GEOGUIDE 3

GUIDE TO ROCK AND SOIL DESCRIPTIONS

GEOTECHNICAL ENGINEERING OFFICE
Civil Engineering Department
The Government of the Hong Kong Special Administrative Region

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FOREWORD

This Geoguide presents a recommended standard of good practice for the description of Hong Kong rocks and soils for engineering purposes. This need was recognized in July 1983, when a Subcommittee of the Building Authority Working Party on Geotechnical Regulations reviewed the application in Hong Kong of the British Standard BS 5930 : 1981, Code of Practice for Site Investigations. With regard to Section 8 of BS 5930 (Descriptions of Soils and Rocks), the Subcommittee concluded that it should not be recommended for general use in Hong Kong, because parts of the section were not relevant to local conditions or conflicted with current Hong Kong practice.

This Geoguide should be used in conjunction with the companion document, Guide to Site Investigation (Geoguide 2), which covers the topics dealt with in Sections 1 to 7 of BS 5930. Together, these two Geoguides expand upon, and largely replace, Chapter 2 of the Geotechnical Manual for Slopes (1984).

As with other Geoguides, this document gives guidance on good practice, and its recommendations are not mandatory. Considerable debate has always existed over the use of 'standardised' methods and terminology for the descriptions of rocks and soils. Many different schemes exist, and it is recognized that the practitioner may wish to use alternative methods to those recommended herein.

The Geoguide was prepared in the Geotechnical Control Office (GCO) under the general direction of Mr J.B. Massey. It was drafted by Dr R.P. Martin, with assistance from Dr R.L. Langford, who wrote most of the material for Appendix A and provided many of the photographic illustrations. The final production was supervised by Dr P.L.R. Pang. The Geoguide incorporates background material and parts of earlier drafts prepared by Dr R. Shaw of the GCO and by Dr S.R. Hencher, a former member of the GCO staff. Dr T.Y. Irfan, together with many other GCO staff members, made valuable comments on earlier versions.

To ensure that the Geoguide would be considered a consensus document by the various interested parties in Hong Kong, a draft version was circulated widely for comment in early 1987 to contractors, consulting engineers, academic institutions and Government Departments. Many organizations and individuals made very helpful comments, and their contributions are gratefully acknowledged.

Practitioners are encouraged to comment at any time to the GCO on the contents of this Geoguide, so that improvements can be made to future editions.

E.W. Brand
Principal Government Geotechnical Engineer
July 1988

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1. INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this Geoguide is to present a recommended standard of good practice for the description of Hong Kong rocks and soils for engineering purposes. It is a companion document to Geoguide 2 : Guide to Site Investigation (GCO, 1987a).

This Geoguide is aimed primarily at the practising civil or geotechnical engineer, but is also intended for use by geologists, engineering geologists and other professionals working in the earth sciences. It has been prepared on the assumption that the user may not have any specialist knowledge of descriptive systems or methods.

The overall structure and many individual text sections of this Geoguide are based on Section 8 of BS 5930 : 1981, Code of Practice for Site Investigations (BSI, 1981). This British Standard (BS) has been selected as the basic reference document for both this Geoguide and Geoguide 2, in the belief that many of its sections are applicable to Hong Kong conditions without the need for major modification. However, the layout of this document differs considerably from that of Section 8 of the BS, and a number of new text sections have been added, together with many more tables, figures and plates. These changes reflect not only differences of emphasis with regard to local geological conditions, but also the need for more illustration and explanation of geological terms for the non-specialist user.

The following section of this chapter contains some general guidance on descriptive methods and terms. The two major chapters of the Geoguide (Chapters 2 and 3) are devoted to methods of description for the two main groups of engineering materials (i.e. rocks and soils). Following these is a shorter chapter concerned with engineering classifications of rocks and soils (Chapter 4). The fifth chapter presents recommended rock and soil symbols to be used for maps, plans and diagrams. Appendix A, which contains a geological summary of the nature and occurrence of Hong Kong rocks and soils, is intended to fulfil a similar role to that of Appendix G in the BS. This is followed by a glossary of terms. Also included separately is a checklist for field or laboratory use.

This Geoguide provides guidance for good practice in the use of one scheme of rock and soil description. It is recognized that practitioners may wish to continue to use other descriptive methods and terminology. Whatever scheme is employed, the important principle is that all descriptive terms should be defined clearly and used consistently.

1.2 GENERAL GUIDANCE

1.2.1 Definitions of Rock and Soil

The engineering usage of 'rock' and 'soil' differs from the geological usage of 'rock' and 'superficial deposits' in current Hong Kong practice. The two schemes can be distinguished for most practical purposes by using the following simple definitions. In engineering terms, a 'soil' is any naturally-formed earth material or fill which can be broken down by hand into its constituent grains; conversely, a 'rock' cannot be broken down, or may only be

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partially broken down by hand, depending on its weathered condition. In geological terms, 'superficial deposit' covers any geologically recent, unlithified, transported material of sedimentary origin (Bennett, 1984a); 'rock' refers to any lithified, solid material of igneous, sedimentary, pyroclastic or metamorphic origin. Practically all of Hong Kong's superficial deposits were formed within the Quaternary period (i.e. within the last two million years), whereas most of the rocks are much older than this (see Appendix A). The simplest way of relating the two schemes is to consider engineering soils as comprising all superficial deposits and fill plus those rocks which have weathered insitu to the condition of a soil in engineering terms. There are one or two exceptions to this general distinction, such as recent hard beach rock and coral (both of which would be mapped by geologists as superficial deposits), but such materials are of very restricted extent in Hong Kong.

The above engineering definitions of rock and soil are used throughout this Geoguide, except in Appendix A and in a few other cases where the geological definitions are clearly implied by the text. It should be emphasised, however, that there are no hard and fast rules; it may well be appropriate to use different definitions, depending on the particular requirements of the engineering project.

1.2.2 The Hong Kong Geological Survey

This Geoguide uses the classification system and nomenclature for rocks and superficial deposits developed by the Geological Survey Section of the Planning Division, Geotechnical Control Office (hereafter referred to as the Hong Kong Geological Survey (HKGS)). The description and classification of rocks used by geologists for mapping purposes requires a detailed consideration of mineralogy and petrography, which may be of interest to engineers only in special circumstances. However, the value of an engineering rock or soil description is often increased if the materials encountered are placed in the context of the geological structure of the area around the site. In this respect, the engineer should consult the geological maps and memoirs produced by the HKGS. In cases of difficulty when identifying rock types, or interpreting geological maps, the engineer should consult a geologist for assistance.

A new programme of detailed systematic geological mapping by the HKGS, at a scale of 1:20 000, has been underway in the Geotechnical Control Office since 1983. As of the end of 1988, six maps and three memoirs will be available (Addison, 1986; GCO, 1986a; 1986b; 1987b; 1988a; 1988b; 1988c; Langford et al, 1988; Strange & Shaw, 1986). The full mapping programme, which is summarised in Geoguide 2 (GCO, 1987a), will cover the whole of the Territory, both onshore and offshore, and will eventually comprise fifteen maps and six memoirs (see pp 188-189). On completion, this mapping will supersede the earlier geological survey work carried out by Allen & Stephens (1971).

1.2.3 Material and Mass Characteristics

Complete rock and soil descriptions should include information on both material and mass characteristics.

For rocks, the distinction between material and mass characteristics depends on the size of the sample in relation to the typical spacing of discontinuities and other aspects of rock structure. Rock material refers to

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the relatively strong cohesive assemblage of mineral particles that form the intact rock blocks between discontinuities in the rock mass. Therefore, rock material characteristics can be observed and described most easily in hand samples of rock and drillcore. Rock mass refers to a larger volume of rock that contains discontinuities such as joints, faults and bedding planes; such features are best described in field exposures, although some indication of mass characteristics may be obtained from boreholes.

For soils, the distinction between material and mass characteristics also depends on the size of the sample being described. In practice, this distinction may not be as clear as for rocks because some of the characteristics, at both the material and mass scales, may be destroyed or altered significantly if the soil has been disturbed or remoulded in relation to its original undisturbed condition. Therefore particular attention should be paid to the degree of sample disturbance when making soil descriptions. Mass characteristics in soils can only be described satisfactorily in undisturbed samples or exposures. Weathering processes are of particular importance in Hong Kong, and many of the soils encountered in engineering works are those derived from insitu weathering of rocks. Where they retain the original rock material texture and fabric, these engineering soils represent a special case for description, because they can be described both as rocks and as soils. This is considered in greater detail in the main text.

1.2.4 Description in Different Locations

Rock and soil descriptions for engineering applications in Hong Kong are typically carried out in three main locations, viz :

(a) in the field, at a natural or man-made exposure,

(b) in the field, on core obtained from a ground investigation drilling rig, and

(c) in the laboratory, on pieces of core or other small hand samples and various types of confined samples.

General guidance on description in each of these locations is given in Table 1. It is emphasised that the scope of the description, and the degree of emphasis given to particular descriptive items, may need to be varied to suit the particular application (e.g. projects involving slopes, tunnels, foundations, etc). It is the responsibility of the project engineer or engineering geologist to decide on the appropriate scope and detail required.

With regard to the description of core samples in the field and in the laboratory, two common aspects of poor practice should be mentioned. First, descriptions should refer only to the specific locations from which the samples have been taken. Descriptions of small disturbed samples obtained from drill bit cuttings are often used wrongly to characterise the nature of the material throughout the complete core run or adjacent core runs. A second related point is that only a small percentage of soil samples recovered by triple-tube core-barrels are ever split open and described. Most samples are usually reserved for laboratory testing. A significant proportion are often discarded at the end of the project without being opened for either description or testing. Even if samples are opened for the purpose of selecting test specimens, the remainder of the core is often discarded without being described. Adequate description of all borehole samples recovered is essential

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to good ground investigation practice.

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2. DESCRIPTION OF ROCKS

2.1 GENERAL

The recommendations in this chapter are generally applicable to all local rock types. For some of the important descriptive characteristics, such as state of weathering, specific recommendations are given only for some of the common rocks. This disproportionate treatment reflects the greater engineering experience gained in certain rock types (mainly granite, granodiorite and some tuffs).

2.2 PURPOSE AND SCOPE OF ROCK DESCRIPTION

The main purpose of a rock description for engineering purposes is to give an indication of the likely engineering properties of the rock. A complete description should comprise a simple rock name, qualified by selected descriptive terms for strength, colour, texture or structure, grain size, state of weathering and alteration, discontinuities and other characteristics as appropriate.

Geological classification of rocks is necessary to interpret the geological structure of an area, and to establish good geological correlation between boreholes; it can also be important when rock is required for construction purposes, for example as building stone, concrete aggregate or roadstone. As with other geological classifications, the HKGS rock classification scheme does not include engineering properties of rock. In practice, however, engineering properties are often closely related to geological characteristics, and engineers with local experience may interpret the HKGS rock classification to some extent in terms of likely engineering characteristics. This is considered further in Section 2.3.5.

In the following sections, "material characteristics" refers to essentially uniform pieces of rock and drillcore; discontinuities and other structural features will not normally be considered in the material description unless they occur as an intrinsic characteristic with a spacing of less than about 200 mm (e.g. slatey cleavage). This is the scale at which detailed description and logging of samples, and most engineering tests, are undertaken. "Mass characteristics" refers to larger volumes of rock that incorporate the usual structural features; they can be fully appreciated only through careful field description. This is the scale which is usually most relevant to engineering design and construction. Mass engineering properties are generally much more difficult to determine than material properties, because of the greater influence of structural defects and the irregular distribution of different component materials within the mass.

In most Hong Kong rocks, the presence of discontinuities and the effects of weathering will have a great influence on engineering behaviour. Hence, the descriptive methods recommended in this chapter place emphasis on such features.

In a rock description, the main characteristics should preferably be given in the following order (based on Hawkins, 1984) :

(a) strength (material),

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(b) colour (material),

(c) texture and fabric (material); structure (mass),

(d) state of weathering and alteration (material and mass),

(e) rock name (in capitals, e.g. GRANITE), including grain size (material),

(f) discontinuities (mass), and

(g) additional geological information.

In the following sections, each of the characteristics in this list is discussed in detail for both rock material and rock mass, as appropriate. The scope of this scheme is similar to the schemes recommended by BSI (1981), Geological Society (1972, 1977) and IAEG (1981). The differences in the present scheme are ones of detail, mainly with respect to the description of the weathered state of the rock material and rock mass, and an expansion of the description of discontinuities and other aspects of rock mass structure.

In addition to description, in some circumstances it may be useful to make an overall classification of rock masses for engineering purposes. Guidance on rock mass classification is given in Chapter 4.

2.3 DESCRIPTION OF ROCK MATERIALS

2.3.1 Strength

A recommended scale of strength, based on uniaxial compressive strength testing (UCS), is given in Table 2. This scale is similar to that used in BSI (1981), but has been extended at the weaker end in order to cover the extremely weak decomposed rock materials that are commonly encountered in Hong Kong. Simple field identification tests have also been added so that the strength terms may be estimated prior to any laboratory testing; these are based on the classifications given by the Geological Society (1977) and Miller et al (1986).

The strength of rock material determined in the uniaxial compression test is dependent on the moisture content of the specimen, anisotropy and the test procedure adopted. A review of compressive strength test practice in Hong Kong has been made by Gamon & Szeto (1984).

The point load test (PLS) is a useful index test for estimating the compressive strength of moderately weak to extremely strong rocks (ISRM, 1985). Approximate PLS values for the granitic and volcanic rocks in Hong Kong are included in Table 2. These values are derived by applying a correlation factor of 24 to UCS values. They are based on the work reported by Lumb (1983) and Gamon (1984), and on a review of existing literature for isotropic igneous and volcanic rocks carried out within the Geotechnical Control Office. The correlation factor of 24 is generally less reliable for rocks at the weaker end of the PLS test scale.

