the grounds that the small variations in geology and engineering materials did not warrant increasing the complexity of the classification.

4. AIR PHOTO INTERPRETATION

Two scales of photography became available to the project; RAF cover at about 1:60 000 (flown in 1953–1959) and 1:25 000 photography flown by the Canadians under the Colombo Plan. The latter set of photographs was used for the definition of the land units.

To obtain a general picture of the terrain the aerial photographs were first used to compile print lay-downs. The print laydowns made the location of individual prints much easier, and they acted as maps upon which the first land system boundaries were drawn.

The luxuriant forests and plantations proved to be a considerable hindrance to air photo interpretation. The trees are of fairly constant height but grow rather taller in the valleys than on hill slopes and crests (Plate 5). From the air the relief appears lower than it really is.

Fortunately, the post-war government policy to encourage re-planting has resulted in many rubber plots being felled and cleared. The dense cover is now perforated at frequent intervals by “windows” of cleared ground and young plantations, where the trees are still sufficiently low to allow the ground surface to be seen. The replacement of many rubber plantations with oil palm has exposed similar tracts of land.

A further complication is added by the very deep weathering of most of the rocks. The intrinsic properties of the rock, such as the attitude of beds and the direction of lineations, are usually obliterated by the mantle of weathered material. Under these conditions geological boundaries can be very indistinct in the lowlands, and in places can be located only approximately using aerial photographs alone.

The only practical solution to the difficulties imposed by the trees and the weathered mantle was to examine the exposed parts of the terrain under the stereoscope, identifying land facets and building up their associations into land systems. Land system boundaries, where they occurred under trees, were interpolated from the nearest areas of exposed ground.

The photo interpretation work was concentrated on the area of lowland hills, where most of the variations in geology and landscape occurred, and where economic and geographic interests are greatest. In the few localities in this region where areas of jungle remain undisturbed some attempt at landscape description was made. But with no exposed patches to reveal the true nature of the land surface it was found impossible to give any but the most general indications of the kind of terrain existing beneath the trees. Some estimate of the relief can be made, and if there is a striking grain to the country, this too can be detected. But none of the topographic minutiae used in defining a land system can be resolved. For example, a tentative land system (Batu Dua) was defined for a large area of jungle south of the Kulai-Kota Tinggi road, and visited in the field for a more complete description. A large area adjacent to the road had been cleared very recently for sugar cane development, and the exposed landscape turned out to be the Skudai land system. The Skudai land system was duly extended to encompass Batu Dua.

The steep granite hills and mountains are clad in a continuous cover of jungle, but the local relief is such that even the smaller valleys can be detected beneath the trees (which can be up to 50 m tall). The few areas that are clear of trees show a simple morphology that may safely be extrapolated to the entire mountain region.

5. CONCLUSIONS

The first aim of this survey was to assess the feasibility of the Oxford-MEXE system of terrain classification in humid tropical conditions, and to determine what modifications were necessary to make it work. The conclusions from the study of the variability of land form and soil characteristics are given in the third Report.

In general the system is applicable to the humid tropics, although it is by no means as straightforward as in savanna lands where terrain conditions are much more easily distinguished. The greatest problems are the intense climatic weathering and the thick covering of vegetation. The weathering tends to eliminate the intrinsic structure of the rocks and so make all the landscapes look more or less the same. The luxuriant vegetation tends to obscure what small differences in landscape there are. The dense natural cover of huge trees totally obscures the ground surface and obliterates all but the major changes in relief. In natural forest areas land regions might be distinguished if the boundaries between them have major changes in relief. It is not possible to recognise land systems of low relief in aerial photographs. Significantly, it is almost as difficult on the ground to detect changes in landscape, when visibility is perhaps only 30m through the trees.

Rubber plantations would present formidable problems to the photo interpreter were it not for the frequent occurrence of cleared areas. These patches of cleared ground give access to the land surface that is essential for the detailed examination of slopes.

The changes of landscape in the lowlands are so subtle that in many places it is impossible to distinguish even the granite from the sediments. Some kind of geological information, however crude, is therefore essential to indicate the main rock types. Once warning is given of a change in geology it is usually possible to place the boundary fairly accurately in the aerial photos. Additional information on soils is of course highly desirable.

Because of the fine variations in terrain, large scale photography (1:25 000) is essential to see the diagnostic characteristics of the land facets in order to build up land systems. It is impractical to delineate tentative land system boundaries unless small-scale cover is available in stereo (i.e. 1:50 000 photography). With this a rapid land region breakdown is possible and useful for organizing the detailed air photo study at 1:25 000.

No fundamental modifications to the existing system of terrain classification were necessary, but the complex terrain generated rather small units. The original proposed mapping scale of 1:30-40 000 for land facets would be too small for West Malaysia; 1:25 000 is the smallest that is practicable. Similarly 1:250 000, the highest scale originally recommended for land system maps, is only just large enough to show the intricate land system boundaries, and the smallest of the land systems.

6. ACKNOWLEDGEMENTS

The survey described in this report was undertaken as part of a wider research programme in West Malaysia. It was made possible by the helpful co-operation of the Director of Public Works, Tan Sri Haji Yusoff bin Haji Ibrahim and his staff. Considerable advice and assistance was given by the Soil Survey of the Department of Agriculture, the Geological Survey and the Survey Department. The bulk of the field work was carried out by P.J. Beaven and D. Newill. Aerial photographs printed in this report were reproduced by permission of the Director of National Mapping, Malaysia, Government of Malaysia Copyright Reserved (DNMM.21.16/60).

