JKR 20709-0336-95

Public Works Institute Malaysia

GEOGUIDE 1

TROPICAL WEATHERED IN-SITU MATERIALS

- OCCURRENCE AND GENERAL NATURE

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April 1996

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PREFACE

This geotechnical application guide is one of a series of documents prepared by J R Cook and Professor A McGown of the Department of Civil Engineering, University of Strathclyde, United Kingdom and the Institut Kerja Raya Malaysia (IKRAM). The object of these GEOGUIDES is to provide JKR engineers with a rational and practical methodology for the investigation and geotechnical characterisation of tropically weathered soil-rock masses.

GEOGUIDE 1 provides background information on tropically weathered in-situ materials (TWIMs) by dealing with their occurrence, general nature and classification. It forms a basis from which the other geotechnical application guides have been developed.

Other geotechnical application guides include:

GEOGUIDE 2 — *Tropical Weathered In-Situ Materials - Site Investigations*

GEOGUIDE 3 — *Tropical Weathered In-Situ Materials - Laboratory Testing*

GEOGUIDE 4 — *Tropical Weathered In-Situ Materials - Geotechnical Character of Profiles*

GEOGUIDE 5 — *Tropical Weathered In-Situ Materials - Engineering Application of Characterisation*

1.0 INTRODUCTION

1.1 General Context

The characteristics of Tropical Weathered In-Situ Materials vary, often significantly, from soils and rocks found in temperate climates on which text book approaches to solutions of geotechnical problems are generally based. These geotechnical characteristics are now recognised as having a great influence on civil engineering projects; from initial studies to ongoing in-service performance. The construction of roads often involves influencing soil-rock masses within those levels most influenced by weathering; hence the importance of appreciating the occurrence and general nature of Tropical Weathered In-Situ Materials.

It should be noted that the information for this GEOGUIDE is drawn from world-wide literature, however examples and conclusions are focused on the Malaysian geotechnical environment.

1.2 Definitions

It is important to clarify the terms to be used in connection with Tropical Weathered In-Situ Materials. To this end the following definitions are listed:

Weathering	The process of physical and/or chemical alteration of a parent material in response to contact with air, water and organisms.
Tropical Weathering	The process of weathering that predominates in tropical climates. It is predominantly a chemical process.
Weathering Grades	Weathering is commonly classified in geotechnics in terms of a number of standard grades.
Soil	An assemblage of organic and/or mineral particles.
Residual Soil	A soil which has been formed in situ by decomposition of a parent material and which has not been transported any significant distance.
Tropical Residual Soil	A soil formed in situ under tropical weathering conditions. The Geological Society (UK) Working Party Report, Geol. Soc.(1990), defined this as being within grades VI, V and IV of the standard weathering classification, Fig. 1.1.
Bedrock	Naturally occurring rock material underlying the soil cover.
Parent Material	The material from which the existing weathered material has been derived.
Tropical Weathered In Situ Materials	Soil and rock materials formed or influenced in situ by the tropical weathering process. For convenience these are termed TWIMs.
Soil-Rock Profile	A vertical profile representing the range of soil-rock materials present at a particular site. It may include materials ranging from fresh rock to residual soil or duricrust.
Tropical Weathered In situ Profile	A vertical profile representing the complete sequence of tropically weathered in situ soil and rock materials present at a location.

Soil-Rock Mass — An assemblage of soil and rock materials whose behaviour is governed by the structure and inter-relationship of the materials as well as the properties of the materials themselves.

Catena — A succession of soils and weathered rocks, usually down a slope, which is repeated in a pattern across a topographical sequence.

2.0 FORMATION

2.1 The Weathering Process

Weathering, in general terms, is "the breakdown and alteration of materials near the earth's surface to products that are more in equilibrium with newly imposed physio-chemical conditions", Ollier, (1969). It forms part of the overall geological cycle of rock genesis, degradation, alteration and reformation, Fig. 2.1.

Fookes et al (1988) summarised the three simultaneous processes involved in chemical weathering as:

i) Breakdown of the parent material structure with the concomitant release of the constituent elements as ions or molecules
ii) The removal in solution of some of these released constituents
iii) The reconstitution of the residue with components of the atmosphere to form new minerals which are in stable or metastable equilibrium with the environment.

Weathering can be considered as a combination of two processes: physical disintegration and chemical decomposition. Tropical weathering is essentially dominated by the latter process and may be thought of as a chemical reaction whereby the parent material is seeking to reach equilibrium with the governing environment. Physical degradation although playing a minor overall role, is considered to play a significant part in tropical weathering. Blight (1988) has reported on the effect of physical degradation in the tropical weathering on some structured sedimentary and metamorphic rocks. Birkeland (1974) has described the enhancement of weathering in granite caused by the alteration of biotite to the clay mineral vermiculite which can be accompanied by up to 40% volume increase and can result in physical fracturing of the rock material. Physical transportation through leaching also has a vital role in the process of tropical weathering, Spears (1983).

A number of physical and environmental factors have been recognised as influencing the tropical weathering process, Geol. Soc. (1990). These are summarised in Table 2.1, with further details in Figs. 2.2 and 2.3.

Tropical weathering of a soil-rock mass is largely concerned with the decomposition of constituent minerals and the formation of stable or metastable secondary products. The relative stability, or resistance to chemical decomposition of the rock forming minerals is indicated by Bowen's Reaction Series, Bowen (1928), Fig. 2.4. Different rock types contain different mineral assemblages; for example, basic igneous rocks contain relatively smaller amounts of silica and greater amounts of the less stable mafic minerals than silica rich rocks such as granite. It may be expected therefore that under similar conditions the former may be expected to weather more readily than the latter. Granite in turn, however, can be seen in Malaysia to weather preferentially with respect to quartzitic sandstones and produce significantly deeper soil profiles, Cook (1996).

The main chemical processes involved in tropical weathering are outlined below and their roles in the weathering of soil-rock masses are summarised in Fig. 2.5:

(a) Hydrolysis: This is thought to be the most important chemical decomposition process. In general terms:

Silicate + H_2O + H_2CO_3 = Clay mineral + cations + OH^- + $HCO3^-$ + H_2SiO_4

A typical clay formation could be:

$2KAlSi_3O_8$(orthoclase) $+2H_2CO_3$ $+9H_2O$ -> $H_4AlSi_2O_9$(Kaolinite) + etc

The fate of the aqueous ions is variable, for instance aluminium is not very soluble over a range of pH and so tends to remain close to the area of release. Iron similarly remains close to the area of release, hence the well known oxidation colours in active weathering areas.

(b) Solution: Solution and associated leaching are vital factors in the development of weathering profiles and are closely associated with hydrolysis. In general terms rain soaks into the ground which contains CO_2 derived from the atmosphere and from the humus zone. Ions become dissolved in the CO_2 enriched water and the solution proceeds down under a hydraulic gradient until a state of saturation is reached.

(c) Oxidation: Oxidation is the process of losing electrons with a resultant gain in positive valency. Oxygen is the most common oxidising agent and iron the most commonly oxidised element in a profile; on being released by hydrolysis into an aerobic environment Fe^{2+} quickly oxidises to Fe^{3+}. Oxidation can disrupt the mineral structure causing it to collapse or leave it more vulnerable to further weathering processes.

(d) Reduction: Reduction is the reverse of the oxidation process. Reduction of iron from the ferric to its ferrous state takes place in anaerobic weathering environments.

(e) Hydration-dehydration: This is a chemical process whereby a mineral takes up or loses water molecules to form a new mineral. A change in volume may be associated with this type of reaction. The process is limited to a few minerals, such as haematite which can hydrate to goethite and halloysite which in turn can dehydrate to metahalloysite

(f) Chelation: Chelating agents are formed by biological processes in the soil aided by lichens growing on rock surfaces. Hydrogen can be released by organic molecules from within iron ring structures to promote hydrolysis. Chelating agents render substances more soluble under certain pH conditions. A common example is aluminium which may be soluble as a chelate over pHs at which it is insoluble as an ion, Birkeland (1974).

It may be appreciated that the availability and movement of groundwater, as the principal chemical agent involved in the weathering process, is critical to the degree and extent of weathering, Table 2.2.