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2.3.2 Colour

Colour may be expressed quantitatively in terms of three parameters : 'hue', 'chroma' and 'value' (Munsell, 1941). 'Hue' is a basic colour or a mixture of basic colours, 'chroma' is the brilliance or intensity of the colour, and 'value' is the lightness of the colour. The complete Munsell system contains a large number of examples of different hues, chromas and values, and is too detailed for general engineering use. A much simpler qualitative system is recommended, as set out in Table 3. In cases where the colour distribution is non-uniform, an additional descriptor should be used in conjunction with the three basic terms (Table 3).

For a more detailed description of colour, the Rock-Color Chart (Geological Society of America, 1963) is recommended. This chart is a simplification of the Munsell system, but it contains many more hues, chromas and values than Table 3.

It should be noted that wetting a rock sample decreases the value (i.e. makes the sample darker), but does not change the hue or chroma. Therefore, a good rock colour description should state whether the sample was wet or dry when described. In written reports, descriptions should ideally be supplemented by colour photographs, which should always include a standard colour chart for reference (e.g. Kodak Color Control Patches).

2.3.3 Texture and Fabric

'Texture' is a broad term that refers to the general physical appearance of a rock. It covers the geometric aspects, such as size and shape of the component grains or crystals, and the relationships between these aspects (e.g. distribution of various grain sizes and crystallinity, or the degree to which crystals have developed in the rock). The term is usually applied to the small-scale features visible in hand specimens. If the rock is composed of very small grains, the description of texture may not be possible without the use of a hand lens or a microscopic examination of a thin slice of the rock. The term 'structure' is used for the larger-scale physical features of a rock and is considered in Section 2.4.2. However, terms describing structural features with a spacing of less than about 200 mm may also be applicable to rock material descriptions.

The most common textural terms applicable to Hong Kong rocks are illustrated in Plate 1 and are defined in the Glossary. The use of these terms is generally restricted to the crystalline igneous and non-foliated metamorphic rocks (Table 5; see also Appendix A.2.5), the grains or crystals of which have usually formed in close mutual association (e.g. during solidification of an igneous rock from a magma).

The main aspects of rock texture illustrated by Plate 1 are <u>relative</u> grain size (e.g. equigranular, megacrystic) and crystallinity. Some methods of textural description, e.g. IAEG (1981), also cover absolute grain size, or the average dimension of the mineral or rock fragments which make up the rock. However, it is common practice in Hong Kong to link grain size terms directly to the rock name. Therefore, grain size is considered in Section 2.3.5. Grain shape is another aspect sometimes taken into account in the description of sedimentary rock textures, but shape terms are more commonly used in soil descriptions when individual intact grains can be easily separated (see Section 3.3.3).

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'Fabric' refers specifically to the arrangement of the constituent grains or crystals in a rock. Preferred orientation of these constituents is often the most noticeable aspect of the rock fabric.

In igneous and other crystalline rocks, the fabric is the pattern produced by the various shapes and orientations of the crystalline and non-crystalline parts of the rock. It is dependent on the relative sizes and shapes of these parts and their positions with respect to one another and to the groundmass, where present. In sedimentary rocks, preferred orientation, where present, of the individual grains and their position in relation to any cementing material are usually the most important aspects of the fabric. Fabrics in fine sandstones and mudstones cannot be described satisfactorily without the use of a hand lens or microscope.

The orientation of grains and crystals may be described in qualitative terms or, alternatively, may be quantified by measurement with a compass-clinometer if the fabric directions are clear to the naked eye. For rocks insitu, fabric orientations may be stated either directly as a compass bearing and dip angle, or indirectly in relation to other parts of the fabric, or to structural planes such as joints and bedding (e.g. elongate particles in a sedimentary rock would often be described as having a preferred orientation parallel to the bedding planes). In recovered samples, fabric orientations can only be described indirectly, unless the configuration of the whole sample in the ground is recorded accurately at the time of sampling.

'Fabric' also includes any small discontinuities or planes of separation through or between grains or crystals. These are commonly termed 'micro-fractures' and may be caused by mechanical weathering, tectonic activity, stress-relief or other factors. Microfractures can have a significant effect on engineering properties and are particularly common features in the coarser-grained granitic rocks. No specific terms are recommended for the description of microfractures, but as a general rule their intensity, spacing, continuity and any preferred orientation should be noted. Plate 2 shows four examples of microfractures, for which appropriate descriptions would be as follows :

(a) Plate 2A. Randomly-oriented microfractures intersecting an iron-stained joint surface in highly decomposed, coarse-grained GRANITE. Spacing variable, 2-20 mm. Some have open apertures up to 1 mm wide. Rock easily crumbled to fine gravel and finer-sized fragments due to microfracturing.

(b) Plate 2B. Continuous subvertical microfractures parallel to tension cracks in sandy SILT (Residual Soil). Spacing 5-20 mm. Soil loose and very friable as a result of microfracturing.

(c) Plate 2C. Continuous curved microfractures following the boundary shape of a large corestone of moderately decomposed, medium-grained GRANITE. Spacing 5-10 mm. Effect of microfractures is to form thin curved shells of rock.

(d) Plate 2D. Intense random microfracturing between and through quartz and feldspar grains in slightly decomposed, medium-grained GRANITE. Spacing generally < 1 mm.

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The description of texture and fabric should include any other notable features of the small-scale physical appearance of the rock. For example, in certain volcanic lavas, small pores or voids (termed 'vesicles') are sometimes visible. The size, shape, spacing and orientation of voids should be described where appropriate.

Texture and fabric are probably the most difficult aspects of a rock description for the non-specialist. It is not easy to give simple precise guidance on the use of appropriate terms. If problems are encountered, the engineer should consult a geologist for assistance.

2.3.4 Weathering and Alteration

(1) General Aspects of Weathering. Weathering has a very significant effect on the engineering properties of rock. Most engineering projects in Hong Kong encounter substantial thicknesses of weathered rock, which may vary significantly in degree of weathering over relatively short distances. Therefore, careful description and assessment of the state of weathering of the rock material is of particular importance.

The two main components of weathering are mechanical disintegration and chemical decomposition. Generally, both mechanical and chemical effects act together and are interdependent, but, depending on the past and present climatic and hydrological regimes, one or the other of these aspects may be dominant.

Mechanical weathering or disintegration is caused by physical processes such as frost action, absorption and release of water, and changes in temperature and stress at or near the exposed rock surface. It results in the opening of discontinuities, the formation of new discontinuities by rock fracture, the opening of grain boundaries, and the fracture or cleavage of individual mineral grains. Disintegration of rock material can also be caused or speeded up by biological factors such as tree root growth in joints.

Decomposition or chemical weathering is the process by which chemical reactions, such as hydration, oxidation, ion exchange and solution, transform rocks and minerals into new chemical combinations that are stable under prevailing environmental conditions. Decomposition causes some silicate minerals such as feldspars to change to clay minerals, but others, notably quartz, resist this action and may survive largely unchanged. Solution is a particularly important aspect of chemical weathering in carbonate rocks such as limestones. Chemical weathering also results in discolouration of the rock when compared with its colour in the fresh (unweathered) state. Decomposition is the dominant aspect of weathering in Hong Kong rocks.

Rock material weathering in Hong Kong rarely produces a homogeneous weathered rock mass where all rock material is weathered to the same degree, or even a simple weathered profile where the degree of weathering decreases progressively with depth. Complex variation of weathering throughout the rock mass is more often the rule. This reflects such variable factors as orientation and spacing of discontinuities in the rock, groundwater flow paths and the removal of overlying weathered material by erosion. To appreciate fully the pattern of weathering in a rock mass, it is necessary to make careful observations of the degree of material weathering in natural exposures, excavations, borehole samples and trial pits.

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Weathering is a gradual, continuous process. It is difficult to describe its effect quantitatively as a precise degree of change from an original unweathered condition. For general descriptive purposes, it is convenient to classify the weathering sequence into a number of easily recognizable grades. In view of the dominance of chemical decomposition in Hong Kong rocks, material weathering grades have been traditionally classified using the term 'decomposed' rather than the more general term 'weathered'. This practice is retained here. The term 'weathered' is used in the rock mass weathering classification in Section 2.4.4.

(2) Classification of Decomposition Grades. Recommendations for the description of decomposition grades of rock material are given in Table 4. The left-hand side of the table gives a summary of the general characteristics that can be used to assess decomposition grade in most Hong Kong rocks. This is generally applicable to all the igneous and pyroclastic rocks, but it can also be used for other rocks which have strengths in the fresh condition similar to those of the granites and tuffs, i.e. in the strong to extremely strong range in Table 2 (Lumb, 1983). However, not all the general characteristics listed in Table 4 are applicable to some of the weaker sedimentary and metamorphic rocks. It may be more convenient to use a different classification for these materials (e.g. Beggs & Tonks, 1985, used four classes for description of sedimentary and metamorphic rocks in the Yuen Long area). If a different number of classes is used, and the class boundaries cannot be equated conveniently with any of those in Table 4, it is recommended that alternative terms and symbols are adopted and defined clearly to avoid confusion.

The grade classification is of very limited use for description of carbonate rocks such as limestone and marble. Since pure carbonate material dissolves completely in contact with weakly acidic groundwater, there is no gradual transition from fresh rock to residual soil. However, most carbonate rocks contain a small percentage of non-soluble impurities (e.g. quartz, iron oxides, clay minerals) which can accumulate in the form of residual debris as the surrounding carbonate material is removed in solution. The only significant carbonate rock in Hong Kong is the marble of the Yuen Long Formation, which generally has a very low percentage of impurities (Pascall, 1987; Langford et al, 1988). Hence the amount of residual debris produced by weathering of the marble itself is usually negligible, and is of little importance for engineering. It should be noted that this debris should not be classified as a true insitu residual soil since the solution of the carbonate material results in a complete collapse of the original rock fabric.

The general characteristics shown in the left-hand side of Table 4 are based on observation or simple tests that require a minimum of field or laboratory equipment (e.g. use of a geological hammer, breakage of lumps by hand, visual evidence of discolouration). A water supply and small container are needed to carry out the slake test, which is used to distinguish between completely and highly decomposed rock. The results of the slake test may be affected by differences in the initial sample moisture content. Generally, it is a fairly reliable indicator when used in partly saturated soils, but it is difficult to apply in fully saturated soils sampled from below the water table (Howat, 1986).

Discolouration may not be an easy indicator to use, because it relies on knowledge of the colour of the fresh rock, which is often not exposed. Generally, it is a good indicator of the differences between fresh, slightly, moderately and highly decomposed rock. Slightly decomposed material can usually be distinguished from fresh rock by staining in the vicinity of rock

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joints (often a brown staining caused by the formation of iron oxides). Moderately decomposed rock is usually stained throughout, while highly and completely decomposed rock commonly show a complete colour change when compared with the fresh rock.

Very few of the general characteristics in Table 4 are definitive for assessing the decomposition grades. It is recommended that a number of different tests and observations should be carried out wherever possible before the assignment of the decomposition grade.

The remaining columns of Table 4 give typical characteristics for the four most common rock types in Hong Kong. These can be used in addition to the general indicators discussed above, providing the rock type can be identified. The characteristics include typical sequences of colour changes, decomposition of certain minerals, and the results of other simple strength index tests.

At the less decomposed end of the scale, the Schmidt hammer is a rapid and simple field test. However, as discussed in Geoguide 2 (GCO, 1987a), care is required when using the hammer on weak, cracked or fissured rocks, or on any rough rock surface. Notes on the use of the hammer are given in Table 4. At the more decomposed end of the scale, a standard hand penetrometer can be used to give an approximate indication of undrained shear strength (Table 4). As with the slake test, the results may be affected by changes in the sample moisture content, but it is generally reliable for distinguishing between highly and completely decomposed rock in granitic materials. In the medium- and coarse-grained igneous rocks, another useful test is to assess the degree of alteration of the feldspar grains by probing with a knife or pin, or by crumbling between the fingers. Different types of feldspars may decompose at different rates; the engineer should consult a geologist for assistance in identification and description where appropriate.

The six decomposition grades in the most common Hong Kong rocks are illustrated in Plate 3. In general, decomposition effects are most obvious in the igneous and highly metamorphosed rocks, particularly coarse-grained types which possess large decomposable minerals. In sedimentary and less highly metamorphosed rocks, the effect of decomposition on changes in colour and mechanical properties is less marked; it may not be easy to assign decomposition grades in these rocks.

Assessment of decomposition grade using Table 4 is adequate for general descriptions, but subdivision of the grades may be justified if a more detailed description is required; for example when making detailed correlations between laboratory test results for engineering design and degree of decomposition. For this type of description, more detailed observations of the rock texture/fabric should be made and individual index test results on specific samples should be quoted. Other, more precise, laboratory and field index tests should also be considered (e.g. quick absorption, density, slake durability and point load strength tests in grades I-III materials; SPT, dry density and particle size distribution tests in grades IV - VI). Further guidance on rock and soil index tests is given by Brown (1981) and BSI (1975) respectively. A review of the use of index tests for engineering assessment of weathered rocks has been made by Martin (1986).

The most detailed method of describing degree of decomposition is to use a wholly quantitative index. An example is the X_d index for granite proposed by Lumb (1962), which is based on a comparison of the weight ratios

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of quartz to feldspar in the fresh and decomposed rock. A number of other quantitative indices have also been defined on the basis of mineralogical examination (Irfan & Dearman, 1978). However, the calculation of these various indices involves the use of detailed petrographical analysis, which is generally inappropriate for routine descriptions.

The distinction between completely decomposed rocks and residual soils (i.e. grades V and VI in Table 4) is important for full description of these materials. Grade VI residual soils have lost all evidence of the original rock texture. Therefore, a full description of these materials can only be made in soil terms (see Chapter 3). Since grade V materials retain the original rock texture, it is recommended that complete descriptions should be made in rock terms (see Sections 2.3.1 to 2.3.6), supplemented where necessary by additional soil terms to cover compactness/consistency and particle size distribution applicable to the remoulded condition. Further guidance is given in Section 3.5.