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8. APPENDIX 1

CLIMATE, GEOLOGY AND GEOMORPHOLOGY OF WEST MALAYSIA

8.1 Climate

The Malay Peninsula lies in the wet equatorial climatic belt, where both rainfall and temperature are high throughout the year. The average temperature in the lowlands remains at 27°C all the year round, with a diurnal range of about 10°C. Even in the mountains the temperature rarely falls below 9°C. The relative humidity almost everywhere varies daily between 70 and 90 per cent. The climate of West Malaysia can only be described as monotonously hot, wet and humid.

The alternating influences of the North-East and South-West Monsoons give West Malaysia a high rainfall, which locally may be markedly seasonal, although not in the south and south-west..

The central and western parts of the Peninsula have 2000-3200 mm of rain p.a., fairly well distributed throughout the year. The east coast as far south as Mersing has a markedly wetter season during November to January when the NE Monsoon is at its height. The total there is 3000-3500 mm p.a. The only areas in West Malaysia with less than 2200 mm of rain p.a. are the central part of the Peninsula (north of Segamat), the coast of Selangor and South Perak, and the extreme north of the country in Perlis.

8.2 Outline of the geology and structural history of West Malaysia

The development of the Malay Peninsula began in the late Cretaceous period with the rise of a whale-backed hump of sediments from the S.E. Asian geosyncline¹. This large hump would have been one of several forming the forerunners of Sumatra, Borneo and the many smaller island chains of S.E. Asia. Lateral pressures from the north-east and south-west folded the rocks into a series of highly contorted fold units, or "coulisses"².

There are eight major coulisses in the Peninsula, forming a group of discontinuous ridges running more or less north-south. They are part of a major tectonic arc running down through Malaysia, swinging east through Sumatra, then north-east through North Borneo and on to the Philippines.

The sedimentary rocks are mainly shales and quartzites with interbedded cherts of Permo-Carboniferous age. Limestones and calcareous bands occur frequently, although no massive limestones were found within the area of this study. (There are hardly any massive limestones south of Kuala Lumpur). Some of the shales and fine grained rocks have been altered to phyllites during the folding. During the deposition of these rocks a contemporaneous series of volcanic and hypabyssal (shallow-depth intrusive) rocks became intercalated in the sediments. Volcanic agglomerates and tuffs are common, varying from rhyolites (acidic) to dolerites (basic).

In Triassic times, while the coulisses were forming, granites were injected into the base of the folds. A second and more important period of granite intrusion occurred in the late Mesozoic (probably Cretaceous) or early Tertiary times. The granites have now been exposed by erosion and form a sequence of mountain ridges following the grain of the folded coulisses. These ridges form the physical control for the major drainage system of the country. It is most likely that the ridges and isolated masses of granite are connected at depth in a batholith underlying the entire Peninsula.

After the Mesozoic era came a period of prolonged denudation and a general fall in sea level which continued right up to the Quaternary. A temporary halt during the Cretaceous produced a marine bevel and the deposition of the Panti Sandstone, which now survives as occasional remnant plateaux on hill tops from 50 to 500 m above sea level. In the mountains at altitudes up to 2000 m, numerous terraces and benches bear witness to many changes in base level of the downcutting streams.

It is thought that the sea halted again at a point about 80 – 150 m above the present level and cut a wide platform around the periphery of the emergent land mass. This platform was later to form the lowland hills region of Malaya, whose low altitude and gentle slopes contrast so strongly with the mountainous hinterland.

When the sea regressed again the platform was left exposed and developed extensive areas of laterite duricrust³. As the sea level fell the laterite capping became eroded, and laterite detritus accumulated at the bottom of slopes to be reworked into the footslope laterites of today. Remnants of the original laterite cap are still present on the crests of many lowland hills, and are characteristic of the Alor Gajah, Udang and Pogoh land systems. It is thought that all the Malaysian laterites are fossil deposits and that virtually none is forming today.

During the Pleistocene or late Pliocene the lowland platform was submerged to a depth of some 40 m, and upon it were laid the clays, sands and gravels of Older Alluvium⁴. There were apparently three main basins of deposition within the survey area; around Johore Bahru and Singapore, south of Kota Tinggi, and

around Kluang, as well as deposits in other areas. A subsequent lowering of sea level re-exposed the Older Alluvium, and the whole lowlands area became dissected.

The geomorphic evolution concluded in Recent times with the re-submergence of the coastline. On the marine platform and in the many drowned valleys fingering inland were laid considerable thicknesses of muds and sands which now form the extensive coastal plain. The plain reaches its maximum width in Perak where it is 40 km wide. On the west coast it is 30 km wide from Muar to the southern tip of the country. The depth of the alluvium reaches 150 m in places along the present seaboard, of which the top 25 – 30 m are occupied by soft, unconsolidated clays and sands, giving very weak foundations. The depth of the alluvium steadily decreases inland until the hills of bedrock protrude through the alluvium like islands. In the inland peat basins, depths of 8 m of peat have been recorded, becoming rapidly shallower at the edges of the basins. Before being artificially drained, the coastal plain was a vast mangrove swamp infested with crocodiles. Now it is almost entirely cultivated for a wide variety of crops, although it is nowhere more than a few metres above sea level.

The topography of the Malay Peninsula may be divided into four distinct zones.

- (1) Mountains. Developed mostly on granite, but admitting some steep and high sedimentary areas, they form the uninhabited interior of the Peninsula, running almost the length of the country in a series of ridge-like masses. They rise to an altitude exceeding 1000m, and the slopes are generally 25 – 35° although locally they approach 45°.
- (2) Steep hills. Like the mountains, developed mostly on granite. They occur peripherally to the mountains, either as spurs of the main mass, or as outlying isolated hills. They may rise to 300 m, with slopes of 15 – 30°.
- (3) Low hills. The altitude may be up to 250m, but in the south it is less than 100m. Relief is 20 – 60m, and the slopes are about 5 – 12°. The low hills are very extensive, lying in a continuous belt around the central highlands.
- (4) Coastal plain. The broad plain, of Recent marine alluvium, has almost no relief and lies between the low hills region and the sea. The alluvium has filled the floors of the seaward valleys of the low hills and “fingers” into the low hills of the interior.