The chemical weathering continuum will naturally tend to produce a parallel alteration pattern to the physical properties of the affected material. Tuncer and Lohnes, (1977) examined the weathering process in detail for basalts as it affected their physical properties, Fig. 2.6, and summarised the stages of its weathering process as follows:

Stage 1 Parent rock with very low void ratio and high intrinsic strength.

Stage 2 Weathering, causing rock disintegration, resulting in an increase in void ratio and decrease in overall strength.

Stage 3 Increased weathering, resulting in increased clay content leading to a decrease in void ratio and permeability but with some increase in strength. Also the specific gravity begins to increase because of the increasing presence of sesquioxides.

Stage 4 Continued weathering causing the sesquioxide content to increase further, however the kaolinite content decreases through conversion to gibbsite. At the same time the sesquioxides cement clay particles and cause the soil to become more granular. Specific gravity increases further due to an increased iron oxide content and the void ratio increases.

Stage 5 Further weathering increases the sesquioxides with additional cementation of aggregates resulting in larger gravel size concretions being formed. The void ratio decreases with an associated increase in strength. Specific gravity may increase or decrease depending on whether iron or aluminium oxides predominate.

Stage 6 Secondary or pedogenic rock is formed.

Although the detail of the above summary may vary with respect to the parent material, the general idea of a gradational, and not always detrimental, alteration in geotechnical properties is a valuable concept to be applied to the understanding the nature of TWIM profiles.

2.2 The Products of Tropical Weathering

Tropical weathering, as a consequence of the relative importance of the factors discussed above, generally results in the formation of a chemical, and consequently a geotechnical, continuum of gradual transitions, DeMello, (1972). For convenience this continuum is commonly described in terms of a number of horizons within a vertical profile. Such profiles may in general contain, in addition to the fresh parent material, some or all of the following:

duricrusts
mature soils
saprolites
altered parent material

Figure 2.7 summarises the basic units of the profile, Millot, (1970).

In reality the nature of tropically weathered profiles may vary considerably over short distances, although this may be in a regular and repeatable manner. In such cases it may be more useful to consider the catena as the fundamental unit as regards understanding the formation of profiles and their relationship to one another. The catena rather than the individual profile more accurately reflects the movement of groundwater down slopes and the variation in hydrological conditions in response to local terrain.

A fundamental requirement for the development of a TWIMs profile is that the rate of weathering must exceed the rate of mass erosion. Thus, high erosion rates may modify the theoretical profile developments, particularly on steep slopes or within land systems subject to recent uplift and denudation. Tropical weathering patterns may be highly variable both horizontally and vertically. Depths of weathering have been noted up to hundreds of metres within stable areas, Thomas, (1994). On a large scale Dobereiner and Porto, (1993) report depths of weathering varying between 20 and 40m in a Brazilian gneiss adjacent to the coast but note that a similar material had weathering up to 120m deep in other inland areas of Brazil.

The products of tropical weathering can be usefully considered in terms of their mineralogy and structure.

2.2.1 Mineralogy.

The principal mineral products of weathering in TWIM profiles are clay minerals, Table 2.3. The commonest found in soil-rock profiles are hydrated silicates of aluminium, iron and magnesium arranged in various combinations of layers; hence the terminology of layer silicates or phyllosilicates.

Within any soil horizon there is usually a variety of minerals resulting from:

i) variable rates of parent minerals alteration to new minerals depending in detail on the silica content, the concentration of ions present, the soil pH and the amounts of leaching.
ii) inherited clay minerals from parent material

iii) clays mineral formed under previous chemical weathering environments.
iv) relict primary minerals

2.2.2 Structure.

The words structure, fabric and texture, although commonly used within the earth science literature, are frequently employed in apparently conflicting senses by soil mechanics, rock mechanics and geological workers. For the purposes of this Geoguide the following definitions are used:

Texture — The morphology, type and size of component particles.

Fabric — The spatial arrangement of component particles.

Discontinuities — The nature and distribution of surfaces separating elements of fabric, material or soil-rock mass.

Structure — The fabric, texture and discontinuity patterns making up the soil-rock material, mass or unit.

In addition, the above may be described at a number of scale levels, again, for the purposes of this Geoguide the following apply:

Micro-level — Generally only described with the aid of a SEM or a petrographic microscope.

Meso-level — Generally seen with the aid of a field microscope or a good hand lens.

Macro-level — Patterns visible to the naked eye in the field.

Mega-level — Patterns that become apparent by means of maps or remote sensing, although individual elements may be visible at field level.

The processes of leaching and new mineral formation results in the assemblage of a new material structure. This may range from a fragile assemblage of minerals in weakly bonded micro-fabric to the robust pedogenic formation of a duricrust, Vaughan (1988) and Charman (1988).

Macro-discontinuities within a TWIM mass are usually inherited features in the form of joints, bedding planes, faults, etc. Some new-formed fissuring can be present as the result of formational soil movement, particularly in, for example, swelling vertisols.

3.0 CLASSIFICATION

3.1 Objectives

The aim of the classification of tropically weathered materials should be to group together those materials that are likely to have similar properties in order to assist in making rational and effective engineering decisions.

3.1.1 Existing Classifications

Soil-rock profile classification systems have historically been based on the concept of weathering grades, e.g. Moye, (1955) Ruxton and Berry, (1957) and Little, (1969). Their objective has been to compartmentalise the perceived physical characteristics and to provide a useful shorthand method for disseminating information on engineering properties, Dearman, (1974). These general systems, which were largely developed for the chemical weathering of granitic rocks, have proved difficult to apply directly in practice in other geological environments and have been the subject of much critical debate and detailed adjustment, Dearman (1986), Martin and Hencher (1986) and Spink and Norbury, (1993).

In addition to these weathering based profile approaches there are systems dealing largely with the classification of the tropical residual soil elements of the profile and many dealing exclusively with duricrust materials. They may be divided into the following groups:

i) Those based on environmental criteria.
ii) Those based on pedological criteria.
iii) Those that extend standard geotechnical soil classifications.
iv) Those that develop a special parameter of relevance to a group of materials or site.

3.1.2 Classification Difficulties

Attempts to provide a general classification system for TWIM profiles encounter a number of basic difficulties. In summary these are:

i) Tropical weathering tends to produce a gradational continuum of properties.
ii) Chemical weathering patterns are unlikely to be similar for different parent materials; even for those in close proximity.
iii) Similar parent materials may undergo different chemical weathering reactions as a result of variations in geomorphology, e.g., oxidation on drained slopes and reduction on waterlogged valley/slope bottoms.

3.1.3 Classification Aims

A more general approach to TWIM profile classification is required which will allow particular systems to be developed to deal with project requirements. The overall aims of this approach must be:

i) To encompass all the materials within the profile.
ii) To be geotechnically significant.
iii) To be generally compatible with the existing range of detailed or specific systems.

3.2 Overall Classification Methodology

The investigation of geotechnical properties for design and construction requires the identification of the materials as having, in general terms, the characteristics of a soil, a rock, or a mixture of both. In order to be of geotechnical significance the classification methodology must use this requirement as a starting point. Price (1993) indicated this type of approach in his classification procedure which is closely tied to engineering relevance,

Figure 3.1 outlines a classification process which can use appropriate general systems in an overall approach to TWIMs. There are two basic aspects of this classification process; firstly weathering and secondly behaviour. In engineering terms the latter can in be considered on the basis of behaviour as a soil, as a rock or as a soil-rock mixture. In some projects this level of sub-division may be all that is practically required in terms of classification, whilst in many others, further division on the lines of the commonly used weathering grades may be required. Table 3.1 illustrates the relationship between basic behaviour patterns and classification for some typical parent materials.

It is emphasised that the scale of classification is engineering and project driven, but that the boundaries of classification divisions are based on the nature of the material or mass. The development of specific classification systems may be based on a combination of engineering, genetic and behavioural grounds, the exact make-up being a function of project requirements.

3.3 Detailed Classification Development

3.3.1 Guidelines

There is now a growing appreciation that the use of a standard overall weathering classification is impractical and that a more general approach is required that takes into account both the characteristics of the parent materials and the mode of weathering. Recent work by the Geological Society Working Party on Weathering, Geol. Soc. (1995), has reinforced the research undertaken in this field by IKRAM and the University of Strathclyde, Nik Ramlan Hassan et al (1994) and Cook (1996).