(3) State of Disintegration. The assessment of decomposition grade should be supplemented by description of the state of disintegration of the rock material. This can be important in terms of the likely engineering behaviour of the rock. For example, an intensely disintegrated, friable, moderately decomposed rock may well show the engineering properties to be expected of highly or completely decomposed material. It should be noted that small-scale cracking and fracturing of rock can be caused by factors other than disintegration (mechanical weathering), see for example Plates 2B and 2D. In many rocks, it is not easy to separate the effects of the different factors. If there is doubt on the origin of cracks and microfractures, they may be described under the general non-genetic heading of 'rock fabric' (see Section 2.3.3). A further difficulty with the description of disintegration is that, unlike decomposition, often it is not possible to distinguish a progressive sequence of increasing disintegration over the complete material weathering scale. Once clay minerals start to form in the weathering process, cracks can be closed or 'healed' as the original rock fabric begins to be destroyed, leading to an apparent reduction in the degree of disintegration with increasing weathering.

(4) State of Alteration. Rocks may be altered by circulation of hot gases and fluids associated with later stage intrusion. Common alteration terms are kaolinized and mineralized (see Glossary). The terms used for description of decomposition grades of rock material may be used where appropriate (e.g. a kaolin deposit may be described as completely decomposed), because in many cases the effects of alteration are not easily distinguished from those brought about by decomposition. In Hong Kong rocks, alteration is often visible in the coarse-grained granitic rocks, particularly around quartz veins. The most common effects are feldspars altered to soft white kaolin in relatively undecomposed material, and an overall reduction in the material grain size. Also, the quartz content may appear lower than in the surrounding unaltered material, due to solution of original quartz by hydrothermal activity.

2.3.5 Rock Name (Including Grain Size)

Recommended rock names are given in Table 5. They should be written in capital letters. This table follows the system of rock classification and nomenclature used by the Hong Kong Geological Survey, but it is intended only as a general guide for engineers. Geological training is required for satisfactory identification of rocks. The engineer need not be overly

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concerned about the large number of igneous rock types shown in Table 5, or the apparent complexity of their classification. Outcrops of most of the basic and intermediate types are only found in small areas of Hong Kong. Granite, granodiorite and rhyolite are the most common igneous rocks in the Territory.

Grain size terms, which refer to the average dimension of the mineral or rock fragments comprising the rock, are included in Table 5, either implicitly in the rock name or as a specific qualifying term. It should be noted that the grain size descriptors for granite, ash tuff and superficial deposits (i.e. coarse, medium, fine) have different limiting dimensions. For this reason, it may not be possible to use the correct term for grain size unless the rock type can be identified accurately. In cases where the rock name is not known, it is recommended that the grain size should be written quantitatively as part of the description, together with an appropriate textural term (e.g. 'megacrystic rock with large grains 10 to 25 mm set in a groundmass of smaller grains 2 to 4 mm'). Strange (1984) has given a clear explanation of the system of textural and grain size terms used for the granites in Hong Kong.

The smallest grain size visible to the naked eye is about 0.06 mm. Identification of grains smaller than this requires the use of a hand lens or a microscope.

With experience, Table 5 can be interpreted to some extent in terms of broad engineering characteristics. For example, average joint spacing in the igneous rocks tends to increase with increasing grain size; compressive strength of fresh igneous and pyroclastic rocks tends to decrease with increasing grain size. However, it is emphasised that Table 5 cannot be used for detailed interpretation of engineering characteristics. Complete engineering descriptions of rocks should include information on the other items covered elsewhere in this chapter, as well as the rock name.

If there is doubt about the correct rock name, this may be indicated in the description by use of a suitable qualifying term (e.g. 'probably') or a question mark. Further guidance and explanation of the HKGS system of rock naming and classification is given in Appendix A.

2.3.6 Additional Information

Any additional features which could be of importance in assessing the nature and engineering properties of the material should be described after the rock name.

It is recommended that the results of any quantitative index tests (e.g. point load strength, Schmidt hammer rebound) should be recorded at this point, even if they have been interpreted in defining other descriptive characteristics such as strength or state of weathering. These results may be useful for the interpretation of other tests carried out on specific samples.

2.3.7 Examples

The following examples of rock material descriptions are given for guidance in the use of appropriate descriptive terms. Samples corresponding to these descriptions are illustrated in Plate 4.

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(a) Plate 4A. (Igneous Rock). Very strong, dry, brownish grey spotted with single black biotite crystals and occasional clusters of small biotite flakes, inequigranular, slightly decomposed, coarse-grained GRANITE. Point load strength 6.5 MPa. N Schmidt hammer rebound value 55 (measured on site).

(b) Plate 4B. (Pyroclastic Rock). Weak, dry, light yellowish brown to pinkish brown, highly decomposed, coarse ash TUFF, with some small (< 100 mm^2) isolated areas of randomly-oriented microfractures, average spacing < 2 mm, located close to the edges of some of the larger intact mineral grains.

(c) Plate 4C. (Metamorphic Rock). Moderately weak, dry, light grey mottled and streaked with orangish brown, very narrowly cleaved, moderately decomposed, PHYLLITE. Prominent orangish or reddish brown mineral coating (iron oxides?) visible on joint surface in part of sample. Exposed small areas of cleavage planes are undulating and shiny.

(d) Plate 4D. (Sedimentary Rock). Moderately strong, dry, light brownish grey striped with dark brown and black, thinly-laminated, fine SANDSTONE and MUDSTONE. Mudstone forms the darker laminations; these are 0.1-2 mm in thickness, mostly continuous but occasionally impersistent with convoluted or branching ends. Rock not significantly affected by weathering, i.e. rock colour and strength not significantly different from fresh material (from field evidence).

2.4 DESCRIPTION OF ROCK MASSES

2.4.1 General

Rock masses should be described by first considering the material characteristics of the rock, then adding information about mass-scale characteristics. With reference to the list in Section 2.2, a mass description would normally include a statement of strength, colour, structure, state of mass weathering and alteration, rock name, discontinuities and additional geological information. More detailed information about the texture/fabric and state of weathering/alteration of different materials within the mass can be added if necessary, but this may not be required, depending on the nature of the project and the stage at which the descriptive information is used (see Section 1.2.4).

Initially, the mass should be divided into suitable descriptive units. This often presents the biggest problem for engineering assessment. It is not possible to give specific recommendations, as the requirements may differ from one project to another, but the general aim should be to divide the mass into geotechnical units, each of which has reasonably uniform characteristics with regard to overall engineering behaviour. In Hong Kong rocks, variations in rock type, degree/extent of weathering and nature/extent of discontinuities are generally the most important characteristics to consider in the selection of geotechnical unit boundaries.

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In a relatively homogeneous rock mass in a single rock type, there may be no need for this subdivision and the description of mass aspects should be quite straightforward. Conversely, in a complex exposure comprising two or more rock types, each of which may vary significantly with regard to weathering and discontinuities, the initial subdivision of the mass will be of great importance for good description. In particular, interbedded sedimentary and mixed pyroclastic/sedimentary rock sequences often present problems for mass description. For example, the presence of one rock which is particularly susceptible to weathering may affect the weathering of adjacent rocks, and the overall engineering properties of the interbedded rock mass may depend more on the one rock type than the others. Granitic rocks, and thick accumulations of single types of pyroclastic rock (tuff), are usually easier to subdivide, with variation in weathering often being the most important aspect.

Once the rock mass has been divided into appropriate geotechnical units, mass characteristics should be assessed in detail and combined with material characteristics (as noted above) to form the complete mass description for each unit. The information on mass characteristics should include :

(a) description of geological structure (see Section 2.4.2),

(b) the nature, orientation, spacing, persistence, roughness, aperture, infilling and seepage aspects of discontinuities (see Section 2.4.3), and

(c) details of the mass weathering profile (see Section 2.4.4).

These three aspects may have to be considered separately for each rock type if a rock mass unit contains more than one rock type. Reference may also need to be made to major geological structures such as faults and folds and different types of igneous intrusions (see Appendix A and Bennett, 1984b, for further information).

The term 'structure' is commonly used in different ways and requires further explanation. In the broadest geological sense, structure includes two main groups of features, i.e. fractures (or discontinuities), and folds (see Appendix A.7). The size of these features can vary widely, both in areal extent and cross-section. Large-scale aspects of regional rock structure, such as major faults and folds, are often not relevant at the scale of an engineering site. The engineer is usually concerned more with the smaller-scale structural features; for example, individual joint systems, lineation and foliation. However, such features are ultimately related to regional structure and cannot be appreciated fully without some understanding of the regional structure.

With reference to the list of descriptive items in Section 2.2, features such as foliation and lineation are included under the item 'structure' in the following section, whilst 'discontinuities' are considered separately in Section 2.4.3. Thus, 'structure' in Section 2.4.2 is used in a narrow sense, for want of a suitable alternative heading. In the broad sense, structure includes discontinuities, as noted above.

Another term in fairly common use by engineering geologists is 'structural domain' (see Glossary). This term should only be applied to changes in the discontinuity pattern in the rock mass, and not to changes in rock type or weathering. It would not be correct to use the term for the geotechnical units created by subdividing a rock mass for description as

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discussed above, unless this subdivision were made solely on the basis of discontinuity variation.

2.4.2 Structure

The structure of the rock mass is concerned with the larger-scale inter-relationship of textural features (see Section 2.3.3). Common terms used to describe sedimentary rocks include 'bedded', 'laminated' or 'massive'; igneous and pyroclastic rocks may be 'massive' or 'flow-banded'; metamorphic rocks may be 'foliated', 'banded' or 'cleaved'. 'Eutaxitic' is a term often applied to welded tuffs containing flattened lenses of pumice or other material which give the rock a distinctive streaked appearance. These terms are defined in the Glossary and are illustrated in Plate 5. Additional information on bedding is given in Section 3.4.1.

Recommended descriptive terms for the spacing of planar structures are given in Table 6. For sedimentary rocks, structures such as bedding may be described as 'thick beds' or 'thickly-bedded'; for example, a 'thickly-bedded sandstone'. For igneous and metamorphic rocks, the appropriate descriptive terms for the structure should be used; for example, 'medium foliated schist', 'very narrowly cleaved phyllite', 'very thickly flow-banded rhyolite'.

There is some overlap between textural characteristics of rock materials and structural characteristics of rock masses. Structural features with a spacing of less than about 200 mm may also be applicable to the description of rock material (see Section 2.3.3).

2.4.3 Discontinuities

(1) Nature and Descriptive Method. A discontinuity is a fracture or plane of weakness in the rock mass across which the rock material is structurally discontinuous and has zero, or a relatively low, tensile strength. 'Discontinuity' is a collective term and includes joints, fissures, faults, shear planes, cleavages, schistocity, bedding planes and other planes of weakness. It is important that discontinuities are described carefully and precisely, because they control the engineering behaviour of most rock masses.

Complete descriptions of discontinuities should include information on their location and orientation, spacing, persistence, roughness, aperture, infilling and seepage characteristics. This list is based on the recommendations given by ISRM (1978), which should be consulted for more detailed information on all these aspects.

Some discontinuities, such as tectonic joints, usually occur in more than one direction in a rock mass and often form a number of distinct sets. A general description of a discontinuity set can often be made by combining characteristic values, or small ranges of values, for each of the aspects in the above list. Alternatively, separate full description of individual discontinuities may be required if they are of particular importance to the engineering project. Other types of discontinuity, such as faults, tend to occur as unique features and should be described individually if they are relevant to the project. Where possible, it is desirable to differentiate between the origins of the various types of discontinuity, because their engineering properties may be related to their genesis (e.g. discontinuities formed by tensile forces, such as stress-relief joints, may behave differently to discontinuities formed by shear,

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such as slip surfaces and faults). General information on various types of discontinuity in Hong Kong has been given by Burnett & Lai (1984), Gamon & Finn (1984a) and Nau (1984).

There are two levels at which a discontinuity survey may be carried out, depending on the amount of detail required. In a subjective (biased) survey, only those discontinuities that appear to be important to the project are described. In an objective (random) survey, all discontinuities that intersect a fixed line, or are located within a demarcated area of the rock face, are described. The main disadvantage with the objective approach is that it is time-consuming and tedious. Subsequent data analysis may require some form of automatic data processing to make the analysis efficient. However, if there is any doubt about the nature of the discontinuity pattern, and its relation to the proposed engineering works, an objective survey should be carried out.

Borehole cores provide essentially one-dimensional data on discontinuities. These data may be seriously biased if joint sets are oriented such that unidirectional boreholes tend to miss them (e.g. sub-vertical joints missed by vertical boreholes). These errors can be reduced by drilling in different directions (e.g. inclined/horizontal holes) and by checking regional joint patterns before commencing ground investigation. Even if borehole data are not seriously biased, cores rarely provide good information on persistence, infilling and seepage characteristics. Good field exposures are needed for full description of discontinuities.

It is common practice to supplement the description of discontinuities in rock core with several quantitative indices relating to the fracture state of the rock mass (see item (9) in this section).

A useful aid for the systematic recording of discontinuity data is a standard data sheet. An example is shown in Figure 1.

(2) Location and Orientation. It is important to record the location of each individual discontinuity described. This is often stated as relative position along a fixed datum line, or ground co-ordinates plus elevation in an exposure. Information should preferably be recorded on a map or plan.

The orientation of a discontinuity is described by the dip direction, the compass bearing of the maximum inclination measured clockwise from true north, and by the dip, the maximum inclination of the discontinuity measured from horizontal. Dip directions and dips are normally measured with a compass and clinometer, and should be expressed to the nearest degree. In order to differentiate clearly between dip direction and dip, the dip direction value should always be given with three digits and the dip with two digits (e.g. dip direction/dip 025/60).

Orientation data can be obtained in various ways. The most common method is to measure the dip direction and dip of discontinuities which intersect a line drawn across an exposed rock face. Data may also be obtained from oriented rock core or by means of a downhole instrument such as the impression packer (GCO, 1987a).

The four main methods of presenting orientation data are by map symbol, perspective diagram, joint rosette and spherical projection. Map symbols are shown in Table 23. Perspective diagrams are particularly helpful for underground work, because they can depict the relationship between the proposed engineering structure and the rock mass structure. Joint rosettes and

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spherical projections are commonly used for the quantitative presentation and analysis of orientation data. Detailed discussion of all these methods is beyond the scope of this Geoguide. The ISRM (1978) report should be referred to for further guidance. A clear introduction to the use of spherical projections has been given by Hoek & Bray (1981).