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9. APPENDIX 2

WEATHERING IN WEST MALAYSIA

The abundant rainfall and constant high temperatures are major factors in the development of the surface forms in West Malaysia. Water has percolated into practically all the rocks and reduced them to deep, fine-grained soils with more or less quartz according to the amount originally present. The depth of the weathering zone varies according to rock type and slope, but it is rarely less than 3m and commonly as much as 20m deep. Ledgerwood¹ records weathering in granite joints at a depth of 460m, due to percolating surface water.

As suggested by both Linton² and Ledgerwood, the most active weathering takes place in the zone of moving ground water, where weathering products are constantly removed and fresh solute is brought into contact with the grains.

The mineralogy and weathering of some of the main Malaysian soil types has been discussed by West and Dumbleton³. Using x-ray diffraction techniques they examined the weathering products of granite, basalt, shale and a sandstone/shale sequence. Particular emphasis was placed on lateritic soils. Under the rapid weathering conditions found in wet tropical climates the weatherable minerals all break down so that the fine fractions of the soils tend to consist of the same minerals regardless of the original rock type. The character of the soils is modified by those minerals which resist weathering and remain in the soil body. Quartz, orthoclase feldspar and white mica are three such "inherited" minerals.

9.1 Weathering of the sediments

There is a complete range of sedimentary rocks in the Malay Peninsula, from shales to sandstones and conglomerates. They are all bedded, jointed and folded, and are all subject to the ingress of water. The result is the complete weathering of most of the sedimentary rocks to a depth of 10m or more, except on steep hill slopes where the soil may be 1–2m thick over partially weathered but identifiable rock strata.

Sedimentary rocks have undergone at least one cycle of erosion and therefore represent accumulations of material that has been broken down mechanically and chemically, and then sorted. Clay minerals and quartz are the only minerals which remain unaltered through a cycle of erosion, and so they are the most common constituents of sedimentary rocks. However, the composition of the rock may be much modified by the presence of secondary minerals and compounds, notably calcium carbonate. The relative proportions of quartz, stable clay minerals and secondary compounds will determine both the character of the rock and the products of its weathering. Most of the sediments weather to clays, with more or less sand according to the amount originally present. Sandstones with some clay in their makeup usually weather to clayey sands.

The fine-grained rocks form the bulk of the rock types present in S.W. Malaysia, and give rise to low hilly landscapes. The original structure and attitude of the beds is not apparent in aerial photographs; most of the landscapes consist of more or less isolated hills with well-organized drainage patterns, not related to the original structure. In the field some of the minor sedimentary structures may be preserved, but usually they are obliterated. Occasionally a thin rubbly band of quartzite remains to indicate the original attitude of the beds.

In the lowlands, occasional prominent hills occur close to the contact between the sediments and the granite, particularly in Johore where the higher hills and ridges follow the granite boundary closely. It is

thought that these rocks were to some extent baked and compressed by the intruding granite and rendered more resistant to weathering.

Rocks containing a higher proportion of sand appear to be present in the more prominent hills, although no very consistent relationship was found between grain size and resistance to erosion. Truly resistant sandstones form the high elongated ridges and occasional mountain masses peripheral to the granite. The ridges are among the few remaining traces of large scale fold structures visible in aerial photographs; in these and in a few lowland landscapes the original strike and joint pattern are still detectable.

The limestones, with their peculiar weathering and spectacular land forms⁴ do not occur in the study area and are therefore not considered here. (Very few occurrences of limestone are known anywhere south of Kuala Lumpur.)

9.2 Weathering of the granite

The granitic rocks underlying the Malay Peninsula present a more uniform suite of minerals for weathering than the sedimentary rocks, although the structure of the granite is by no means uniform. Its response to weathering is determined by the minerals present, grain size, and the distribution of the joints.

The micas and feldspars weather to kaolin and related clay minerals, although potassium feldspar (orthoclase) may remain in a highly weathered profile as part of the coarse fraction, with quartz. Only the larger quartz grains can withstand the continuous dissolution and survive into the soil phase.

The distribution of the joints is thought to be the most important factor determining the land form of the weathered granite. The granite mass possesses about four major directions of jointing: three vertical systems and one more or less horizontal. In the mountains and higher hills the vertical joint systems are visible in aerial photographs as weaknesses controlling the pattern of dissection (Plate 6). In the lowlands the generally deeper weathering has masked the jointing and the stream courses are only very weakly controlled, if at all (see Plate 2).

The "horizontal" system of joints lies in a plane roughly parallel to the present land surface and may be an unloading joint, developed after the removal of overburden. "Horizontal" joints appear to act as planes of release for moving ground water. The water, having weathered the minerals in the upper rock layers, is thought to reach a horizontal joint and move laterally out of the rock mass. This produces a profile of soil or completely weathered rock resting directly on hard, "ringing" granite (Plate 7). In places where no well-developed horizontal joint plane exists, a transitional zone of partly-weathered rock is present beneath the soil profile.

A characteristic in the weathering of granite is its tendency to form "coreboulders", ellipsoidal boulders of solid granite lying in a matrix of completely weathered rock. The boulders are commonly 0.5–5m or more across.

The reason for the development of these residual boulders appears to lie in the disposition of joints and microfractures in the rock mass. Closely-jointed or fractured rock allows water to enter and attack the mineral constituents, while unjointed rock is impermeable and resistant to weathering. Fig. 3 shows the weathering of granite boulders exposed on a beach near Kuantan. Hair-line fractures can be seen in the joints, which are being picked out by wave action. The inter-joint areas have no microfractures and stand out as knobs and boulders.