The development of specific classification systems may be based, as indicated in Fig. 3.1, on a combination of genetic and behavioural grounds; the exact make-up being a function of project requirements. In any event, the following guidelines apply to the set-up of classification grades:

i) Grade descriptions must apply to uniform materials.
ii) Index tests should back-up grade definitions.
iii) Consistent grade numbering should be used.
iv) Classification grades must be recognisable in naturally occurring profiles.
v) The complete range of materials must be accounted for.
vi) Boundaries must have an engineering significance.

3.3.2 Genetic Classification

Classifications based on formational processes provide a sound, logical and scientific basis for development. The combination of the traditional rock-type classification, Table 3.2, in conjunction with one for tropically weathered materials could provide such a basis.

The Engineering Group of the UK Geological Society, Geol. Soc. (1990), included a comprehensive and scientifically based classification system, Table 3.3. They also attempted to relate environmental influences, pedogenic terminology and common engineering terms. This classification can effectively form a rational base for the more detailed specific classification of tropical soils and their geotechnical investigation.

3.3.3 Behavioural Classification

To be of engineering significance a classification system must take into account general behaviour. For rock-like materials the traditional behaviour classification has been based on strength, e.g., ISRM (1984). Although of engineering significance, this alone is not sufficient for rock-like material in the tropical environment. A measure of the susceptibility to disintegration is a relevant index for classification bearing in mind the structural sensitivity of many apparently rock-like tropical materials. The use of the slake index is therefore recommended. Figure 3.2 illustrates the use of the slake index for a selection of Malaysian materials.

Wesley (1988) indicated a useful geotechnical classification that may be used with advantage for soil-like and some rock-like materials. In essence Wesley divided tropical soils into three main groups:

i) Soils without a strong mineralogical influence.
ii) Soils with a strong mineralogical influence coming from conventional clay mineralogy normally found in sedimentary soils.
iii) Soils with a strong mineralogical influence coming from special clay minerals not found in normal sedimentary soils.

He also indicated further subdivisions on the basis of the influence and engineering importance or not, of fabric and discontinuities at the micro level

3.3.4 Specific Classifications

Behavioural and genetic classifications in combination with local influences can produce engineering relevant classifications specifically for use with rocks types, with certain projects or within regions. The formation of these classifications can usefully be undertaken at an early stage of a project investigation.

Although recent typical specific classifications by Komoo and Mogana, (1988) and Lee and deFreitas, (1989) include many of the characteristics covered above, neither includes specific reference to a behaviour based tropical soils classification. Examples of specific classifications produced as part of a research programme on the East-West Highway associated with these GEOGUIDES are included within GEOGUIDE 4.

4.0 GEOTECHNICAL NATURE

4.1 General Character

The in-situ geotechnical character of a tropically weathered soil-rock mass is a function of the chemical weathering process allied to any relict characteristics. It may depend on the material characteristics, such as fabric, texture and mineralogy, and the mass characteristics, such as the relative amounts and nature of the materials and the structure of the mass.

The identification of soil-like and rock-like behaviour patterns, discussed above with respect to basic classification, is a fundamental step in the assessment of the character of tropically weathered profiles. The main difficulties arise in the characterisation of the tropically weathered soils and more particularly those materials with composite soil-rock behaviour patterns.

4.2 Unusual Characteristics

There are several tropically weathered materials whose behaviour is significantly different from sedimentary soils from which the standard principles of soil mechanics were derived. Their behaviour may not be based on stress history but on factors such as mineral bonding or soil suction. Further the mass characteristics of TWIM profiles may have behaviour patterns that will be significantly different from those expected from more temperate climates. These characteristics may have both detrimental and beneficial effects on civil engineering performance. In either case their appreciation and recognition is essential. These characteristics are both internal and external and may be summarised as follows:

(i) Internal:

material - complex clay mineralogies
leached or voided fabrics
weakly bonded fabrics

mass - relict structures
development of pedogenic layers

(ii) External:

partial saturation

4.3 Character and Performance

Tropically weathered materials have a range of definable characteristics that will influence their geotechnical performance under project conditions. Therefore there is an important distinction to be made between their inherent in-situ characteristics and those that become apparent during construction, Fig.4.1. In conventional soil mechanics this distinction has become blurred with the application of empirical relationships derived from the very large body of existing knowledge. In tropical soils many of these empirical relationships are not applicable and it is important to establish the behaviour patterns directly rather than indirectly , Vaughan, (1988).

The general character of TWIM profiles can be considered under the headings of intrinsic, fabric influenced and structurally influenced behaviour. Distinguishing between, and establishing, the intrinsic, textural and structural behaviour patterns means that a more relevant correlation must be made between the in-situ character and the likely performance. An indication of the relationships between project activities and material-mass behaviour patterns are presented in Table 4.1.

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GEOGUIDE 1

TROPICAL WEATHERED IN-SITU MATERIALS OCCURRENCE AND GENERAL NATURE

TABLES

BLE 2.1 ***Factors Influencing Tropical Weathering, Patterns***

CTOR	INFLUENCE	COMMENT
ology	Parent material; its nature, structure, variability. Geological history in terms of tectonic stability and alteration.	Steep dip on discontinuities=deeper weathering Erosion a function of uplift
mate	Evapo-transpiration patterns and variations. Palaeoclimate	See Weinert (1974) Climatic Index. Role of Climate: Fig 2.2
dform	Slope and relief influence mainly through drainage and erosion rates. Geomorphological stability.	Role of landform: Fig 2.3
drology	Groundwater, its location, chemistry and variation and its rate of movement through the weathering medium.	Water: crucial role in chemical weathering Drainage = leaching
me	Formation of TWIM profiles influenced by the rate of chemical reaction and hence by time.	Chemical weathering rates highly variable between geological and engineering time scales; Fookes et al (1988).
getation	Organic matter; a crucial element in the tropical weathering chemical reactions through breakdown of plant tissue to supply soluble organic substances, mineral compounds and metal cations	Change in vegetation can lead to increased erosion patterns

ABLE 2.2 ***The Influence of Hydrology on Tropical Weathering***

NFLUENCING FACTOR	INFLUENCE ON WEATHERING PATTERN
roundwater table movement	Leaching and deposition cycle
ranspiration percolation	Influx of fresh water recharges the chemical reaction process
rainage	Good drainage required to encourage the above percolation and oxidising conditions. Poor drainage results in closed chemical system, and reducing conditions.
ransportation	Removal of ions and eroded particles from system.

TABLE 2.3: Clay Minerals (Phyllosilicates) Commonly Found in TWIMs Resulting from Chemical Weathering

GROUP (Structure)	MINERALS	IDEAL FORMULA	A⁰ Spacing	COMMENTS
Kaolinite (1:1)	Kaolinite	$Al_4Si_4O_{10}(OH)_8$	7	Platy
	Halloysite	$Al_4Si_4O_{10}(OH)_8.4H_2O$	10	Tubular
	Meta-Halloysite	$Al_4Si_4O_{10}(OH)_8.0.6H_2O$	7	Tubular
Serpantine (1:1)	Serpantine	$Mg_6Si_4O_{10}(OH)_8$	7	
Illite-Micas (2:1)	Illite		10	Fine
	Muscovite	$K_2(Si_6Al_2)(Al_4)O_{20}(OH)_4$	10	Coarser
	Biotite	$K_2(Si_6Al_2)(MgFe^{2+})_6)O_{20}(OH)_4$	10	Coarser
Chlorite (2:1:1)	Mg-rich chlorite	$(Si_{8-x}Al_x)(Mg_{12-y}Al_y)O_{20}(OH)_{16}$	14	
	Fe-rich chlorite	$(Si_{8-x}Al_x)(Fe_{12-y}Al_y)O_{20}(OH)_{16}$	14	
	Al-rich chlorite	$(Si_{8-x}Al_x)(Al_{12})O_{20}(OH)_{16}$	14	
Vermicullite (2:1)	Vermicullite	$(Si_{8-x}Al_x)$ $(MgFe)_6O_{20}(OH)_{16}.M_xH_2O$	10-15 *	Swelling
Smectite (2:1)	Montmorillonite	$(Si_8(Al_4-Mg_x)_6O_{20}(OH)_4.M_x$	10-15 *	Swelling
	Nontronite	$(Si_8-Al_x)Fe_4O_{20}(OH)_4.M_x$	10-15 *	Swelling
Mixed Layer	Illite-smectite			Swelling
	Chlorite-smectite			Swelling
	Kaolinite-smectite			Swelling
Non-crystalline	Allophane	(Paracrystalline hydrous aluminosilicates)	30-50	Hollow spheres
	Imogolite		20	Tubes

Notes: * Spacing a function of humidity.