Although stereographic projection analysis is a popular and powerful technique, it can easily be misused if its limitations are not fully appreciated. (Brand et al, 1983; Hencher, 1985). The project engineer should be aware of this when making discontinuity descriptions. Wherever possible, a further inspection of the rock exposure should be made after the analysis is complete to check that the results are valid.

(3) Spacing. Recommended terms for the description of discontinuity spacing are given in Table 7. These terms can be applied to both rock core and rock face exposures. They may be used to describe the spacing of discontinuities in a single set or for the average spacing of all discontinuities measured along a traverse line.

The description of discontinuity spacing can be supplemented by reference to the shape of the rock blocks bounded by the discontinuities. Common terms are 'blocky', 'tabular', 'columnar' and 'polyhedral'. These are defined in the Glossary and are illustrated in Figure 2. The use of such terms requires an understanding of the distribution of discontinuities in three dimensions; therefore, they cannot be used in the description of drillcore.

(4) Persistence. 'Persistence' refers to the areal extent or size of a discontinuity within a plane. It is one of the most important items in discontinuity description; unfortunately, however, it is difficult to quantify accurately because it is rarely possible to see the three-dimensional extent of a discontinuity. For most practical purposes, persistence can only be assessed very approximately by measuring the discontinuity trace length on the surfaces of rock exposures. A discontinuity set often tends to have a characteristic range of persistence which differs from that of other sets within the same rock mass.

For the description of individual discontinuities, it is recommended that the measured maximum persistence dimension should always be used where possible. The description should also state whether the discontinuity extends outside the exposure, terminates against solid rock, or terminates against other discontinuities. In the case of general descriptions of different discontinuity sets, relative terms should be used. For example, in a rock mass with three discontinuity sets, the most persistent set could be described as 'persistent', the intermediate set as 'sub-persistent' and the least persistent set as 'non-persistent'.

(5) Roughness. The 'roughness' of a discontinuity is made up of two components : large-scale 'waviness' and small-scale 'unevenness' (Figure 3). 'Waviness' refers to undulations of the surface of the discontinuity over distances of typically tens of metres. 'Unevenness' refers to the bumps, asperities and small ridges on the surface of the discontinuity over distances of typically one centimetre to a few metres. Other general terms which are used quite commonly are 'first-order' roughness for waviness and 'second-order' roughness for the smaller-scale superimposed unevenness.

Roughness may be measured quantitatively by using linear profiling, a compass and disc-clinometer or a photogrammetric method. A clear

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introduction to these three methods has been given by ISRM (1978). The most commonly-used is the compass and disc-clinometer, which involves measuring discontinuity dip direction and dip angles on a series of circular plates of different diameter (GCO, 1987a). The results are usually presented and analysed stereographically.

For general descriptive purposes, waviness should be assessed by estimating dimensions of wave length and wave amplitude (Figure 3). These could be single values for a single discontinuity or characteristic values for a discontinuity set. Unevenness should be described using two terms, the first referring to lengths of several centimetres and the second to lengths of up to several metres. Nine classes of unevenness are formed by combinations of these two terms, as illustrated and defined in Table 8. The term 'slickensided' should only be used if there is clear evidence of previous shear displacement along the discontinuity, such as striations in the direction of inferred movement.

The main reason for describing discontinuity roughness is to assist in estimating discontinuity shear strength (GCO, 1987a; Hoek & Bray, 1981; ISRM, 1978). Hencher & Richards (1982) and Richards & Cowland (1982) have described in some detail the effect of roughness on the field shear strength of granite sheeting joints in Hong Kong. If quantitative measurements are not made, the descriptive terms in Table 8, in conjunction with the estimation of waviness, can be used to make comparative assessments of the contribution of roughness to shear strength, as discussed by ISRM (1978).

(6) Aperture. 'Aperture' is the perpendicular distance between adjacent walls of an open discontinuity, in which the intervening space is filled by air or water. It should be distinguished from the width of an infilled discontinuity (see item (7) below). Apertures are caused by a number of factors, such as tensile opening, washing out of infilling materials, solution, or shear displacement of discontinuities with significant roughness. Description of aperture size is important because it has a marked effect on the shear strength and hydraulic conductivity of a discontinuity.

Aperture size should be described using the terms given in Table 9. If the discontinuity is closed, with zero aperture, it should be described as 'tight'. The use of these terms may not provide a reliable indication of the hydraulic properties of discontinuities, particularly where the discontinuities have been disturbed by blasting or surface weathering. The influence of aperture on the hydraulic properties of the rock mass is best assessed by insitu permeability testing (GCO, 1987a).

(7) Infilling. 'Infilling' is the term for the material that separates the adjacent rock walls of a discontinuity. This term is preferred to 'filling', which is normally used to describe the placement of fill materials (see Section 3.7). It should be noted, however, that not all infill materials are necessarily transported into the discontinuity at a later stage; some can form insitu, e.g. by the action of intense weathering along a joint.

Infill materials are usually weaker than the parent rock. This is often the most important engineering characteristic. Typical infill materials are soil, decomposed or disintegrated rock, minerals such as quartz or calcite (often termed 'veins'), manganese or kaolin, or, in the case of faults or shear zones along which significant displacement has occurred, fault gouge or breccia (see Appendix A.7 and the Glossary).

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No specific terms are recommended for the description of infill materials. If the materials are decomposed/disintegrated rocks or soils, they should be described in accordance with Section 2.3 or 3.3 respectively. If they are specific minerals, the mineral type, particle size and strength (compactness/consistency) should be described where possible. Whatever the type of material, descriptions of infilling should always include some information on their width (ideally maximum, minimum and average widths in mm) and seepage aspects (e.g. are the materials dry, damp/wet, do they show permanent seepage?)

(8) Seepage. Seepage along discontinuities is often of great engineering importance and deserves very careful assessment in a comprehensive rock mass description. Seepage aspects of unfilled discontinuities should be described using one of three basic terms, viz 'dry', 'damp/wet' (but with no free water) and 'seepage present'. For the last category, the quantity of water flowing at the point of observation should be noted in litres/second or litres/minute, either by estimation or approximate measurement. Unless the rock mass is completely dry, it is often difficult to select characteristic values of seepage for discontinuity sets, in which case supplementary description of seepage variability within the mass should be given. The date of observation should always be noted when seepage is described, so that the seepage amount can be related to the wet and dry seasons. If possible, subsequent observations should be made at the height of the wet season and at the end of the dry season in order to give an indication of maximum and minimum seepages.

In most unweathered rocks and partially weathered rocks in the PW90/100 zone (Table 10), the flow of water takes place mainly through discontinuities. Some sedimentary rocks may be exceptions to this rule, because a significant proportion of the flow can occur through the intact rock material. In more intensely weathered rock masses (the PW50/90 to PW0/30 zones in Table 10), it is much more difficult to give a general indication of typical groundwater movement, because the rock material weathered to a soil may be at least as permeable as the discontinuity system. Careful observation of seepage sources in natural exposures and excavations can provide valuable information on the hydrogeology of the rock mass, particularly when related to other data sources such as piezometric levels measured in boreholes (GCO, 1982).

(9) Fracture State. A number of indices can be used for quantitative description of the fracture state of the rock mass as determined from borehole cores. These are Total Core Recovery, Solid Core Recovery, Rock Quality Designation and Fracture Index. These indices should be used whenever possible to supplement the description of discontinuities in rock core.

Only natural geological fractures should be taken into account for the description of fracture state. Artificial fractures produced, for example, by drilling or blasting should be excluded from the assessment, although precise interpretation of fracture origin may be difficult. A rough surface with fresh cleavage planes in individual rock minerals usually indicates an artificial fracture. A generally smooth or weathered surface, or a surface coated with infill materials such as calcite or kaolin, clearly indicates a natural discontinuity. Additional guidance notes on the interpretation of fracture origin are given by ISRM (1978). In cases of doubt, it is customary to regard the discontinuity as natural.

Previous inconsistency in the use of fracture index definitions has led to some difficulty in measurement and interpretation. The definitions and terms

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given below are based on the recommendations made by Norbury et al (1984).

'Solid core' is the key term to be defined in the assessment of fracture state; it is regarded as core with at least one full diameter (but not necessarily a full circumference) measured along the core axis between two natural fractures. On the basis of this definition, the four quantitative fracture indices are illustrated schematically in Figure 4, and are defined as follows :

(a) Total Core Recovery, TCR (%), is the percentage ratio of core recovered (whether solid, intact with no full diameter, or non-intact) to the total length of core run.

(b) Solid Core Recovery, SCR (%), is the percentage ratio of solid core recovered to the total length of core run.

(c) Rock Quality Designation, RQD (%), is the total length of solid core pieces, each greater than 100 mm between natural fractures, expressed as a percentage of the total length of core run.

(d) Fracture Index, FI (No./m run), is the number of clearly identifiable fractures per metre run of intact core pieces, measured over core lengths of reasonably uniform character. This index does not necessarily apply to whole core runs. If there is a marked change in fracture frequency during a core run, the fracture index should be calculated for each part of the run separately. The term 'non-intact' (NI) should be used when the core is fragmented. Additional detail can be given by quoting the maximum, mean and minimum length of core pieces recovered for any core length of reasonably uniform character.

It is important to note that measures of fracture spacing such as RQD and Fracture Index may be biased, depending on the orientation of the borehole in relation to the dominant discontinuity sets. This problem is discussed in some detail by Beggs & McNicholl (1986) in relation to site formation works at Ap Lei Chau, Hong Kong.

2.4.4 Rock Mass Weathering

A section through a weathered rock mass often shows a range of rock material at various stages of decomposition and disintegration. Although the proportion of the more intensely weathered rock is generally greater close to the ground surface, it is unusual to encounter a weathering profile which shows an orderly progression of successively less weathered layers, from a residual soil at the surface to an unweathered rock mass at depth.

To account for complex weathering profiles, descriptive schemes for rock mass weathering should be flexible and simple to apply in the field. For engineering purposes, the usual method of description is to identify pre-defined weathering zones within the rock mass. Different zonal classification schemes may be appropriate, depending on the nature of the engineering project (e.g. tunnelling, foundation design, slope stability assessment). The scheme recommended below may require modification (e.g. by subdivision or amalgamation of zones), or replacement by an alternative scheme, to suit particular situations.

Rock mass weathering classifications are usually established on the basis of differing proportions of rock and soil, the presence or absence of mass structure, and the degree of discolouration of discontinuity surfaces. A simple general scheme based on these characteristics is given in Table 10. It should be noted that this zonal classification differs substantially from that recommended in BS 5930 (BSI, 1981). In order to avoid confusion between the two, new self-explanatory zone descriptions and symbols are used.

The scheme in Table 10 is based on the four-zone scheme originally proposed by Ruxton & Berry (1957), a modified form of which is given in the Geotechnical Manual for Slopes (GCO, 1984). The important differences between the two schemes may be summarised as follows :

(a) The present scheme (Table 10) is expanded to six zones because there appears to be a broad consensus of opinion that a four-zone scheme is not adequate for engineering purposes. The extra two zones are created by the addition of an 'unweathered' zone, comprising 100% rock (which, in fact, is implicit as a fifth zone in the Ruxton & Berry scheme), and by the introduction of a 30% rock boundary.

(b) Whereas the Ruxton & Berry scheme refers only to geological characteristics, some generalised engineering characteristics are included in Table 10. However, it is emphasised that these characteristics are only intended as a very approximate guide to the engineering behaviour of the different zones.

(c) Unlike the Ruxton & Berry scheme, the present scheme is not intended to represent an idealised weathering profile. Rather, it is intended that the scheme should be applied in a flexible sense to suit the actual distribution of weathering zones in the rock mass. This point is illustrated in Figure 5 and explained further below.

The rock percentages in Table 10 are notionally by volume. In most cases, however, information on the three-dimensional extent of the mass is limited, and it is usually only possible to make a rough estimate of these percentages.

One of the most striking features of mass weathering in certain rocks is the development of corestones (Ruxton & Berry, 1957; see also Plate 6). In general, the coarser-grained, more widely-jointed Hong Kong rocks such as granite and lapilli tuff tend to weather with the development of corestones, whereas the finer-grained, more closely-jointed rocks do not. In principle, Table 10 is applicable to all rock types, but in practice it is much easier to apply in corestone-forming rocks, because the different proportions of rock and soil in the partially weathered zones can be recognized more readily in the field. For the non-corestone-forming rocks, it is necessary to make a careful assessment of the different grades of rock material decomposition before dividing the mass into weathered zones using this scheme. Sometimes, it may be found that the rock weathers so uniformly that it is impossible to identify the intermediate zones given in Table 10, in particular the PW50/90 and

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PW30/50 zones. In such cases, it may be appropriate to use a smaller number of classes by combining certain zones. Alternatively, use of a different zonal classification should be considered.

It is often found that some weathering zones are absent, or are present only to a very small extent. The distribution of weathering zones can be determined by mapping natural exposures and excavations, but these may not be representative of the whole mass. Figure 5 illustrates an idealised weathered profile, an example of a complex but more realistic profile, and a section through a corestone-forming rock mass showing the subdivision of the mass into weathered zones using the scheme given in Table 10. Examples of complex weathered rock mass exposures are shown in Plate 7.

In carbonate rocks, only small amounts of soil are produced during weathering unless the rock contains a high percentage of impurities (see Section 2.3.4(2)). The partially weathered PW50/90 to PW0/30 zones are rarely developed to any significant thickness. Typically, weathered profiles show a relatively thin layer of residual debris overlying an irregular surface of unweathered or partially weathered PW90/100 rock. The contact between the rock and soil is usually very sharp. Karst features formed by solution along discontinuities are the most distinctive aspects of mass weathering in carbonate rocks and are often of great engineering significance and concern. Useful information on the description and engineering assessment of weathering effects in carbonate rocks is given by Dearman (1981) and Fookes & Hawkins (1988). The occurrence of cavernous ground in the buried marble at Yuen Long is described by Pascall (1987).