If zones of microfractures are closely spaced coreboulders will not develop; the rock weathers evenly to a soft mass which may give way at depth to partially weathered rock or pass abruptly into solid granite. A detailed discussion of the origin and formation of coreboulders is given by Linton².

Plates 8, 9 and 10 illustrate different stages of granite weathering. These profiles represent a sequence of granite weathering, but it is unlikely that any particular profile goes through all the steps in the sequence.

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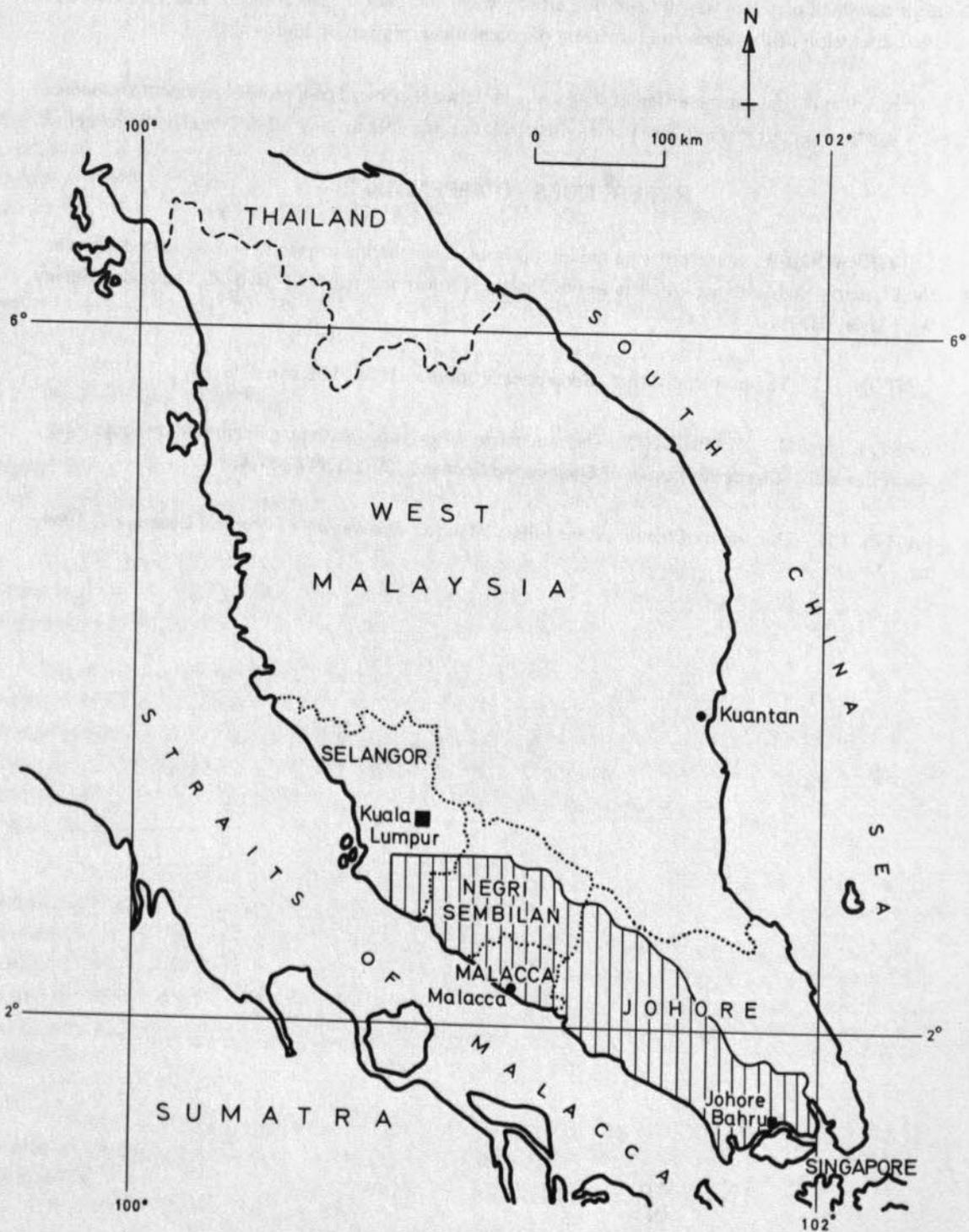