TABLE 3.1 Behaviour - Classification Relationship for Typical TWIMs

TROPICAL WEATHERING PRODUCT (See Figure 3.1)	BEHAVIOUR RELATED TO PARENT MATERIAL	TYPICAL BEHAVIOUR PATTERNS			TYPICAL STANDARD GRADES
		MUDSTONE (Rock)	GRANITE (Rock)	VOLCANIC DEBRIS (Soil-rock)	
P	Slightly modified	Soil-rock	Rock	Soil-rock	I - II
AP	Derived with significant parent influences	Soil	Soil-rock	Soil-rock	III-IV
CAP	Largely derived, some relict influences	Soil	Soil	Soil	V-VI
D	Totally derived	(unlikely)	Rock	Rock	VI

[illegible]

Grain size, mm	Bedded rocks (mostly sedimentary): Grain size description		At least 50 % of grains are of carbonate	At least 50 % of grains are of fine-grained volcanic rock		Obviously foliated rocks (mostly metamorphic): Grain size description		Rocks with massive structure and crystalline texture (mostly igneous)	Grain size description				
More than 20 20 6 2	RUDACEOUS	CONGLOMERATE Rounded boulders, cobbles and gravel cemented in a finer matrix Breccia Irregular rock fragments in a finer matrix	LIMESTONE and DOLOMITE (undifferentiated) Calcirudite*	Fragments of volcanic ejecta in a finer matrix Rounded grains AGGLOMERATE Angular grains VOLCANIC BRECCIA	SALINE ROCKS Halite Anhydrite	COARSE	GNEISS Well developed but often widely spaced foliation sometimes with schistose bands Migmatite Irregularly foliated: mixed schists and gneisses	MARBLE QUARTZITE Granulite HORNFELS Amphibolite Serpentine	COARSE	Pegmatite GRANITE[1] These rocks are sometimes porphyritic and are then described, for example, as porphyritic granite	Diorite[1,2]	GABBRO[3]	Pyroxenite Peridotite
0.6 0.2 0.06	ARENACEOUS Coarse Medium Fine	SANDSTONE Angular or rounded grains, commonly cemented by clay, calcitic or iron minerals Quartzite Quartz grains and siliceous cement Arkose Many feldspar grains Greywacke Many rock chips	Calcarenite	Cemented volcanic ash TUFF	Gypsum	MEDIUM	SCHIST Well developed undulose foliation; generally much mica		MEDIUM	Microgranite[1] These rocks are sometimes porphyritic and are then described as porphyries	Microdiorite[1,2]	Dolerite[3,4]	—
0.002 Less than 0.002	ARGILLACEOUS	MUDSTONE — SILTSTONE Mostly silt SHALE Fissile — CLAYSTONE Mostly clay	Calcareous mudstone Calcisiltite Calcilutite CHALK	Fine-grained TUFF Very fine-grained TUFF		FINE	PHYLLITE Slightly undulose foliation; sometimes 'spotted' SLATE Well developed plane cleavage (foliation)		FINE	RHYOLITE[4,5] These rocks are sometimes porphyritic and are then described as porphyries	ANDESITE[4,5]	BASALT[4,5]	—
Amorphous or crypto-crystalline		Flint: occurs as bands of nodules in the Chalk Chert: occurs as nodules and beds in limestone and calcareous sandstone			COAL LIGNITE		Mylonite Found in fault zones, mainly in igneous and metamorphic areas			Obsidian[5]	Volcanic glass		
		Granular cemented-except amorphous rocks				CRYSTALLINE				Pale ← colour → Dark			
		SILICEOUS	CALCAREOUS	SILICEOUS	CARBON-ACEOUS	SILICEOUS		mainly SILICEOUS		ACID Much quartz	INTERMEDIATE Some quartz	BASIC Little or no quartz	ULTRA BASIC

SEDIMENTARY ROCKS
Granular cemented rocks vary greatly in strength, some sandstones are stronger than many igneous rocks. Bedding may not show in hand specimens and is best seen in outcrop. Only sedimentary rocks, and some metamorphic rocks derived from them, contain fossils.

Calcareous rocks contain calcite (calcium carbonate) which effervesces with dilute hydrochloric acid.

METAMORPHIC ROCKS
Most metamorphic rocks are distinguished by foliation which may impart fissility. Foliation in gneisses is best observed in outcrop. Non-foliated metamorphics are difficult to recognize except by association. Any rock baked by contact metamorphism is described as a 'hornfels' and is generally somewhat stronger than the parent rock.

Most fresh metamorphic rocks are strong although perhaps fissile.

IGNEOUS ROCKS
Composed of closely interlocking mineral grains. Strong when fresh; not porous

Mode of occurrence: 1. Batholiths; 2. Laccoliths; 3. Sills; 4. Dykes; 5. Lava flows; 6. Veins

TABLE 3.3 Summary of the Geological Society Engineering Group Classification of Tropical Residual Soils

I DURICRUSTS

CLASSIFICATION/Subdivisions	GENERAL DESCRIPTION	COMMON TERMS
SILCRETE a. Grain supported fabric b. Floating fabric c. Matrix fabric d. Conglomeratic	Indurated deposits consisting mainly of Silica which may have been formed by lateral or vertical transfer. Subdivision on the basis of fabric. Commonly poor in Fe, Al, Ca, K and P.	Silcrete
CALCRETE a. Calcified soils b. Powder calcrete c. Nodular calcrete 1 Nodular 2 Concretionary d. Honeycombe calcrete 1 Coalesced nodules 2 Cemented e. Hardpan calcrete 1 Cemented honeycombe 2 Cemented powder 3 Recemented 4 Coalesced nodules 5 case hardened calcic f. Laminar g. Boulder	Variably indurated deposits consisting mainly of Ca and Mg carbonates. Includes non-pedogenic forms produced by fluvial or groundwater action, otherwise by lateral or vertical pedogenic transfer. Subdivision usually on basis of degree and type of cementation.	Calcareous soil becoming hardpan, calcrete or dolocrete with increasing concretionary growth.
FERRICRETE a. Water table cuirasses 1 Local 2 Plinthite 3 Petroplinthite b. Plateau cuirasses *Or* a. Pisolitic b. Scoriaceous c. Petroplinthite	A form of indurated deposit containing accumulations of sesquioxides, mainly iron, within one or several ferruginous or ferrallitic soil horizons. It amy be formed by deposition from solution, moving laterally or vertically, or as a residue after removal of silica, alkalis etc. It may be pedogenetic by retention or accumulation of minerals and by segregation within vadose profiles. May also be reworked or detrital. Subdivision on the basis of degree and type of induration.	Lateritic (red) soil or plinthite becoming hardpan or laterite with increased concretions or induration
ALUCRETE a. Pisolitic b. Scoriaceous c. Petroplinthite	A form of variably indurated deposit containing Al and Fe in residual laterite deposits, with Al in sufficient quantity to be of commercial use. Otherwise similar to ferricretes	Bauxite,Alucrete

TABLE 3.3 (Continued)