When cores in decomposed rock are logged, the decomposition grades of the rock material should be included in the description, but not the rock mass weathering zones. Zonal interpretation should not be done as part of routine core description. A borehole is essentially a line sample through the rock mass, and it may not be representative of the overall pattern of mass weathering. It is particularly difficult to construct a reliable weathering zone model in corestone-forming rocks from borehole evidence alone.

For examples of the use of specific weathering zone classifications for engineering projects in Hong Kong, reference should be made to Gamon & Finn (1984b) for assessment of large excavations in granite at Kornhill, Irfan & Powell (1985a) for foundation assessment in granodiorite at Tai Po, and Watkins (1979) for tunnelling and dam foundation studies in various igneous and volcanic rocks in the eastern New Territories.

2.4.5 Additional Information

Any additional information that will assist the engineer in understanding the nature of the rock mass should be recorded. An example is the possible occurrence of voids in carbonate rocks such as limestone and marble. If discovered, the geometry of any voids should be described where possible, as well as their relationship to discontinuities in the surrounding rock mass and any signs of groundwater or seepage.

Special note should be made if any of the mass characteristics described are considered to be unusual in relation to the rest of the mass description. It is particularly important to indicate whether the sample of the rock mass described is considered to be representative of the whole mass which is relevant to the engineering project. The limitations inherent in making mass

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descriptions from small isolated exposures, or from borehole evidence alone, should always be kept in mind. A considerable degree of professional judgement and commonsense is required. The engineer should assess the validity of the geotechnical model used in the design as engineering works proceed and further exposures become available. If variable ground conditions are encountered, rock mass descriptions should be revised during construction where necessary.

2.4.6 Examples

Two examples of rock mass descriptions are given for guidance in the use of appropriate descriptive terms. The rocks corresponding to these descriptions are illustrated in Plate 8.

(a) Plate 8A. (Pyroclastic Rock Mass). The mass is split into two basic units for description :

(i) Unit 1 : Very strong, greenish grey, massive, partially weathered PW90/100, coarse ash TUFF, with three major joint sets : (a) 010/87, medium-spaced, persistent, smooth and stepped, tight, dry; (b) 120/35, very closely-spaced, sub-persistent, smooth and planar, extremely narrow, generally dry but with several minor seepage points of < 1 litre/min in western lower half of face; (c) 345/60, closely-spaced, non-persistent, smooth and planar, tight, dry.

(ii) Unit 2 : Weak, reddish brown, partially weathered PW0/30, coarse ash TUFF.

Unit 2 overlies Unit 1. The boundary is sharp and dips at approximately 30° to the west across the excavation face.

(b) Plate 8B. (Igneous Rock Mass). The length of core from 23.73 to 27.05 m is split into two units on the basis of differing grain size and fracture frequency :

(i) Unit 1 (23.73 to 26.26 m) : Very strong, grey mottled with pink and dark brown, slightly decomposed, medium-grained GRANITE, with widely-spaced, rough and undulating, brown-stained joints dipping 0 to 10°. TCR 100%. SCR 100%. RQD 100%. FI 1.2.

(ii) Unit 2 (26.26 to 27.05 m) : Very strong, light greyish pink, slightly decomposed, fine-grained GRANITE, with closely- to medium-spaced, generally rough and stepped but also smooth and planar (one subvertical joint), brown-stained joints dipping 0 to 10°, 40° and 85°.

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TCR 100%. SCR 55%. RQD 44%. FI 7.6.

The core was wet when described.

(Note : Since only a very small portion of the mass is exposed in the core, the description is made essentially in terms of rock material characteristics, plus information on discontinuities.)

2.5 ADDITIONAL GEOLOGICAL INFORMATION

Once the material and mass characteristics of the rock have been described, the final item in a complete rock description should be the name of the geological formation from which the sample rock material or mass has been selected. A guide to the name of the geological formation is given in the maps and memoirs produced by the Hong Kong Geological Survey. The name should be written with capital initial letters (e.g. Ap Lei Chau Formation). The geological formation should be named where this can be done with confidence, but it is often difficult to identify a formation name from a small sample, or to locate formation boundaries in a borehole or exposure; conjecture should be avoided.

The principal rock types associated with a specific formation are often indicated on the geological map, but it should be remembered that, at a particular location or horizon, the actual rock type may be completely different from that indicated under the heading of principal rock type. Geological formations may be quite variable in their range of rock types, and a knowledge of the formation will often indicate the possible range of rocks to be expected. For example, the Shing Mun Formation of the Repulse Bay Volcanic Group is a complex formation that contains lapilli, coarse ash and fine ash tuffs, tuffites and a range of sedimentary rocks from conglomerate to mudstone. The engineer should refer to the HKGS maps and memoirs for guidance, or consult a geologist for assistance where necessary.

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3. DESCRIPTION OF SOILS

3.1 GENERAL

The recommendations in this chapter are generally applicable to all types of superficial deposits, including fill. Some of the recommendations are also applicable to soils derived from the insitu weathering of rocks. In view of their importance for engineering in Hong Kong, soils derived from insitu rock weathering, colluvium, and fill are considered in greater detail under separate sections (see Sections 3.5 to 3.7). These sections follow the recommendations for a general descriptive method for soils given in Sections 3.2 to 3.4.

3.2 PURPOSE AND SCOPE OF SOIL DESCRIPTION

The main purpose of a soil description for engineering purposes is to give an indication of the likely engineering properties of the soil. In this sense, soil descriptions in principle can be made using the same approach adopted for rock descriptions in Chapter 2, but there is one important difference. Unlike rocks, most soils can be easily disturbed during excavation, sampling or testing, and this may have a marked effect on engineering properties. Soil descriptions should include a note on the degree of sample disturbance, where this is considered to be important. The degree of disturbance ranges from the completely undisturbed, insitu field condition to the fully disturbed, remoulded condition of a sample that has been completely broken down into its constituent grains. Further information and guidance on sampling methods in relation to soil disturbance is given in Geoguide 2 : Guide to Site Investigation (GCO, 1987a).

Soil descriptions can be made directly from field exposures and excavations or from samples recovered from boreholes or excavations. In the following sections, "material characteristics of soils" refers to those characteristics that can be described from visual and manual examination of relatively small volumes of soil in either disturbed or undisturbed samples. "Mass characteristics of soils" refers to characteristics that can only be described satisfactorily if the original soil structure remains intact, i.e. they can be observed only in the field or to some extent in a large undisturbed sample. Additional geological information, such as the geological formation, age and type of deposit, should also be included in the description whenever possible, but these aspects may not be readily determined without a detailed geological study of the area around a site.

In a soil description, the main characteristics should be given in the following order :

(a) strength, i.e. compactness or consistency (material),

(b) colour (material),

(c) particle shape and composition (material),

(d) structure (mass),

(e) state of weathering (mass),

(f) soil name (in capitals, e.g. SAND), grading and plasticity (material),

(g) discontinuities (mass), and

(h) additional geological information.

In the following sections, the material characteristics in this sequence are considered in Section 3.3 and the mass characteristics in Section 3.4. The scope of this scheme is similar to the schemes recommended by BSI (1981) and IAEG (1981), but the layout of these two sections, and the order in which individual characteristics are considered, have been modified to conform as closely as possible to the scheme used for rock description in Chapter 2.

It should be noted that the term 'structure' as used in this chapter refers to macrostructure, i.e. structural features of a soil mass which can be identified by the naked eye. The description of soil microstructure is considered in Section 3.4.4.

The recommended scheme for the rapid identification and description of soils is summarised in Table 11. Each main item in this Table is discussed in further detail in the following text sections.

In addition to description, it may be useful in some circumstances to make an overall classification of soils for engineering purposes. Guidance on soil classification is given in Chapter 4.

3.3 MATERIAL CHARACTERISTICS OF SOILS

3.3.1 Strength

The strength of a soil may be altered significantly by disturbance or remoulding during sampling and testing. Strength should therefore be described in the undisturbed field condition whenever possible; alternatively, the highest-quality, least disturbed sample should be used.

The strength of cohesive soils is noticeably affected by moisture content. In Hong Kong, this is particularly the case for soils in the unsaturated zone above the water table, where significant short-term and seasonal fluctuations in moisture content can occur. Strength descriptions of cohesive soils should therefore include an indication of the moisture condition. For example, possible moisture condition classes could be 'dry', 'moist', 'wet', etc. Any classes used should be defined in terms of simple field recognition criteria for particular soils, and should be related to laboratory-measured moisture contents where possible. As a general rule, soil strength in the field should be described at the natural field moisture content, and any samples taken should be kept at that same moisture content. Guidance on the handling and storage of samples is given in Geoguide 2 (GCO, 1987a).

The recommended qualitative scales for strength assessment are given in Table 11. The strength of coarse and very coarse soils (sands, gravels, cobbles and boulders) is described in terms of compactness or relative density (e.g. 'loose' or 'dense'). The strength of fine soils is described in terms of consistency (e.g. 'soft', 'firm', 'stiff', etc). Equivalent quantitative scales of strength for these two groups of soils are given in Table 12. Compactness and consistency terms cannot be applied easily to organic soils, which should be

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described as 'compact', 'spongy' or 'plastic' (Table 11).

The compactness terms for sands and gravels in Table 12 are based on N values measured in boreholes by the Standard Penetration Test (BSI, 1975). This scale is recommended for use only in transported soils. There is no generally accepted classification of N values and density terms for soils derived from insitu rock weathering in Hong Kong; for descriptive purposes, any measured N values in these soils should be recorded directly. When used for design purposes, a correction factor is often applied to N values to account for overburden pressure, energy dissipation in the drill rods, and the effect of low permeability in fine sands and silty sands (Rodin et al, 1974; Skempton, 1986). If the descriptive terms are based on corrected N values, this should be noted.

The consistency terms for fine soils in Table 12 are based on values of undrained shear strength. For descriptive purposes, a rapid approximate value of undrained shear strength can be obtained by using a small laboratory shear vane or hand penetrometer (Head, 1980).

The presence of a mineral cement in the soil may have a significant effect on the soil strength. Very few studies have been carried out on cementation in Hong Kong soils, but it appears that colluvial matrix material (Ruxton, 1986) and fine-grained marine soils (Howat, 1984; Tovey, 1986a; Yim & Li, 1983) can have relatively high strength and stiffness due to the presence of iron oxide, and possibly other, cementing agents. The presence of iron oxides in the soil is often indicated by a distinctive brown or reddish brown colouration. If a mineral cement appears to be present, it is useful to note whether slaking occurs on immersion of a non-saturated sample in water. Non-cemented soils usually slake in water.

3.3.2 Colour

It is recommended that soil colours should be described according to the scheme given for rocks in Table 3. This scheme is also summarised in Table 11. As with rocks, it should be stated if the soil was wet or dry when described, because this can have a marked influence on the colour description. (Note that the moisture condition may already have been recorded in the description of strength; see Section 3.3.1).

Sample disturbance or remoulding may destroy some of the original soil colouring. Therefore, soil colours should be described in the undisturbed field condition whenever possible. Bedding planes, relict joints and other structural features often show a distinctive colour change when compared with the surrounding soil matrix, and this should be noted where applicable.

3.3.3 Particle Shape and Composition

Particle shape may be described by reference to the three-dimensional form of the particles, their angularity (which indicates the degree of rounding at edges and corners) and their surface texture. In general, simple visual assessment of these characteristics is adequate for routine descriptions, but more precise measurements may be required in some cases (e.g. assessment of granular soils as potential sources of aggregate, detailed assessment of sedimentary texture and fabric, etc).

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Common terms for simple description of form and angularity are illustrated in Tables 13 and 14. For a more rigorous description of shape characteristics, form and angularity may be quantified by reference to the axial ratios of the particle diameters and the radii of curvature of the particle corners in the projected plane. A quantitative classification of particle form is shown in Figure 6. A quantitative measure of particle roundness is given by :

$$P = \frac{\Sigma \frac{r}{R}}{N} \qquad \qquad (1)$$

where r is the radius of curvature of a corner of the particle surface, R is the radius of the maximum inscribed circle in the projected plane and N is the number of corners. As roundness increases, r approaches R and P approaches one.

Common terms used to describe the surface texture of particles are 'smooth', 'rough', 'glassy', 'honeycombed', 'pitted' and 'striated' (see Glossary).

The composition of particles visible to the naked eye or under a hand lens may also be described. Gravel and larger particles are usually rock fragments (e.g. granite, tuff, schist). Sand and finer particles are generally individual mineral grains (e.g. quartz, mica, feldspar). Gravel and sand particles may be coated with specific minerals, such as limonite and other iron oxides, manganese or calcite. Soils containing an appreciable proportion of shells may also be described as 'shelly' (see also Section 3.4.1).

3.3.4 Soil Name

(1) General Aspects. The basic soil types and their sub-divisions are shown in Table 11. The soil name is based on particle size distribution and plasticity properties. These characteristics are used because they can be estimated with sufficient accuracy for descriptive purposes, and can be measured with reasonable precision if required. They give a general indication of the probable engineering characteristics of the soil at any particular moisture content. Table 11 provides guidance essentially for the rapid identification of the soil type by hand and eye in the field or in the laboratory. If necessary, the soil type can be confirmed by determining the particle size distribution and plasticity properties from laboratory tests (BSI, 1975).

Because of the subjective nature of the rapid identification procedure, it is often found that the initial description of soil type is not consistent with the results of laboratory grading and plasticity tests. In such cases, it is good practice to revise the soil name in line with the laboratory test data, but the original description should still be preserved as a record of the observer's opinion. A note should always be added to the description if the soil name has been modified on the basis of laboratory tests.

Table 11 is a slightly modified and rearranged form of the version given by BSI (1981) . This method of naming and identifying basic soil types has been criticised in some detail by Child (1984) and Norbury et al (1984). They proposed an alternative method which is based more on the probable mass engineering behaviour of the soil (following the scheme used in CP 2001 (BSI, 1957)), rather than on strict grading limits as in the present scheme. However, the use of this alternative method depends more on the judgement of

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the individual who makes the description. The scheme outlined in Table 11 is considered to be easier for the non-specialist to apply and is therefore recommended.