Fig 1
Map of the study area

LAND SYSTEM

Alor Gajah land system

Gentle hills with broad terraced river valleys

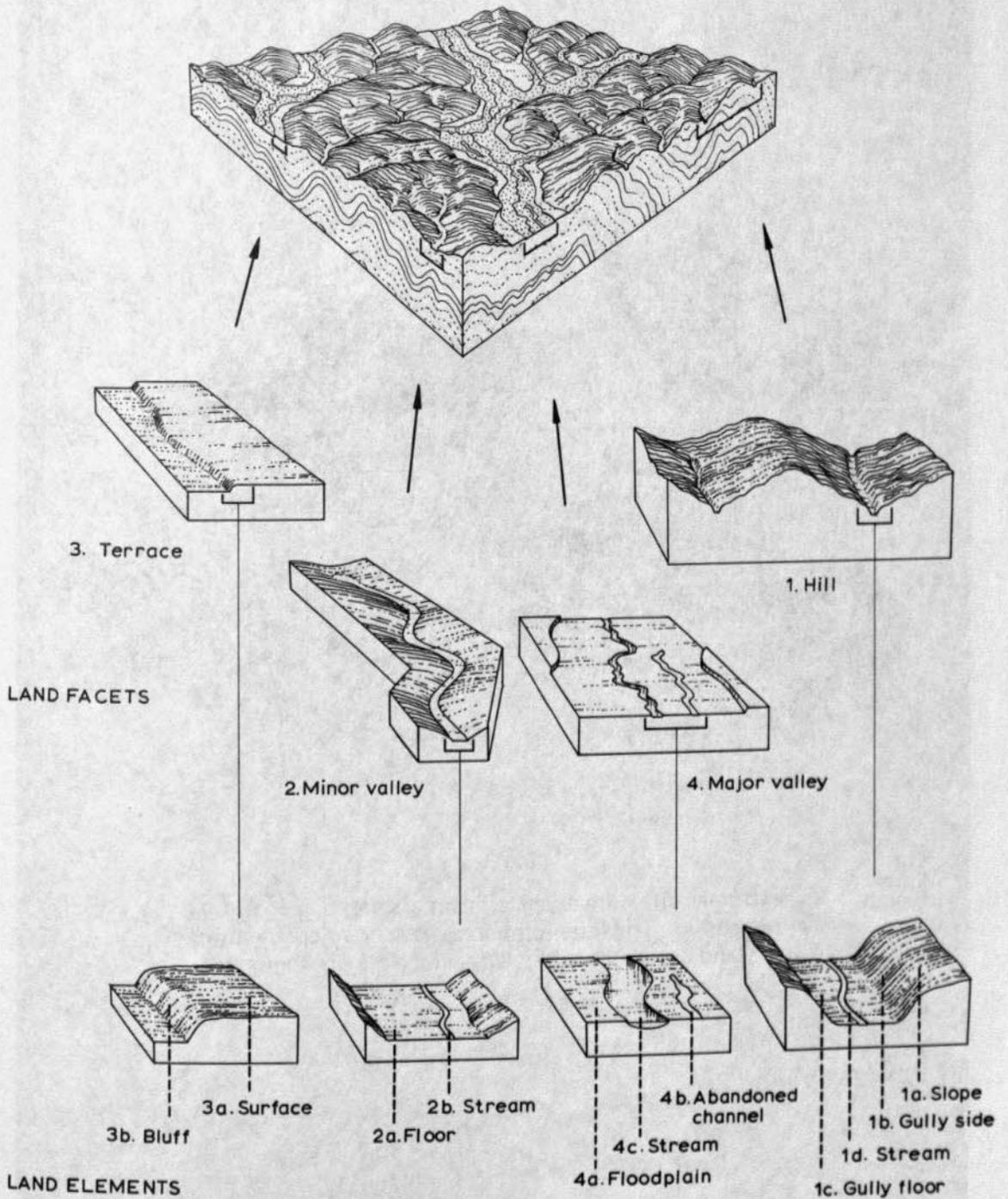


Fig 2

Diagram to show the relationship between land system, land facet and land element

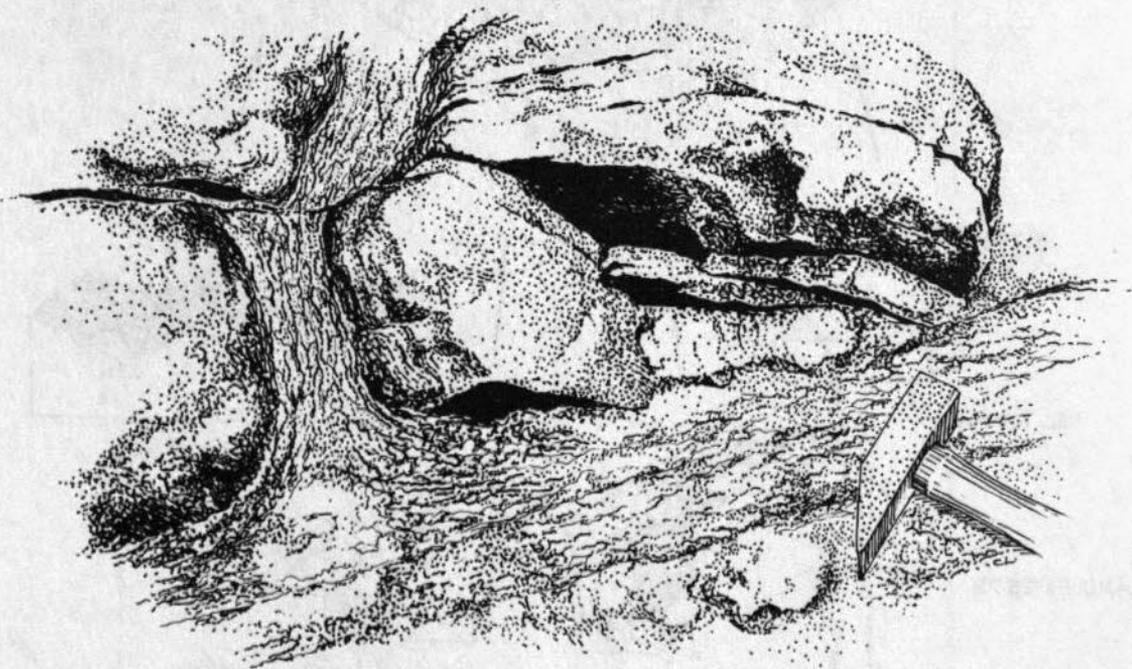


Fig 3

Zones of microfracture along joints in granite, picked out by marine erosion. The inter-joint areas have no microfractures, and stand out as boulders. (Drawn from a photograph)



PLATE 1

Aerial photograph showing a landscape pattern developed
on sedimentary rocks



PLATE 2

Aerial photograph showing a landscape pattern developed
in the lowlands on granite
The major streams still follow the jointing in the
granite (see also Plate 6)