II MATURE SOILS

CLASSIFICATION	GENERAL DESCRIPTION	COMMON TERMS
VERTISOLS a. True vertisols 1 Developed 2 Slightly developed b. Coloured vertic soils 1 Intergrades & ferruginous 2 Vertic brown soils	Dark coloured mature soils rich in swelling clays strongly bonded to humic compounds. Typically show vertical mixing due to clay volume changes, likely to contain contraction fissures and slickensides.	Black swelling clays; black cotton soils; tropical black clays
ANDOSOLS (Fersiallitic) a. Vitrisols b. True Andosols 1 Humic 2 Differentiated 3 Hydromorphic c. Andic soils	Clayey soils, derived partly or wholly from volcanic, often andesitic, deposits. Often dark coloured, essentially amorphous allophane-humus complexes which have large water holding capacity, exceeding 100% and can reach 200% hydromorphic varieties. Desiccation can lower this capacity irreversibly. High exchange capacity, very clay and iron rich; indurate on drying. Young andosols - vitrisols, rich in volcanic glass.	Andosols, red-brown tropical soils
FERSIALLITIC SOILS a. Fersiallitic brown soils b. Modal fersiallitic red soils	Soils with some reddening. 2:1 clays dominant by both transformation and neoformation. When vertical is incomplete they form brown fersiallitic soils. When complete they form almost saturated or saturated complex red fersiallitic soils.	
FERRUGINOUS SOILS a. Argillic 1 Eutrophic 2 Oligotrophic 3 Hydromorphic b. Ferrisols 1 Ferrisol (weak Bt) 2 Ferrisol (Weathered Bt) 3 Hydromorphic 4 Humic	Soils intermediate between fersiallitic and ferrallitic; primary minerals weathered between fersiallitic and ferallitic states. Some removal of silica by drainage. Neoformed clays usually kaolinitic but some 2:1 clays persist. Often in from of kaolinitic saprolites; development strongly influenced by age	Latosols, lateritic soils, tropical red clays.
FERRALLITIC SOILS a. Ferrallitic 1 Kaolinitic 2 Gibbsitic b. Ferrallites 1 Ferrites 2 Allites c. Ferrallitic (with hydromorphic seggregations of iron) 1 Hydromorphic 2 Plinthitic 3 Indurated	Final phase of true soil profile development in tropical climates in which most primary minerals, including quartz are affected by total hydrolysis. Oxides of iron, aluminium, silica and bases are liberated but iron and aluminium are retained while the bases and some silica are removed. Neoformed kaolinites are poor in silica. Mainly quartz, kaolinite, gibbsite, haematite or goethite.	Plinthite.

TABLE 4.1 Behaviour - Project Relationships

BEHAVIOUR PATTERN	DESCRIPTION	PROJECT ACTIVITY
Intrinsic Remoulded, de-structured material	Behaviour a function of particle type (mineralogy),shape and size (texture). Dependant on moisture condition.	Well compacted fill, haul road performance, erosion.
Meso-Structured Undisturbed material.	Behaviour is a function of intrinsic properties and the material fabric and meso-structure.	Possibly lightly compacted fill, erosion, aggregates.
In-situ Mass Macro--structured mass	Behaviour a function of intrinsic and micro/meso, and macro-structural properties of the mass and component materials, allied to the influence of relict mega-discontinuities and material boundaries	Cut slopes, foundations

GEOGUIDE 1

TROPICAL WEATHERED IN-SITU MATERIALS
THEIR OCCURRENCE AND GENERAL NATURE

FIGURES

Figure 1.1 Standard Weathering Grade Diagram (after BS 5930, 1981)

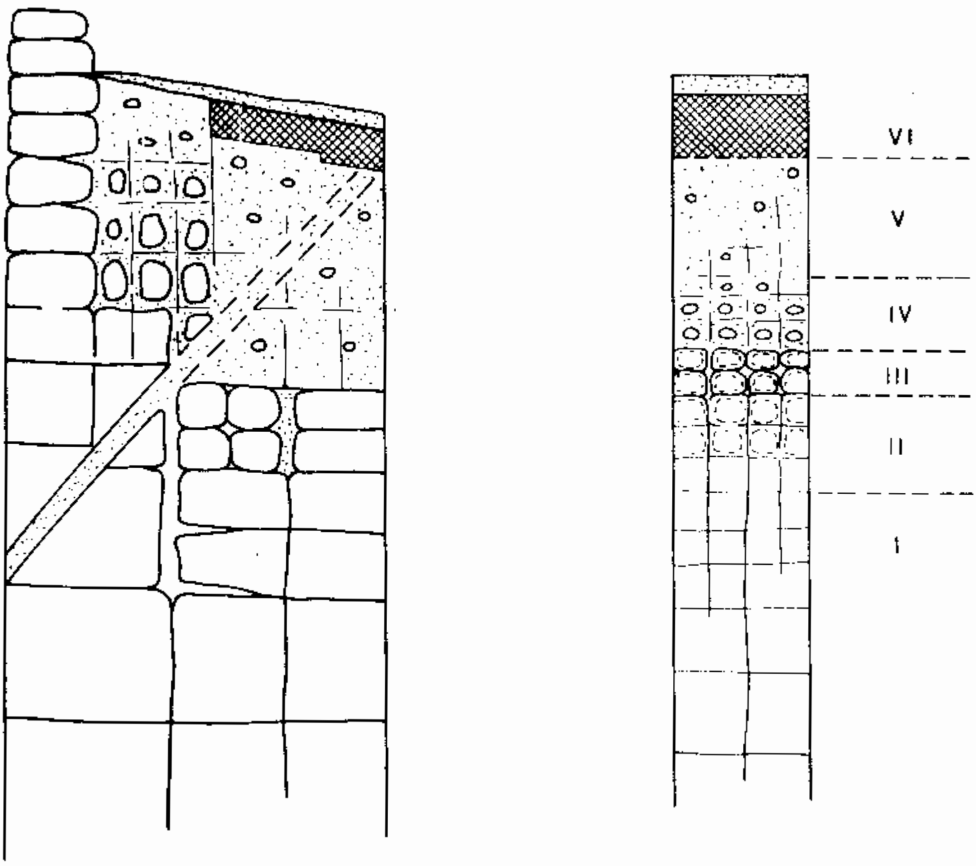


Figure 2.1 The Geological Cycle (after Escher, Geol. Assoc. 1994)

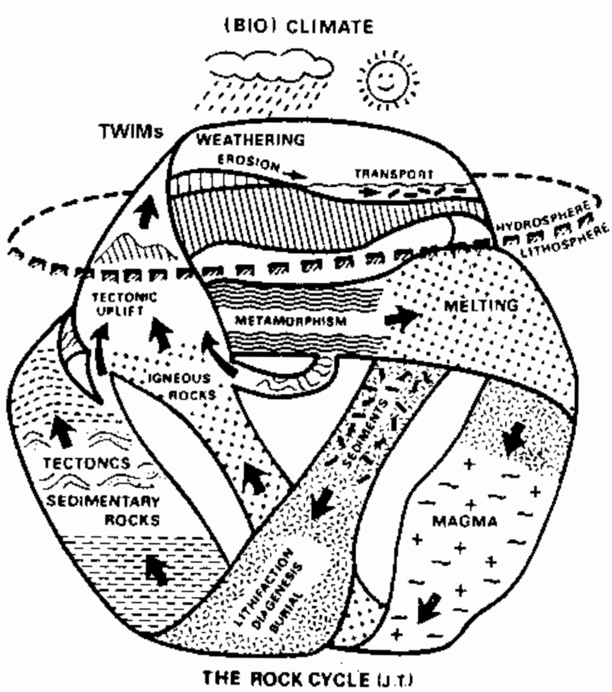


Figure 2.2 The Relationship between Climate and Weathering Mode (after Clark and Small, 1982)

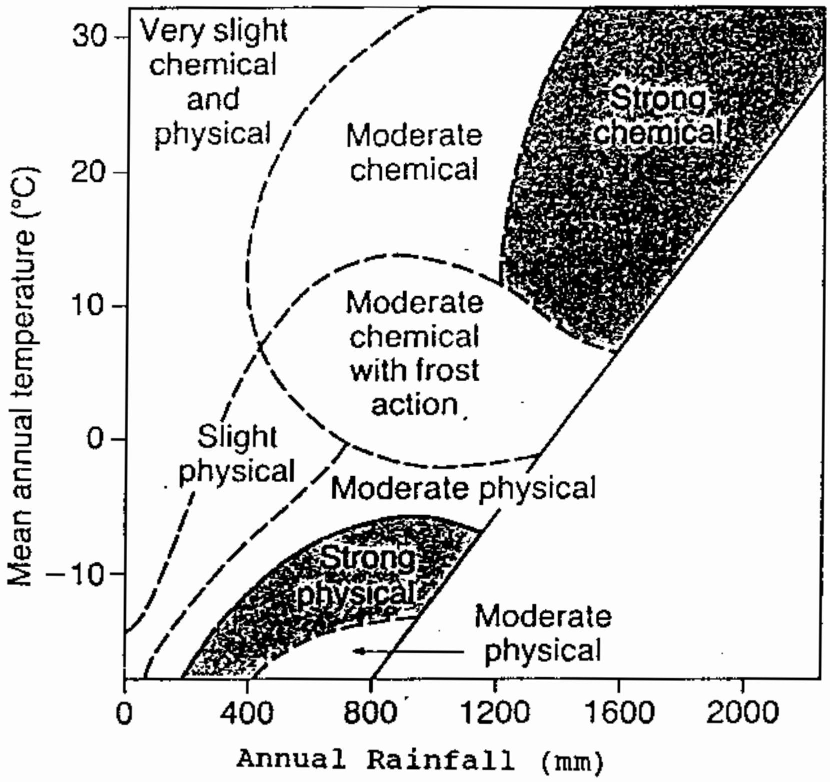


Figure 2.3 The Role of Geomorphology in Duricrust Development (after Charman. 1988)