In addition to identification of the soil name, grading and plasticity characteristics can also be used to make an engineering classification of soils. This is considered further in Chapter 4.

(2) Particle Size Distribution. From Table 11, it can be seen that, where a soil (excluding any boulders or cobbles) contains about 35% or more of fine material, it is described as a 'silt' or 'clay' (fine soil). With less than 35% of fine material, it is described as a 'gravel' or 'sand' (coarse soil). In the field, or when laboratory descriptions are made in advance of grading tests, these percentages can only be estimated. If accurate determination is required, laboratory tests are necessary. The gravel, sand and silt particle size ranges can be further subdivided into coarse, medium and fine particles (Table 11). The grading of sands and gravels may be qualified as 'well-graded' or 'poorly-graded'; poorly-graded materials may be divided further into 'uniform' and 'gap-graded' as defined in Table 11. Terms such as well- or poorly-graded are used here in the engineering sense and are the reverse of the sorting terms used in the geological sense. For example, a soil that comprises a wide range of particle sizes is a well-graded soil to an engineer, but a poorly-sorted soil to a geologist.

The broad basis for the description of composite soils (i.e. mixtures of basic soil types) is also given in Table 11. The terms are defined according to the percentage of secondary constituents and are prefixed to the main soil name. These terms refer only to mixtures of two basic soil types (e.g. a silt or clay with a gravel or sand).

Since the coarse fraction in a composite soil can itself be divided into approximate proportions of sand and gravel by estimation, it is possible to describe more complex soil mixtures in terms of three basic soil types, or more than three if the soil also contains very coarse material (cobbles and boulders). The full explanation of the use of secondary constituents for describing composite soils is given in Tables 15 and 16. Both tables include examples to illustrate the appropriate use and sequence of terms.

It should be noted that no guidance is given for the simultaneous description of silt and clay where both are present in a fine soil or in a composite soil. Terms such as 'silty clay' or 'very clayey silt' can only be used satisfactorily after determination of grading and plasticity properties by laboratory tests (Norbury et al, 1984). For rapid descriptions, one of the names should be used if the fine fraction appears to be dominated by either silt or clay. Where no distinction can be made between silt and clay, both names should be used, separated by a stroke. This method can be applied to the fine fraction as either the principal or secondary constituent (e.g. 'very silty/clayey SAND', 'slightly sandy SILT/CLAY'). The term 'FINE SOIL' may also be used as the name of the principal constituent when it is not possible to distinguish between silt and clay.

The recommended method of naming very coarse (boulder and cobble size) soils, and soils comprising mixtures of very coarse and finer (gravel to clay size) material, is given in Table 16. Usually, these soils can only be described satisfactorily in excavations or exposures. It is often useful to record the rock type of the constituent boulders or cobbles (Table 5), because this may help in constructing a geological model of the site. Further guidance

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on the description of colluvial soils containing very coarse material is given in Section 3.6.

Organic soils may often be recognized by the presence of plant remains. Soils that consist predominantly of plant remains, either fibrous, or pseudo-fibrous or amorphous, may be described as 'peat'.

A rapid assessment of particle size distribution has to be made on the basis of the appearance and 'feel' of the soil sample. It is relatively easy to distinguish between gravels and sands, or between gravelly and sandy fine soils, because the particle size which separates gravel and sand (2 mm) is easily visible. Particles of 2 mm size are about the largest that will cling together when moist owing to the capillary attraction of water. Well-graded and poorly-graded materials can also be distinguished by visual inspection, although this is more difficult for sand than for gravel. It is less easy to distinguish between sand and silt. Material of 0.06 mm size feels harsh but not gritty when rubbed between the fingers, and the particles are at the limit of visibility with the naked eye. Finer pure silt-sized material feels smooth to the touch. The 'feel' of a fine soil can also be used to make a very approximate distinction between silt and clay. Silt feels slightly gritty when rubbed on the teeth whereas clay feels greasy (this simple test should only be carried out on non-organic samples, for health reasons). A rapid assessment of plasticity usually provides a more reliable means of distinguishing silt from clay (see item (3) below).

(3) Plasticity. As shown in Table 11, clay and silt, both alone and in mixtures with coarser material, may be classified for descriptive purposes into three groups, viz non-plastic or low plasticity (generally silts), intermediate plasticity (lean clays), and high plasticity (fat clays). For rapid description in the field or in the laboratory, these classes may be estimated on the basis of visual identification and hand tests, which are summarised in Table 11 and are discussed in more detail below. A more accurate description of plasticity can also be made on the basis of laboratory determination of the liquid limit (BSI, 1975) and the extended classification scale given in Table 17.

The rapid method is based on the general assessment of cohesion and plasticity in coarse soils which contain a significant fine fraction. In fine soils, the method is based on the assessment of dry strength, toughness and dilatancy.

In order to examine coarse soils for cohesion and plasticity, a sample should first be loosened if necessary, for example by crushing with the foot or a hammer. A handful of the material should then be moulded and pressed together in the hands. It may be necessary to add water and to pick out the larger pieces of gravel. A soil shows cohesion when, at a suitable moisture content, its particles stick together to give a relatively firm mass. A soil shows plasticity when, at a suitable moisture content, it can be deformed without rupture, i.e. without losing cohesion. A firm cohesive piece of soil which deforms readily without rupture will generally contain a significant proportion of clay. Conversely, a soil which loses cohesion quickly and crumbles quickly when deformed will tend to have a high proportion of silt in the fine fraction.

Notes on dry strength of silts and clays are included in Table 11. 'Toughness' of a fine soil refers to the character of a thread of moist soil rolled on the palm of the hand, moulded together, and rolled again until it has dried sufficiently to break at a diameter of about 3 mm, as in the plastic limit

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test (BSI, 1975). In this condition, inorganic clays of high plasticity are fairly stiff and tough, those of low plasticity are softer and more crumbly. Inorganic silts give a weak and often soft thread that breaks up, crumbles readily, and may be difficult to form.

In the dilatancy test, a small piece of soil moistened to be soft, but not sticky, is held on the open horizontal palm of the hand. The side of the hand is then jarred against the other hand several times. Dilatancy is shown by the appearance of a shiny film of water on the surface of the soil; when the soil is squeezed or pressed with the fingers, the surface dulls as the soil stiffens and finally crumbles. These reactions are marked only for predominantly silt-sized material and very fine sand, and will generally indicate the presence of these materials.

Further useful guidance on the rapid description of plasticity with reference to dry strength, toughness and dilatancy is given by ASTM (1985a).

In organic soils, small quantities of dispersed organic matter can produce a distinctive odour and a dark grey, dark brown or dark bluish grey colour. With larger quantities of organic matter, fine soils usually have high, very high or extremely high liquid limits, sometimes extending up to several hundred per cent, but these values may drop significantly if the soil is air-dried. Close to the plastic limit, organic soils and peat have a very weak, spongy or fibrous thread, which may be difficult to form at all, and their lumps crumble readily.

3.3.5 Additional Information

Any additional information on the strength, colour, composition, grading and plasticity of the soil that would be of value in assessing its nature and engineering properties should be recorded. Special note should be made if any of the descriptive characteristics of the material are considered to be unusual in relation to the rest of its description. It should be indicated if there is doubt as to whether the sample described is representative of the material from which it was sampled, due, for instance, to the fracture of particles or loss of fines during sampling, or to the sample size or borehole diameter being too small in relation to the grading of the material being sampled. Some information should also be given on the degree of disturbance of the sample if this is considered to be important (e.g. in relation to description of strength and colour).

3.4 MASS CHARACTERISTICS OF SOILS

3.4.1 Structure

The important types of structure in soils are bedding in superficial deposits, and relict rock structures (see Plate 5) and discontinuities in soils derived from insitu rock weathering.

General characteristics that should be considered in the description of bedding include the type of bedding, arrangement of the beds, and the spacing between bedding planes. Other characteristics that are relevant specifically to individual bedding planes, such as orientation, surface texture, openness, etc, are considered in Section 3.4.2.

Common types of bedding are illustrated in Figure 7 and are defined in

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the Glossary. In Hong Kong soils, the occurrence of bedding is usually limited to alluvial and marine deposits.

The arrangement of beds may be described by reference to the degree of stratification and the spacing of the strata. 'Interstratified' deposits are those in which there are layers of different types of material, which may be of constant thickness, or may thin out locally or occur as lenses. If beds of alternating soil types are too thin to be described individually, the soil may be described as 'interbedded' (e.g. 'SAND with interbedded CLAY'), the first soil type mentioned being dominant; or as 'interlaminated' (e.g. 'thinly interlaminated SILT and CLAY'). 'Partings' are bedding surfaces that separate easily, e.g. a thin layer of silt in more cohesive material. The nature of any parting material should be noted. Where two or more soil types are present in a deposit, arranged in an irregular manner, the soils may be described as 'intermixed' (e.g. 'SAND intermixed with CLAY'). Thick beds which consist essentially of one soil type and show no significant variation in material can be described as 'homogeneous'.

Apart from variation in basic soil types, bedding features can also be identified by other sedimentary structures, such as shell bands and root holes. Knowledge of shell types and density within a bed may assist in stratigraphic correlations. Dominant shell types should be noted (by correct scientific name), sketched or photographed (Strange & Shaw, 1986; Wang & Yim, 1985; Whiteside, 1983).

Multiple sequences of deposition involving combinations of marine and alluvial soils have been identified in Hong Kong (Liu & Gammon, 1983; Yim, 1983). Abrupt changes in bedding characteristics may occur in such sequences. Further general information on bedding characteristics and the depositional environment of local alluvial and marine soils is given by Dutton (1984), Holt (1962) and Lumb (1977).

Two other general structural terms commonly applied to sedimentary soils are 'fissured', if the soil is cracked or fragmented, and 'intact' if no fissures are present. Fissures are most common in fine-grained marine and alluvial soils, particularly where these soils have been exposed to air drying. Organic soils are commonly described as 'fibrous' or 'amorphous' (Table 11).

The spacing of bedding planes, fissures, shell bands and other sedimentary structures should be described using the terms given for planar structures and discontinuities in Tables 6 and 7, as summarised in Table 11.

Apart from sedimentary soils, planar structures may also be visible in soils derived from insitu rock weathering. They should be described in accordance with the terms defined in Section 2.4.2 and Table 6.

3.4.2 Discontinuities

As discussed for rocks in Section 2.4.1, detailed description of soil structure (in its broadest sense) should include a full account of <u>individual</u> discontinuities, in addition to the <u>general</u> description of planar structures outlined in the previous section. The discussion in Section 2.4.1 of the variable use of the term 'structure' for rock descriptions applies equally well to soils.

Soil discontinuities are individual bedding planes, lamination planes and

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fissures in transported soils, and relict joints in soils derived from insitu rock weathering. Faults and shear planes may also occur in both types of soil but are generally much less common.

If a full description of discontinuities in a soil mass is required, the same procedures and terms given for rock discontinuity description in Section 2.4.3 should be used. However, with regard to strength, deformation, permeability and other engineering characteristics, the influence of discontinuities on mass behaviour is generally much less marked in a soil mass than in a rock mass. Therefore, a full description of soil discontinuities may only be required in particular circumstances (e.g. discontinuities which control slope stability).

Further information on the description and engineering assessment of discontinuities in some Hong Kong soils is given by Harris (1985), Hunt (1982) and Koo (1982a, 1982b).

3.4.3 State of Weathering

A clear distinction must be made between the weathering of superficial deposits (i.e. transported soils) and the weathering of rocks insitu which has led to the formation of engineering soils (see Sections 2.2.4 and 2.3.4). Description of soils derived from insitu rock weathering is considered further in Section 3.5. This section is concerned only with the description of weathering in transported soils.

It is highly likely that the transported soils in Hong Kong are generally much younger than the soils derived from insitu rock weathering (Bennett, 1984a). Also, the transported soils, unlike the igneous and pyroclastic rocks, have not formed under conditions of high temperature and pressure, which means that their susceptibility to weathering processes in general is much lower. Therefore, the degree and extent of weathering in the transported soils is generally much less marked than in the thick zones of intensely weathered rock found over much of the Territory. Nevertheless, the changes brought about by weathering can still have a significant effect on the engineering properties of transported soils.

The occurrence of weathered transported soils in Hong Kong is generally limited to the older colluvial and alluvial deposits. Most of the marine deposits show no obvious signs of weathering, but some weathered marine soils can be found in areas where they have been exposed previously during periods of lower sea-level.

In fine soils, where individual mineral and rock fragments cannot be identified by eye, the most distinctive aspect of weathering is discolouration caused by decomposition of the soil particles and precipitation of various oxides. Discolouration is most noticeable in alluvial sediments. A non-uniform colour distribution (Table 3), often comprising mottled yellow, red and brown colours, can be a distinctive feature in these soils (Shaw et al, 1986; Willis & Shirlaw, 1983). In offshore sedimentary sequences, there is often a marked contrast between mottled, weathered alluvial sediments and the overlying unweathered marine muds (Plate 9).

In coarse soils, or composite soils containing coarse fragments, the weathered state of individual gravel and larger-sized rock fragments can also be described, in addition to discolouration of the whole soil. Since these

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fragments are pieces of rock material, the terms and methods given in Section 2.3.4 can be used to describe their weathered state. Common weathering features are decomposition of individual mineral grains or whole rock fragments, and cracking or disintegration, which may show up as concentric layering approximately parallel to the fragment boundary. Further guidance on weathering description in colluvium is given in Section 3.6.

Weathering features in soils may be destroyed by sample disturbance or remoulding. These features should therefore be described in the field whenever possible; alternatively, the highest-quality undisturbed sample should be used.

3.4.4 Additional Information

Because of sample disturbance or inadequate sample size, it is often difficult to make a full description of the mass characteristics of soils. Even in a field exposure, very careful and detailed inspection may be necessary for accurate identification of structural features. Additional information should be added to the description if the sample is not considered to be representative of the soil mass, or if it shows signs of significant disturbance.