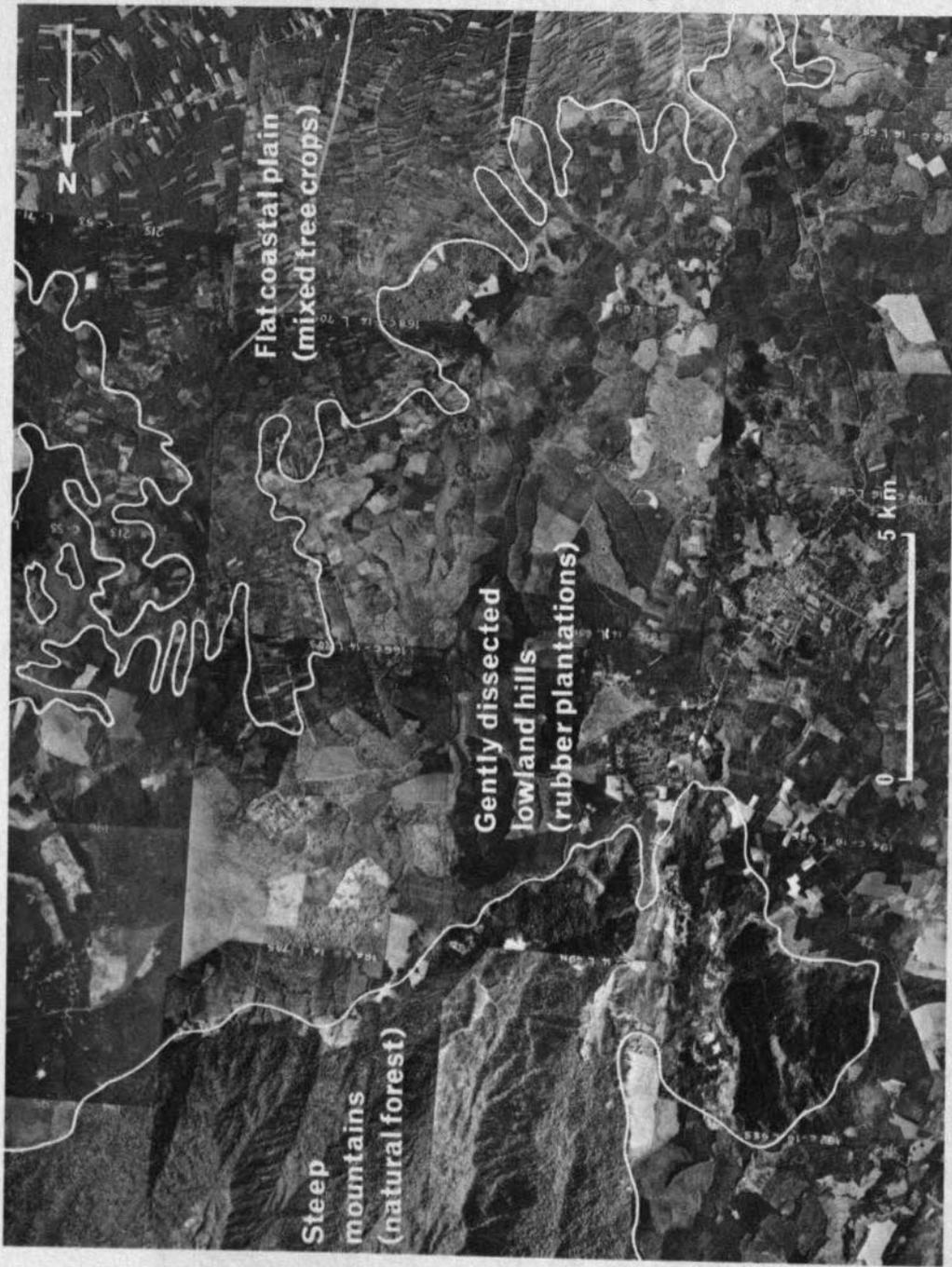


PLATE 4

Print laydown of aerial photographs showing the changes in air photo pattern between the coastal plain, the lowland hills and the mountains



PLATE 5

Brisu land system (facet 1) showing trees growing taller in the valleys (indicated by arrow), thereby masking the true relief. Facet 3 (river valley) in foreground



PLATE 6

Aerial photograph illustrating the contrasting joint systems of the granite and the sedimentary rocks. The granite (area A) has three main vertical systems, at approximately 60° to each other. The sediments (area B) apparently have only two, at right angles, characteristically dividing the sediments into long, parallel ridges