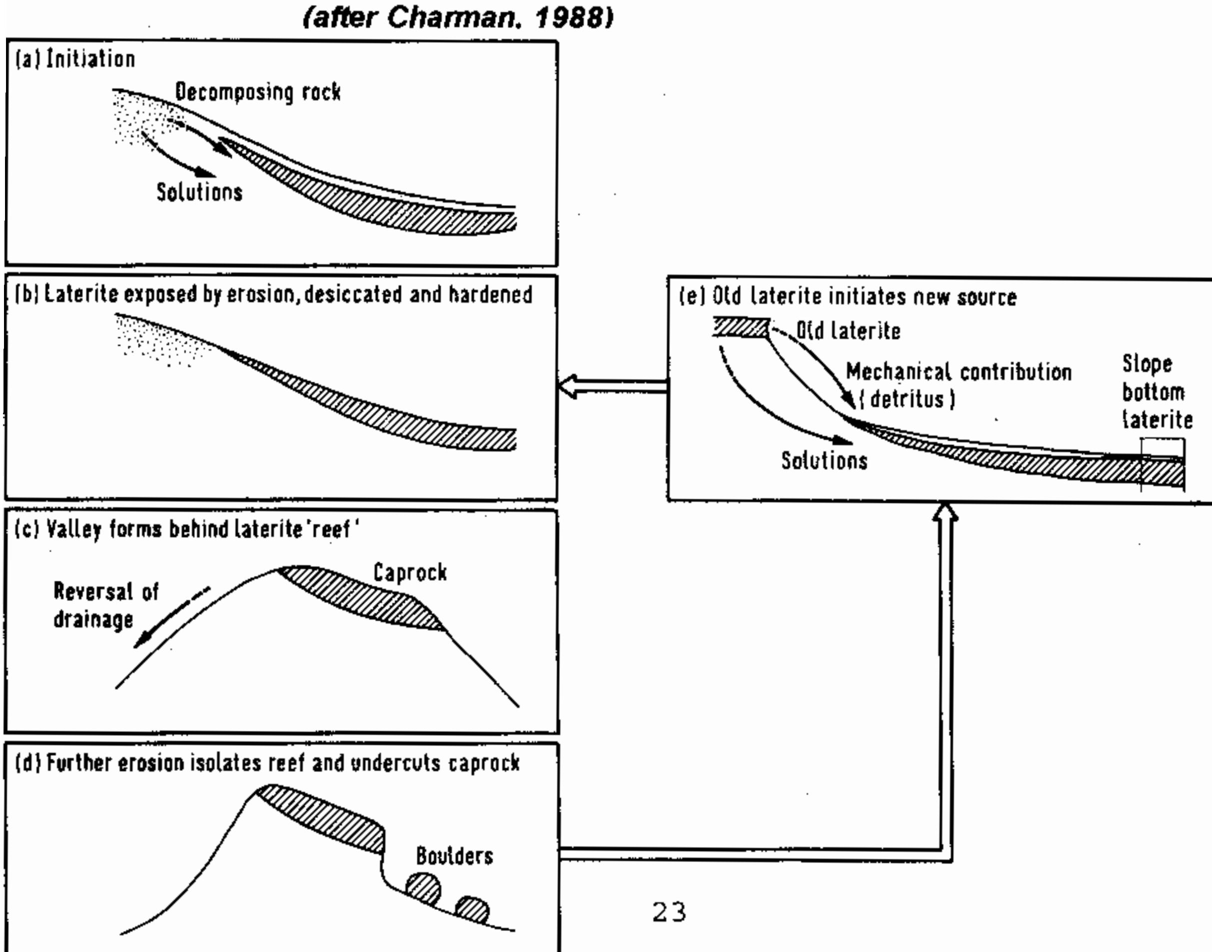


Figure 2.4 The Relative Stability of Common Minerals (after Bowen, 1928)

STABILITY OF MINERALS	BOWEN'S REACTION SERIES	
Most stable		
Iron oxides (hematite)		
Aluminum hydroxides (gibbsite)		
Quartz	**Last to crystallize**	
Clay minerals	Quartz	
Muscovite mica	Muscovite	Albite
Potassium feldspar (orthoclase)	Orthoclase	
Biotite mica	Biotite	
Sodium-rich feldspar (albite)		
Amphibole	Amphibole	
Pyroxene	Pyroxene	
Calcium-rich feldspar (anorthite)		Anorthite
Olivine	Olivine	
Calcite		
Halite		
Least stable	**First to crystallize**	

INCREASING STABILITY

INCREASING RATES OF WEATHERING

Mafic minerals

Plagioclase feldspars

Figure 2.5 Chemical Weathering Processes (after Fitzpatrick, 1983)

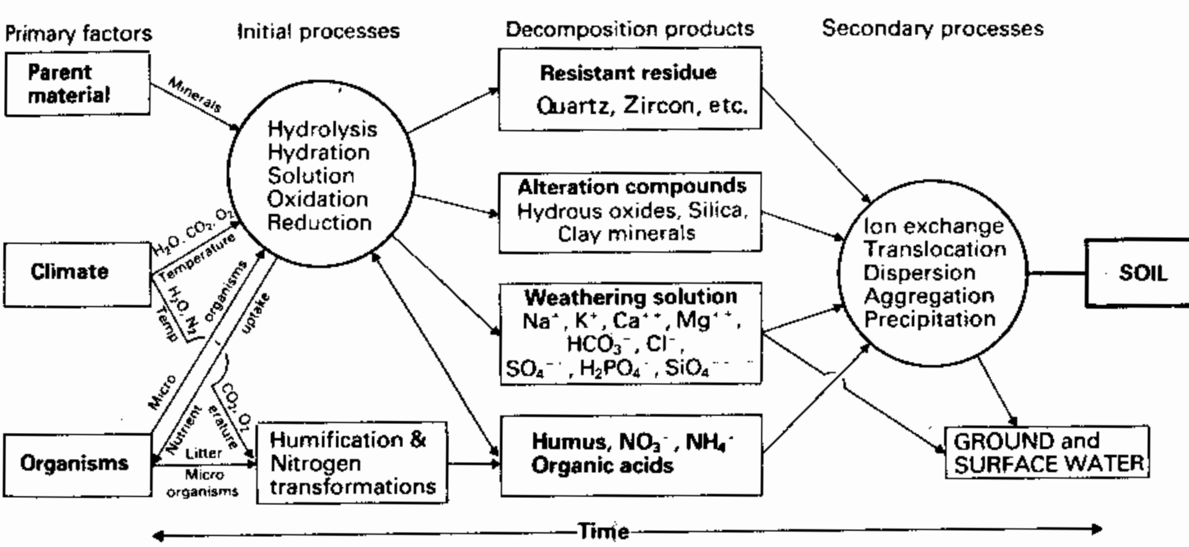


Figure 2.6 Variation in the Geoetchnical Properties of Basalt in response to Tropical Weathering (after Tuncer and Lohnes, 1977)