One other group of features which should always be described if present in the soil is voids. The most important types of void are pipes and tunnels caused by subsurface erosion (Nash & Dale, 1983), but other features such as animal burrows and root holes should also be noted if they are likely to have a significant effect on the mass properties of the soil. Soil pipes have been recorded in Hong Kong in both colluvium and soils derived from weathered rocks. In some cases they have been observed within landslide scars (Nash & Chang, 1987), and have therefore been considered as a possible cause of slope instability. The geometry and seepage aspects of voids should be recorded where possible.

The recommendations in Sections 3.4.1 and 3.4.2 do not cover the description of soil microstructure. This can be important for engineering purposes, e.g. soils with pronounced small-scale fabrics, such as very thin laminations in marine clays, microfractures through and around mineral grains in soils derived from insitu rock weathering, etc. Partial assessment of these features by eye may be possible, depending on their spacing and continuity, but, if the soil microfabric is of particular importance to the engineering project, the use of a microscope is recommended. A general introduction to the study of soil microfabric, using optical microscopy, electron microscopy and X-ray diffraction techniques, is given by Tovey (1986b). Further information on microfabric description in granitic soils, and its relationship to engineering properties, is given by Baynes & Dearman (1978a, 1978b). At a slightly larger scale, McGown et al (1980) provide useful guidance on the classification and description of fabric features visible to the naked eye or under a hand lens in sediments.

3.5 SOILS DERIVED FROM INSITU ROCK WEATHERING

Soils derived from insitu rock weathering occur over much of Hong Kong, both on land and offshore. Assessment of the engineering behaviour of these soils is of great importance for many aspects of the design and construction of site formations and foundations. The starting point for such assessments is a good engineering description.

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These soils can be divided into two main types, viz :

(a) soils that retain the original texture, fabric and structure of the parent rock, also known as 'saprolites', and

(b) soils in which the rock texture/fabric/structure has been destroyed, properly described as 'residual soils'.

Both these soils are shown in the context of weathering of the parent rock in Tables 4 and 10. At the material scale, the first of these soil types (saprolite) corresponds to completely decomposed rock (grade V) in Table 4, but may also include less decomposed intensely disintegrated material (e.g. grade IV) that can be completely broken down to a soil. The second type is the grade VI residual soil.

At the mass scale, saprolite forms the non-rock material in the partially weathered (PW90/100 to PW0/30) rock mass zones in Table 10. The second soil type (the structureless residual soil) comprises the RS zone in Table 10; this is identical to the residual soil (grade VI) in Table 4 but simply refers to a larger volume of material.

Different approaches are recommended for making full descriptions of these two main soil types.

Saprolites (i.e. soils that retain the rock texture, fabric and structure) are a special case for description, because they can be described either in rock (see Chapter 2) or soil (see Chapter 3) terms, or both. The recommended scheme is to use the rock terms given in Chapter 2, together with the soil strength (see Section 3.3.1) and soil name (see Section 3.3.4) applicable to the remoulded condition added in brackets. For example, the description of a hand sample might be 'extremely weak, dry, light yellowish brown, equigranular, completely decomposed, coarse-grained GRANITE (dense, slightly silty gravelly SAND)'. The exception to this recommendation comes when there is doubt about the origin of the soil, e.g. a very small sample might not contain sufficient evidence of original rock texture for the origin to be determined. In such cases, the sample should be described by means of the soil terms given in Chapter 3, followed by an interpretation of the parent rock and weathered state in brackets, e.g. 'stiff, moist, greyish brown, slightly gravelly sandy SILT/CLAY (completely decomposed coarse ash TUFF?)'. At the mass scale, a full description of a saprolite should include a detailed description of discontinuities such as relict joints (see Section 2.4.3).

Full descriptions of residual, structureless soils should be made by means of the soil terms defined in Sections 3.2 and 3.3. If there is sufficient field evidence in the weathering profile to identify the parent rock from which the residual soil has formed, this should be added in brackets, e.g. 'firm, dry, brown, slightly sandy SILT/CLAY (Residual soil derived from fine ash TUFF)'. Residual soils may be difficult to distinguish from other soils such as colluvium and fill. This is considered in Section 3.6.

True residual soils are rarely developed to any significant thickness in Hong Kong (usually less than 3 m). Generally, they are much less important to engineering than the saprolites.

Further information on the nature, description and engineering properties of Hong Kong soils derived from insitu rock weathering is given by Bennett (1984a), GCO (1982), Hencher & Martin (1982), Lumb (1965) and Ruxton &

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Berry (1957). Some illustrated examples of complete descriptions are given in Section 3.9.

3.6 COLLUVIUM

Colluvial soils or 'mass wasting deposits' (see Appendix A.6.2) are formed by earth materials slipping, flowing or rolling down slopes under the action of gravity. Typical colluvial deposits in Hong Kong are structureless mixed accumulations of soil and rock fragments deposited on and at the base of natural slopes. The younger colluvium is often loose, whereas some of the older colluvium may be partially or wholly cemented. The deposits often have a distinctive lobe- or fan-shaped surface form and may be interlayered with alluvial fan deposits formed by the action of running water. Colluvium is widely distributed throughout the hilly terrain of Hong Kong. It occurs mostly in the form of scattered, relatively small accumulations on the lower parts of the steep major slopes. The maximum thickness of colluvium recorded in Hong Kong is about 35 m, but this is exceptional; most colluvium deposits are less than 10 m thick.

Detailed field studies of the locations, shapes and compositions of colluvial deposits by the Hong Kong Geological Survey has enabled a classification of the deposits to be made according to their mode of formation by different mass movement processes. On the 1:20 000 HKGS Maps (e.g. GCO, 1986a), mass wasting deposits are subdivided into debris flow deposits, talus (rockfall) deposits, mixed debris flow and talus deposits, and slide deposits. Further information on the nature of the material in each of these classes is given by Addison (1986) and Bennett (1984a).

For routine purposes, the description of colluvium should follow the recommendations given in Sections 3.2 to 3.4. Since most colluvial deposits contain very coarse (cobble- and boulder-size) fragments, the discussion of composite soils in Section 3.3.4 (2) and Table 16 is of particular relevance for description. Although colluvial deposits are usually described as 'structureless', Ruxton (1984) suggested that a variety of structures exist in the colluvium in the Mid-levels area of Hong Kong Island. If present, structural types can only be identified and described adequately in large exposures.

Use of the procedures and terms in Sections 3.3 and 3.4 should give a satisfactory basic description. However, if the colluvium is of particular importance to the engineering project, it is recommended that the following additional aspects should be described :

(a) the proportion of very coarse fragments (cobbles and boulders) to the nearest 10%,

(b) any preferential distribution of the very coarse fragments,

(c) the angularity, strength and decomposition grade of the very coarse fragments, using the terms given in Table 14, Section 2.3.1 and Section 2.3.4, and

(d) the thickness of any clearly identifiable weathering rinds developed on the very coarse fragments (measured in mm), together with any other notable features of this rind (e.g. colour, decomposition grade, degree of

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fracturing) relative to the remainder of the cobble or boulder.

The importance of these additional observations has been demonstrated by detailed investigations carried out in the Mid-levels area of Hong Kong. These investigations have indicated that three separate classes of colluvium may be recognized on the basis of the colour and stiffness of the matrix, the ratio of very coarse fragments to matrix material, and the degree of decomposition of the very coarse fragments (GCO, 1982; Lai & Taylor, 1983). These classes probably reflect different ages of deposition. Where different classes can be observed clearly in the field, it is useful to note this in the description. Recognition of different classes may assist in interpreting the geological structure of a site, and in assessing laboratory test results on matrix materials.

Colluvium may be difficult to distinguish from other types of soil, particularly soils derived from insitu rock weathering and fill. Distinctive features that can help to distinguish between these soil types are shown in Table 18. One particular problem that is often encountered in the description of drillcore and small excavations (e.g. trial pits) is the definition of the boundary between the base of the colluvium and the underlying decomposed rock. The two most reliable distinguishing characteristics are usually a change in colour and the absence of small-scale rock texture in the colluvial matrix material. Examples are shown in Plate 10.

An example of the description of colluvium is given in Section 3.9.

3.7 FILL

Fill or 'made ground' is a very common type of soil found in the developed areas of Hong Kong. The extent and thickness of fill soils vary widely, ranging from relatively small fill platforms used for building developments on steep slopes, to large areas of coastal reclamation. Characteristics of fills such as colour, compactness/consistency and grain size can vary over a very wide range, dependent mainly on the origin of the material, and the methods of placement and compaction.

Good engineering descriptions are of great importance in fill materials, which may be difficult to sample and test satisfactorily if they are heterogeneous, or if they contain large fragments of 'foreign' materials.

The description of fill should follow the recommendations given in Sections 3.2 to 3.4. However, this type of routine description should be accompanied by additional information, where considered relevant to the engineering project, on the following aspects :

(a) origin of the fill material, whether natural earth material or otherwise (e.g. domestic refuse, pulverized fuel ash, etc),

(b) presence of large 'foreign' objects, such as pieces of concrete, masonry, brick, wood, metal or plastic,

(c) presence of voids or collapsible hollow objects,

(d) presence of chemical waste, particularly if it appears to contain dangerous or poisonous substances,

(e) organic matter content and any strong smell,

(f) striking colours, and

(g) dates readable on buried newspapers, etc.

With regard to item (a) in this list, information about the origin of the fill is often useful in major earthworks, e.g. in the assessment of laboratory test results and field measurements of compaction performance.

Concerning the structure of the soil (see Section 3.4.1), it is important to describe any layering that may be present. On slopes, layering approximately parallel to the original slope surface indicates that the fill has probably been end-tipped and is likely to be in a loose condition. The boundaries between different fill layers, or between fill and the underlying natural soil, are often marked by abrupt changes in root content of the soil and the presence of older, buried topsoils rich in organic matter.

Fill that does not contain obvious inclusions of foreign materials may be difficult to distinguish from other types of soil. The penultimate paragraph of Section 3.6 and Table 18 should be noted.

An example of the description of fill is given in Section 3.9.

3.8 ADDITIONAL GEOLOGICAL INFORMATION

Once the material and mass characteristics have been described, the final item in a complete soil description should be a geological name which indicates the geological origin or soil type. Many of the appropriate names are shown in the legends on the geological maps produced by the HKGS. The name should be written with capital initial letters (e.g. Alluvium, Fill, Marine mud, Colluvium). As a general rule, a geological name should only be added to a description where the origin of the material is reasonably certain; conjecture should be avoided. However, if the observer wishes to record doubtful interpretation, an acceptable alternative is to indicate the uncertainty by use of a suitable qualifying term or a question mark (e.g. 'probably Colluvium', 'Residual soil?')

3.9 EXAMPLES

Seven different soils are illustrated in Plate 11. The first four are hand samples and the last three are mass exposures. The full descriptions of these soils are listed below for guidance in the use of appropriate terms.

(a) Plate 11A. (Residual Soil). Loose, dry, yellowish brown, with occasional rounded quartz grains 2 to 4 mm size, silty gravelly SAND (Residual soil, from field evidence probably derived from coarse ash or lapilli TUFF). Slakes readily in water.

(b) Plate 11B. (Completely Decomposed Granite). Extremely weak, dry, light yellowish brown spotted with grey, dark brown and white, completely decomposed, medium-

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grained GRANITE, with occasional, discontinuous, randomly-oriented microfractures, of average spacing 2 to 5 mm, visible in several small areas (< 50 mm^2) on surface of sample, generally separating intact feldspar grains from surrounding matrix. One prominent microfracture, aperture 1 mm, length 20 mm, crosses centre of sample. Slakes readily in water. Hand penetrometer shear strength index 180 kPa. (Loose, slightly silty/clayey, gravelly SAND). (Note : material is described as a decomposed rock, except for the compactness and particle size distribution applicable to the remoulded condition, which are added in parentheses).

(c) Plate 11C. (Marine Mud). Stiff, moist, dark brownish grey, slightly sandy SILT/CLAY (Marine mud). Shear vane strength index 120 kPa. Contains occasional small fragments of white shells.

(d) Plate 11D. (Marine Sand). Loose, moist, light brown, slightly gravelly fine to coarse SAND (Marine sand). Contains some angular and subangular shell fragments and whole shells up to 30 mm in length. SPT N value of 8 recorded in borehole A1 at the level of this sample.

(e) Plate 11E. (Colluvium). For descriptive purposes, the colluvial deposit is divided (top downwards) into three layers, mainly on the basis of differing size and proportion of the very coarse fragments and degree of cementation of the matrix. Layer 1 is about 2 m thick and forms approximately the upper half of the deposit. Layers 2 and 3 are both about 1 m thick.

(i) Layer 1. Dense, dry, yellowish brown (large cobbles and boulders are light grey), bouldery COBBLES with much finer material (slightly gravelly, sandy silt/clay). (Colluvium). Very coarse fraction comprises mostly angular and subangular cobbles of very strong to moderately strong, slightly to moderately decomposed, fine ash tuff; also contains some angular and subangular boulders up to 0.8 m diameter and several detached, partly fragmented blocks of rock (fine ash tuff) up to 1.2 m diameter showing closely-spaced joints. The finer material is partially cemented; removed easily by hammer but crumbled by hand only with difficulty.

(ii) Layer 2. Very stiff, dry, yellowish brown, slightly gravelly, sandy SILT/CLAY with many (approximately 30%) subangular to subrounded cobbles and small boulders of strong to moderately strong, moderately decomposed, fine ash tuff (Colluvium). The matrix is partially cemented (as in layer 1).

(iii) Layer 3. Very stiff, moist, dark brown (boulders are light grey), slightly sandy gravelly SILT/CLAY with many (approximately 40%) subangular to subrounded cobbles and occasional rounded boulders of very strong to moderately strong, slightly to moderately decomposed, fine ash tuff (Colluvium). The matrix is wholly cemented; requires firm blows of hammer to remove and cannot be crumbled completely by hand.

Based on the degree of cementation of the matrix, layers 1 and 2 are probably much younger than layer 3.

(f) Plate 11F. (Alluvium). This small exposure is described as an interbedded deposit because the scale of the individual layers is too small to warrant a separate description for each layer.