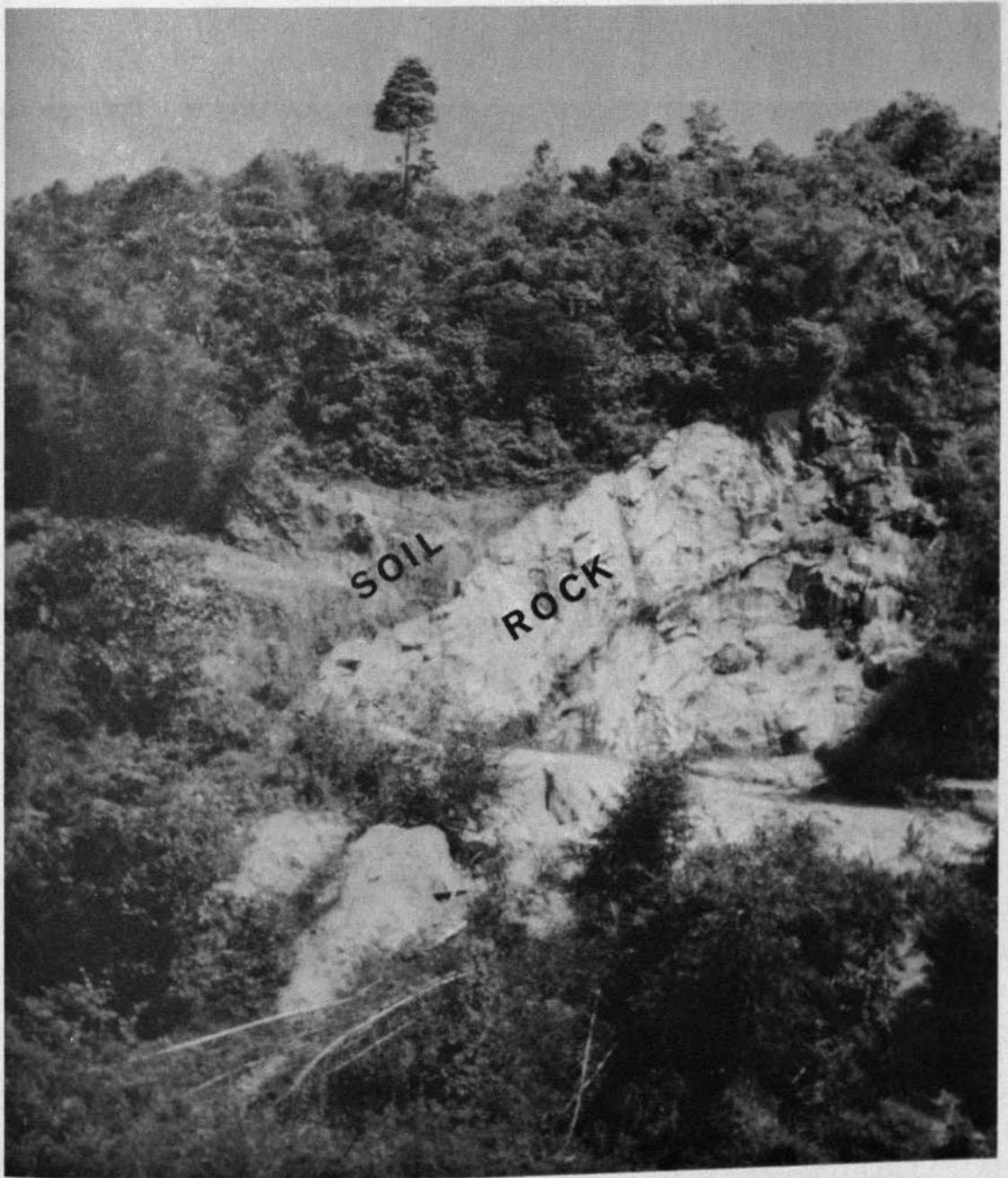


PLATE 7

Photograph in a granite quarry to show the abrupt boundary between the soil and unweathered rock, following a horizontal joint plane.

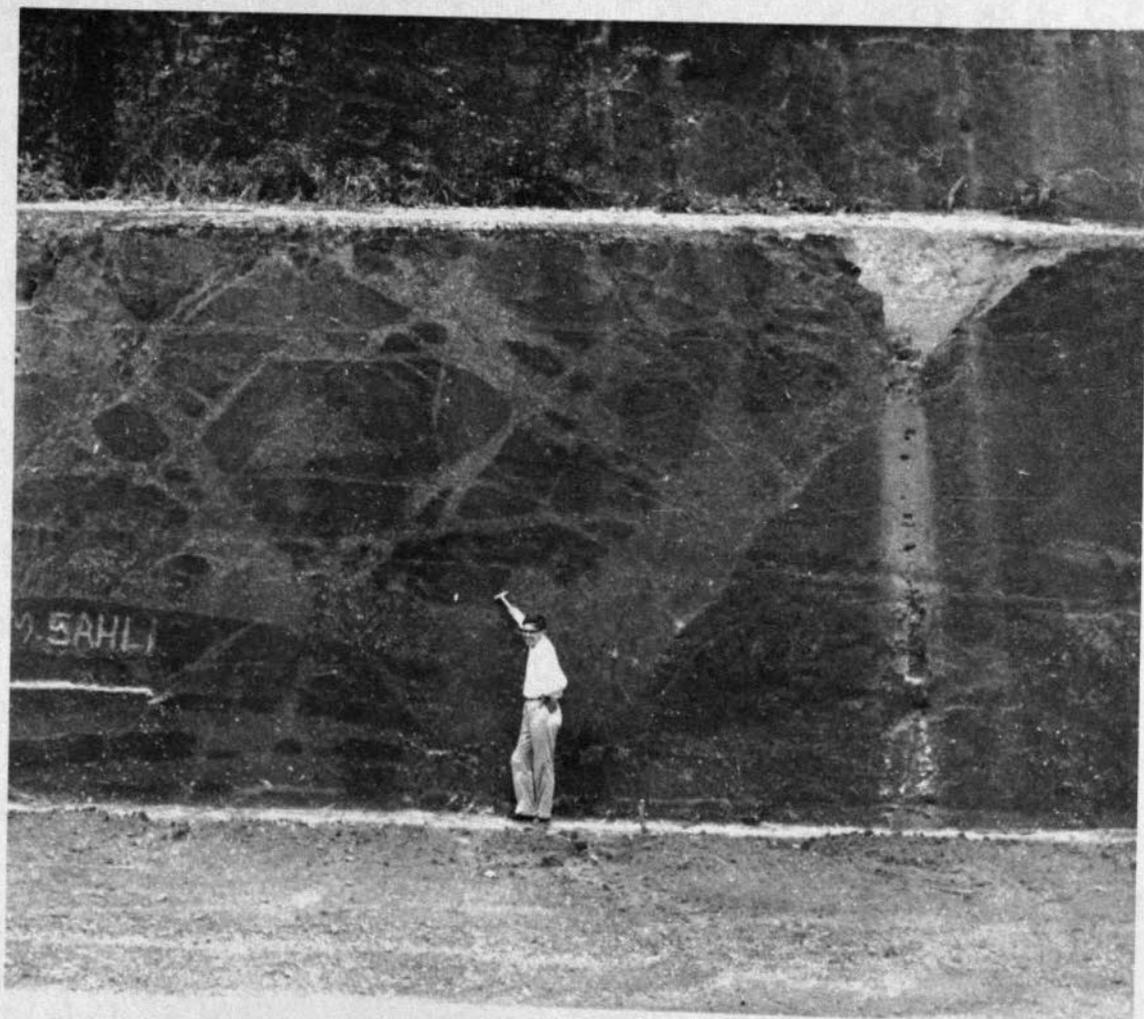


PLATE 8

Photograph of a road cutting in granite showing the more complete weathering along joints