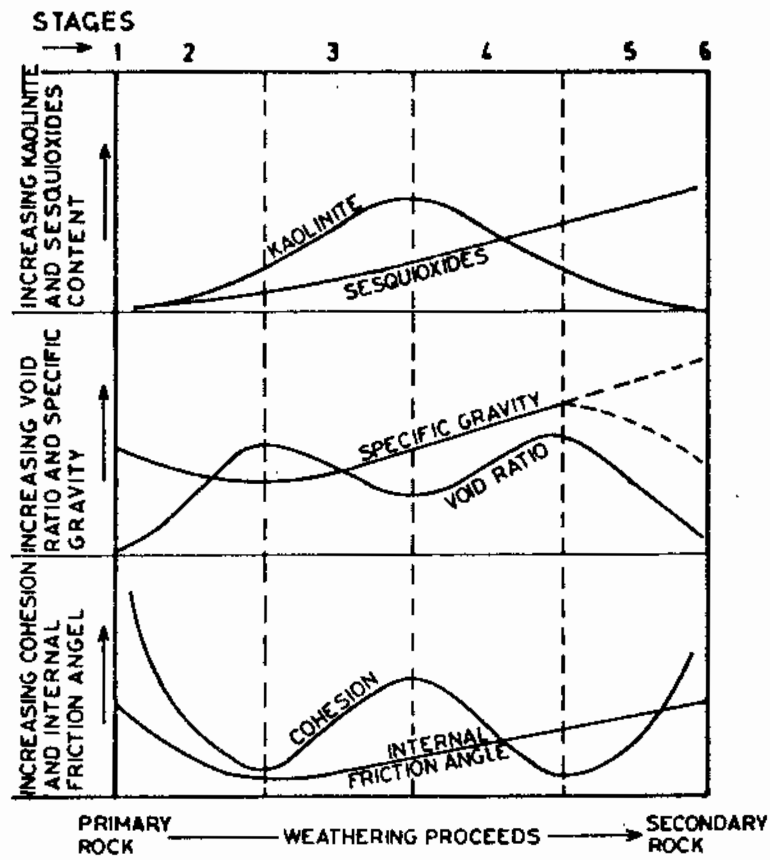
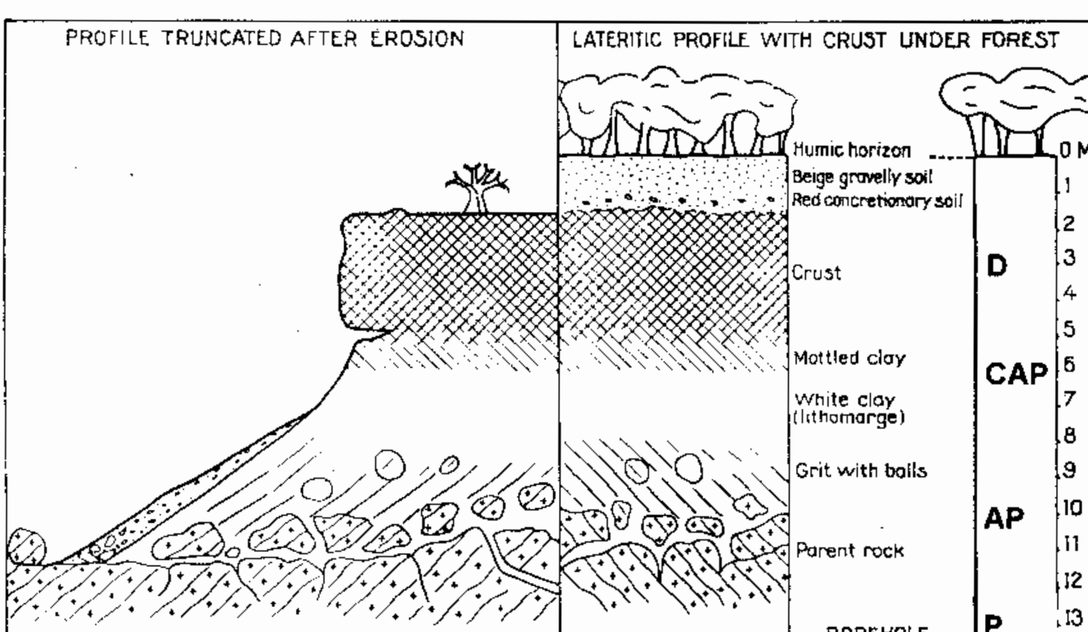


Figure 2.7 Basic Weathering Classification Grades in Profile (after Millot, 1970)



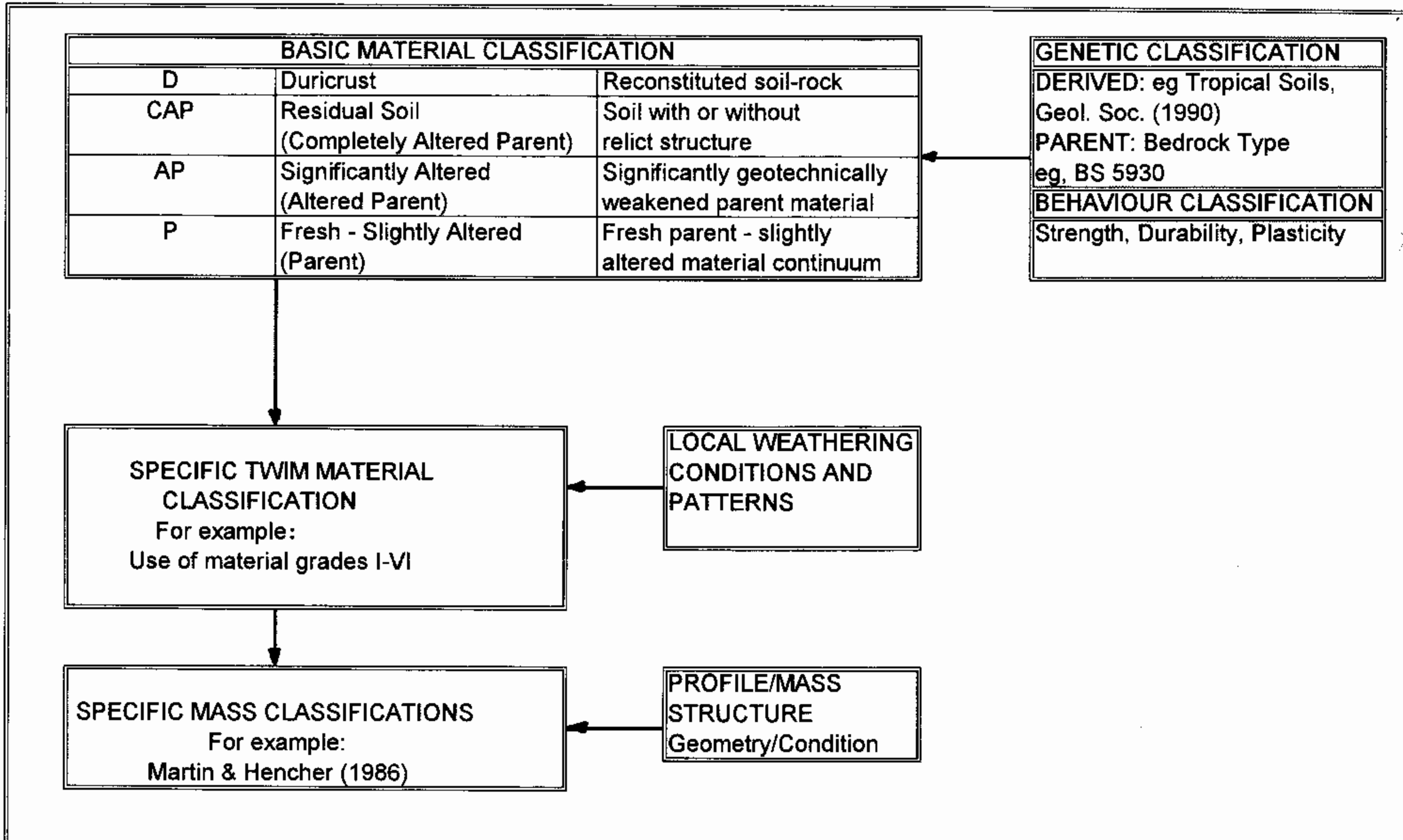

BASIC MATERIAL CLASSIFICATION
D Duricrust Reconstituted soil-rock
CAP Residual Soil (Completely Altered Parent) Soil with or without relict structure
AP Significantly Altered (Altered Parent) Significantly geotechnically weakened parent material
P Fresh - Slightly Altered (Parent) Fresh parent - slightly altered material continuum
GENETIC CLASSIFICATION
DERIVED: eg Tropical Soils, Geol. Soc. (1990)
PARENT: Bedrock Type eg, BS 5930
BEHAVIOUR CLASSIFICATION
Strength, Durability, Plasticity
SPECIFIC TWIM MATERIAL CLASSIFICATION
For example:
Use of material grades I-VI
LOCAL WEATHERING CONDITIONS AND PATTERNS
SPECIFIC MASS CLASSIFICATIONS
For example:
Martin & Hencher (1986)
PROFILE/MASS STRUCTURE
Geometry/Condition

Figure 3.2 Slake Durability Index Data for Typical Malaysian TWIMs

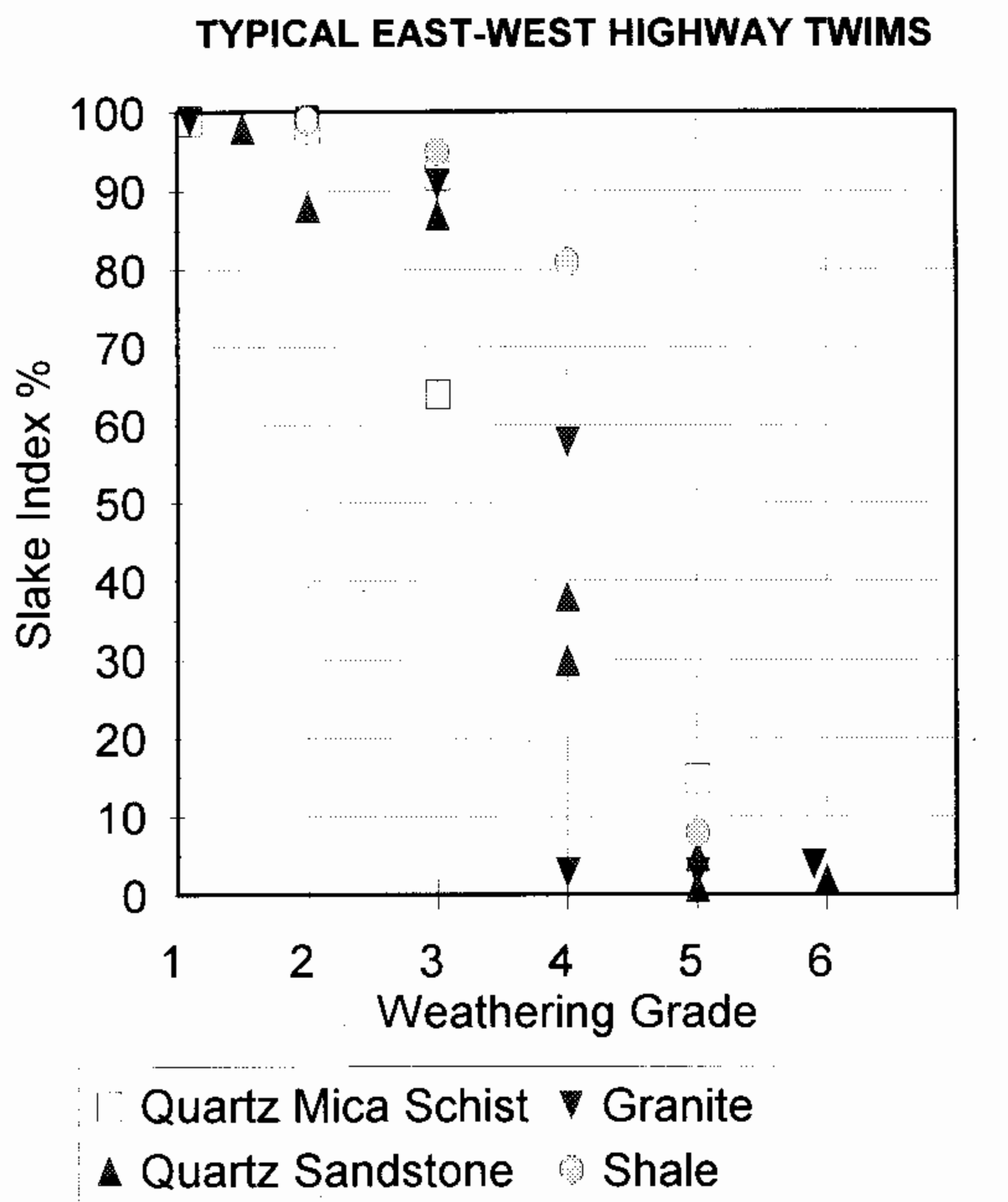
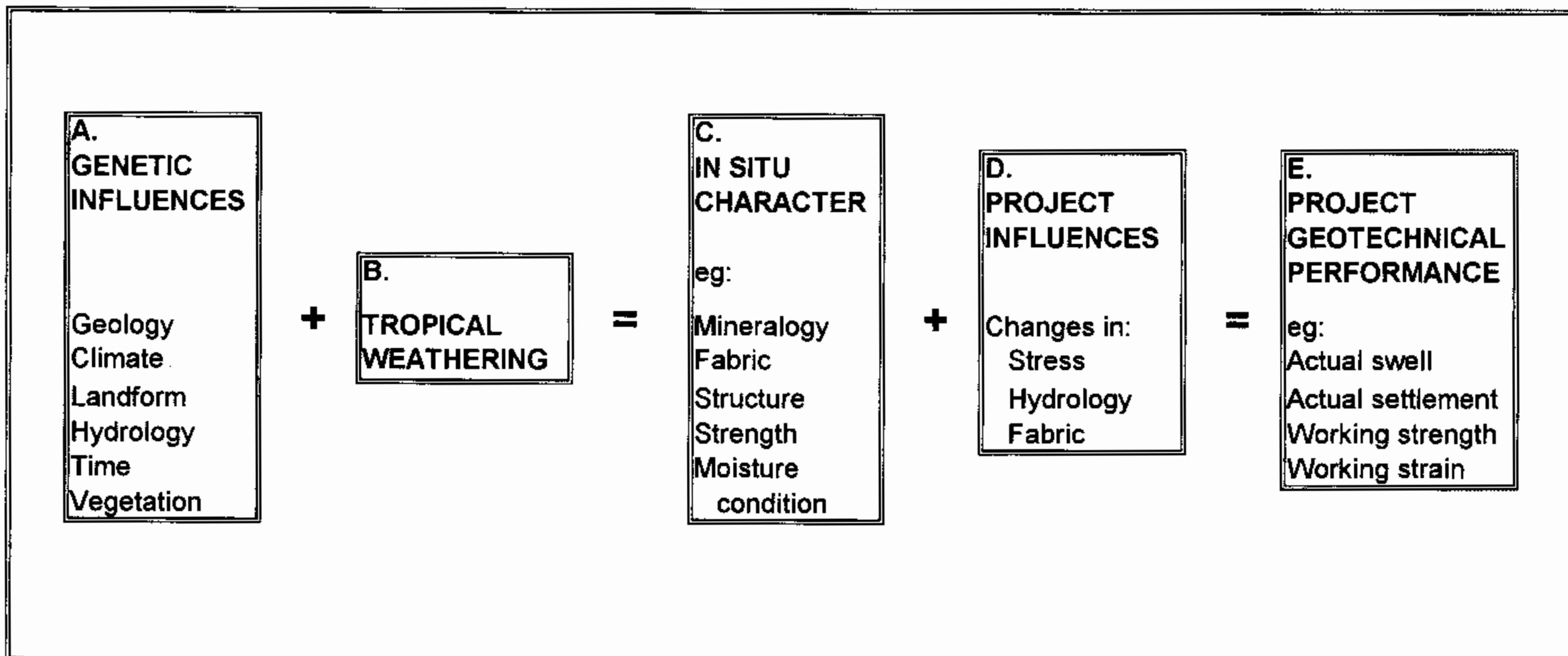


Figure 4.1 Relationship between Character, Project and Performance



DICETAK OLEH
PERCETAKAN NASIONAL MALAYSIA BERHAD,
IBU PEJABAT, KUALA LUMPUR
1996

PNMB

IKRAM

ISBN 983-99855-2-3

Percetakan Istitute Kerja Raya Malaysia