PLATE 9

Photograph of a road cutting in granite showing an isolated core boulder of unweathered rock, surrounded by soil. Note that the boulder has had to be blasted in half

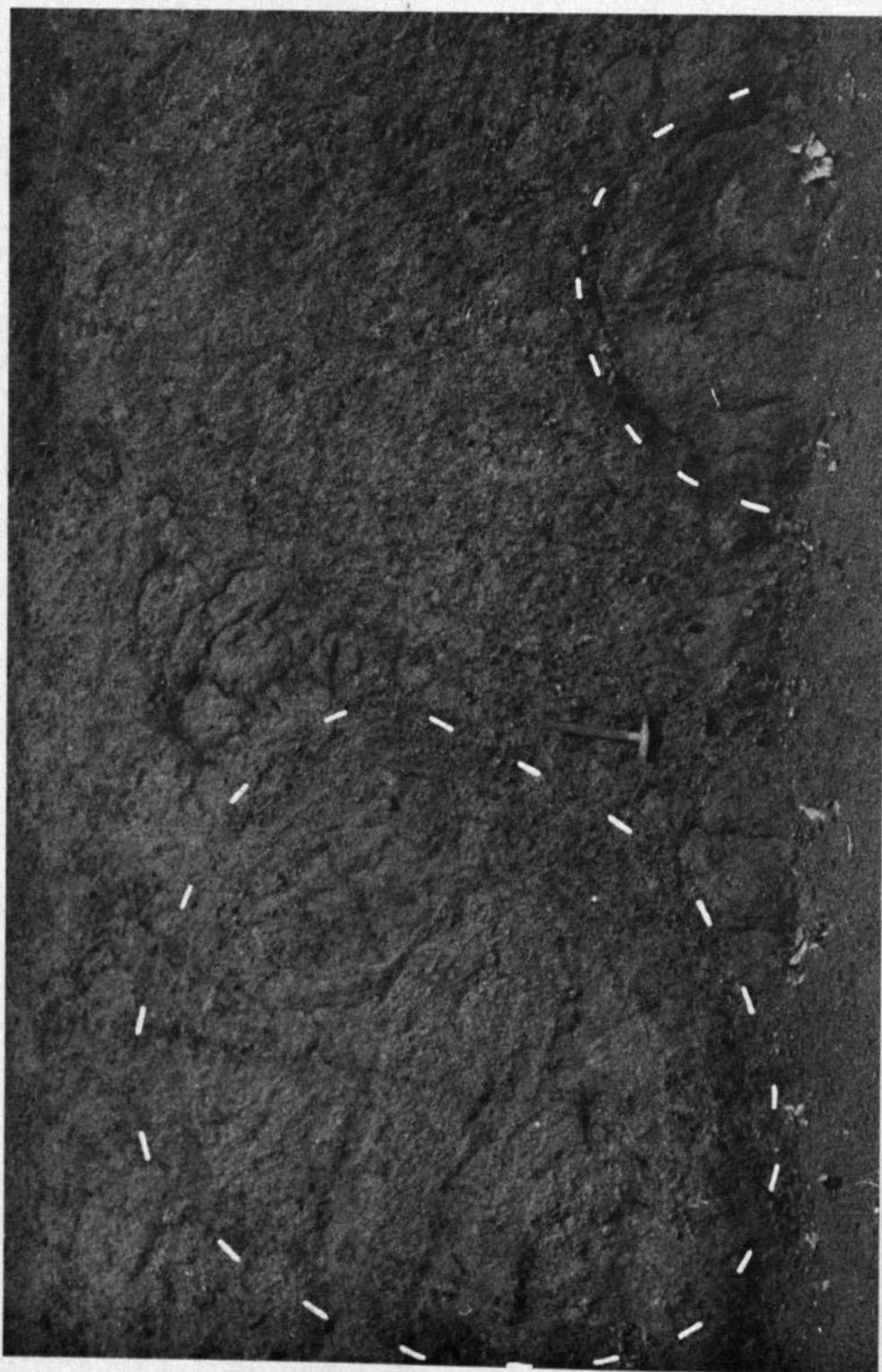


PLATE 10

Photograph of a road cutting in granite, showing relict
core boulders, now reduced to granitic soil, surrounded
by the soil matrix

ABSTRACT

Terrain evaluation in West Malaysia Part 1. Terrain classification and survey methods:
C J LAWRENCE: Department of the Environment, TRRL Report LR 506: Crowthorne, 1972 (Transport and Road Research Laboratory). This report is the first of three on the application of terrain evaluation to highway engineering in the humid tropics. The study area is the south west corner of the Malay Peninsula, and this report describes the procedure for classifying its terrains, using aerial photographs. The Oxford-MEXE system of land classification is explained, and briefly compared with the work of other organisations. The procedure for classifying the terrains of south West Malaysia is then described. The dense vegetation severely hindered air photo interpretation, but in the lowlands, where most of the terrain variations occurred, there were enough gaps in the tree cover to see the land surface.

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