Loose, moist, light brown, slightly silty/clayey, gravelly SAND with interbedded soft, moist, greyish brown, slightly sandy SILT/CLAY (Alluvium). Thickness of sand beds in the range 80 to 200 mm ; clay beds 20 to 60 mm. Interbed boundaries generally planar and sub-horizontal, occasionally highly irregular and show slump structure. Some sand beds have a thickly-laminated structure, others are homogeneous; clay beds are thinly-laminated.

(g) Plate 11G. (Fill). Four distinct layers are visible in the trial pit and are described from the top downwards. The third, dark-coloured layer is much thinner than the other three layers.

(i) Layer 1. Soft, dry, light yellowish brown, sandy SILT/CLAY with many angular cobbles and small boulders of moderately strong to moderately weak, moderately to highly decomposed, ash tuff and occasional pieces of brick (Fill). Boulders concentrated at the base of the layer with occasional discontinuous voids up to 100 mm diameter. Roots up to 5 mm diameter are scattered throughout the layer.

(ii) Layer 2. Soft, moist, brownish red, slightly sandy SILT/CLAY with some rootlets and small angular cobbles of moderately strong to moderately weak, moderately to highly decomposed, ash tuff (Fill).

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(iii) Layer 3. Soft to firm, wet, dark greyish brown, slightly gravelly sandy SILT/CLAY (Fill).

(iv) Layer 4. Firm, wet, brown, slightly sandy SILT/CLAY with occasional small subangular cobbles of moderately weak, highly decomposed, ash tuff (Fill).

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4. ENGINEERING CLASSIFICATIONS OF ROCKS AND SOILS

4.1 GENERAL

A complete rock or soil description gives information on the characteristics of a specific sample, whether this is a hand-sized piece of material, a length of drillcore or a mass exposure. Few samples have identical descriptions. Engineering classification, on the other hand, involves placing the rock or soil into a limited number of broad groups, each of which can be expected to show reasonably distinctive engineering behaviour. It is emphasised that classification in this sense refers to the overall grouping of rocks or soils with regard to general engineering behaviour. It should be distinguished from the HKGS geological classification of rocks and superficial deposits (Table 5, see also Appendix A) and from specific classifications of individual characteristics, such as the classification of rock material strength (Table 2) or decomposition grade (Table 4).

The main value of broad engineering classifications is to give a simple general guide to the behaviour of the rock or soil during construction. Because of the emphasis on construction aspects, these classifications are usually established mainly with reference to mass behaviour. There are various methods of classifying the mechanical behaviour of rock masses. These are considered in Section 4.2. For soils, engineering classifications based on grading and plasticity can give a good guide as to how the remoulded soil will behave when used as a construction material. This is considered in Section 4.3.

Engineering classifications of rocks and soils have not been applied extensively in Hong Kong. The text in the next two sections is therefore deliberately short. The aim is to provide brief general guidance, and to quote key references and examples that can be followed up in greater detail if required.

4.2 GEOMECHANICAL CLASSIFICATION OF ROCK MASSES

Geomechanical classifications of rock masses are based on combining several characteristics of the rock mass and rock material into groups which can be used to assess the overall engineering behaviour of the rock mass. A general introduction to this topic is given by Bieniawski (1976).

The best-known examples of these classifications come from the field of tunnelling and underground excavations, in particular the Norwegian (NGI) system (Barton et al, 1974) and the South African (CSIR) Rock Mass Rating system (Bieniawski, 1974). These systems were set up by combining such characteristics as drillcore quality (RQD), compressive strength of rock material, spacing and condition of discontinuities, and groundwater conditions, to give an overall rating or rock mass quality in relation to the requirements for tunnel support. For example, the CSIR system has five rock mass classes ranging from very good rock to very poor rock.

Other well-known classification schemes are the fracture spacing/point load strength classification charts used to assess rippability or ease of excavation (Franklin et al, 1971), and the empirical strength criteria developed by Hoek & Brown (1980) for a rock mass classification based on rock type, joint spacing and degree of joint weathering. Rock mass weathering zones

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(see Section 2.4.4.), when used in conjunction with other mass and material properties (e.g. discontinuities and strength), can also form the basis of a rock mass engineering classification. For example, Dearman et al (1978) used the BSI (1981) mass weathering scheme to make a six-fold classification of weathered granites and gneisses from the point of view of ease of excavation, tunnel support, foundation suitability, drilling rates and other factors. A useful summary of seven different rock mass classifications developed for various engineering works in Japan has been compiled by the Japan Society of Engineering Geology (1987).

In Hong Kong, rock mass classifications have been applied to a limited extent in the field of tunnelling and large rock excavations. McFeat-Smith et al (1985) used a simple five-fold classification based on mass weathering and joint spacing for the assessment of temporary tunnel support and for contractual tendering and payment purposes. Beggs & McNicholl (1986) examined the use of a simplified CSIR system during the investigation and design stage of large rock excavations for housing development at Ap Lei Chau, Hong Kong Island. Six-fold weathering-based classifications were used by Watkins (1979) for construction-stage mapping of foundations and tunnels for the High Island water scheme, and by Powell & Irfan (1986) for preliminary assessment of failure modes and design of remedial measures at three landslide sites. Whiteside & Bracegirdle (1984) developed a five-fold classification, similar to the NGI system, for assessing rock mass looseness and the requirements for underground support in small excavations in several different Hong Kong rocks.

The Hoek & Brown (1980) rock mass strength classification has also been applied in Hong Kong in several cases of slope stability design in disturbed, closely jointed volcanic rocks (unpublished work by the GCO). Hoek (1983, 1986) has commented on the practical application of this approach to mass strength assessment.

4.3 SOIL CLASSIFICATION FOR ENGINEERING PURPOSES

The aim of most engineering soil classifications is to place a soil into a limited number of groups on the basis of the grading and plasticity of a disturbed sample. These characteristics are independent of the particular condition in which a soil occurs, and they disregard the influence of the structure of the soil mass. Therefore, the value of this type of classification is that it gives a guide as to how the disturbed soil will behave, at different moisture contents, when used as a construction material. It does not provide any guidance as to how the undisturbed soil mass will perform during construction (e.g. in relation to settlement under foundation loading or stability of excavation faces).

A well-known example of a soil classification system is the British Soil Classification System (BSCS), which is described by BSI (1981). This system, slightly modified in accordance with Table 15, is summarised in Tables 19 and 20, and in Figure 8. The principal soil groups are the same as those shown in Table 11, but the subgroups are divided further on the basis of laboratory tests.

This classification is carried out on material nominally finer than 60 mm. Coarser material (boulders and cobbles) should be removed and its proportion of the whole soil should be estimated and recorded as 'cobbles' and/or 'boulders' (see Section 3.3.4(2)). The grading of the gravel and finer material, and the plasticity of that fraction of the material passing a 425 μm sieve, is then determined from laboratory tests.

Grading and plasticity characteristics are divided into a number of clearly defined ranges, each of which may be referred to by a descriptive name and a descriptive letter, as shown in Table 19. The soil groups in the classification are formed from combinations of the ranges of characteristics. Table 20 gives the names of the groups and the symbols that should be used. The letter describing the dominant size fraction should be placed first in the symbol (e.g. CS, sandy CLAY; SC, very clayey SAND; S-C, clayey SAND). Any group may be qualified as 'organic' if organic matter is a significant constituent, in which case the letter 'O' is suffixed to the group symbol (e.g. CHO, organic CLAY of high plasticity; CHSO, organic sandy CLAY of high plasticity). However, the most important group of organic soils is that which plots below the A-line, MO (Figure 8), and which comprises most M-soils of high liquid limit and above.

Particle size distribution can be plotted on a grading chart, as shown in Figure 9. This assists in designating the soils as 'well-graded' or 'poorly-graded', and, if poorly-graded, whether 'uniform' or 'gap-graded'. Typical examples of the grading curves of these and other materials are shown in Figure 9. Many Hong Kong soils, particularly colluvium and soils derived from insitu weathering of coarse-grained igneous rocks, are characterised by a very wide range of grain sizes from gravel to clay (excluding very coarse material) and can be described as 'widely-graded' (Figure 9).

Soil classification systems have not been widely used in Hong Kong, but they may have application in projects involving major earthfilling works or the use of natural or screened soils as road construction materials. However, caution is needed in the use of these systems for soils derived from insitu rock weathering.

The grading and plasticity characteristics of saprolites and residual soils may be affected by pretreatment methods or variations in moisture content (e.g. whether tested in an air-dried or natural condition). BS 1377 (BSI, 1975) draws attention to the difficulty of testing "certain tropical soils" and "highly aggregated soils", with regard to the use of dispersing agents and pretreatment methods in grading tests, and air-dried or natural moisture condition samples in Atterberg limit tests. However, no explicit recommendations are given in BS 1377 for dealing with these problematical soils. Very little work has been done on this topic in Hong Kong. Useful background information and data for saprolites and residual soils in other parts of the world are given by Mitchell & Sitar (1982) and the Committee on Tropical Soils of the ISSMFE (1985). In addition to normal grading and plasticity tests, dispersion tests (ASTM, 1985b; Decker & Dunnigan, 1977; Flanagan & Holmgren, 1977; Sherard et al, 1976; Standards Association of Australia, 1980, 1984) may prove useful in the interpretation of the likely engineering behaviour of these soils. It is recommended that the use of any pretreatment methods or dispersants for grading and plasticity tests should always be recorded in full on laboratory test results sheets and in reports.

Apart from the general difficulties which may be met in the classification of soils derived from weathered rocks, the use of the BSCS in particular has been criticised when applied to coarse-grained granitic soils. The distinction between coarse and fine soils in the BSCS (i.e. 35% passing a 63 μm sieve), means that a significant proportion of decomposed granitic soils would be classified as fine soil, according to the average gradings given by Lumb

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(1962). Granitic soils tend to be regarded as coarse soils in current Hong Kong practice as far as their general engineering behaviour is concerned. Therefore, other classification systems, such as the American UCS system (ASTM, 1985c), may be more appropriate for this type of soil.

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5. LEGEND FOR MAPS, PLANS AND DIAGRAMS

5.1 SYMBOLS FOR ROCKS AND SOILS

Recommended symbols are listed in Table 21 for the principal rock and soil types that are likely to be encountered in Hong Kong. The symbols are simple and distinctive, and they combine easily into symbols for composite types of rocks and soils. The symbols are based upon those given by the Geological Society (1972), with some alterations; additional symbols are also given in the same publication.

5.2 OTHER SYMBOLS

5.2.1 Symbols for Borehole Records

Recommended symbols for borehole records are given in Table 22. Examples of completed borehole logs are given in Geoguide 2 : Guide to Site Investigation (GCO, 1987a).

5.2.2 Symbols for Geological Structures and Boundaries

Recommended symbols for general planar structures are given in Table 23. For each structural type, the long bar of the symbol indicates the strike direction, and the short bar indicates the dip amount in degrees measured from the horizontal. Formerly, the dip arrow was used exclusively to indicate the direction and amount of dip of bedding planes. It is still used occasionally and provides an acceptable alternative to the bar symbol.

Bedding, foliation, banding and cleavage in sedimentary and metamorphic rocks may be corrugated or undulating, although the general disposition may be horizontal, inclined or vertical. These conditions may be indicated by sinuous strike bars.

Recommended symbols for other geological structures and geological boundaries are given in Table 24. A distinction is made on the Hong Kong Geological Survey maps between boundaries of superficial deposits and boundaries of solid rock. Some indication is usually given of the accuracy of boundaries, broken lines denoting uncertainty in the positions of solid rock boundaries and faults. This principle may be applied to the trend and, where appropriate, to the position of the traces of other planar structures.

On large-scale engineering geological plans, faults and fault zones do not call for distinctive structural symbols. They are usually mapped as zones, of which the margins are plotted and for which the internal structures and filling materials are mapped in detail. The symbol on Table 22 may be used to indicate the margins of the fault, and the same principle may be applied to the details included in the borehole record.

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Table 1 - Guidance on Rock and Soil Description in Different Locations

<table>
<tr><th>Location</th><th colspan="2">Field</th><th colspan="2">Ground Investigation Drilling Rig</th><th colspan="2">Laboratory</th></tr>
<tr><td>Typical Sample</td><td colspan="2">Rock and Soil : Natural or man-made exposure (e.g. trial pit or cutting)</td><td colspan="2">Rock : Core
Soil : Samples from split triple-tube core-barrels, driven samplers and core-barrel cutting shoes, SPT liners</td><td colspan="2">Rock : Pieces of core and irregular hand samples
Soil : Samples from split triple-tube core-barrels, extruded thick/thin-walled samplers, SPT liners, hand-cut blocks, trimmed test specimens</td></tr>
<tr><td>Descriptive Scale</td><td>Material</td><td>Mass</td><td>Material</td><td>Mass</td><td>Material</td><td>Mass</td></tr>
<tr><td rowspan="2">Items for Rock Description</td><td>Strength
Colour
Texture/Fabric
Weathered State
Alteration State
Rock Name
Additional Information (e.g. results of index tests)</td><td>Structure
Discontinuities (nature, orientation, spacing, persistence, roughness, aperture, infilling, seepage)
Mass Weathering
Additional Information (e.g. representability of mass sample)</td><td rowspan="2">Strength
Colour
Texture/Fabric
Weathered State
Alteration State
Rock Name
Additional Information (e.g. results of index tests)</td><td rowspan="2">[Structure]
Discontinuities (nature, spacing, roughness, aperture, infilling, fracture indices)
Mass Weathering</td><td rowspan="2">Strength
Colour
Texture/Fabric
Weathering State
Alteration State
Rock Name
Additional Information (e.g. mineralogy, results of index tests)</td><td rowspan="2">(Normally not applicable)</td></tr>
<tr><td colspan="2">Additional Geological Information (e.g. geological formation, age)</td></tr>
<tr><td rowspan="2">Items for Soil Description</td><td>Strength
Colour
Particle Shape/ Composition
Soil Name (based on rapid assessment of grading/plasticity)
Additional Information (e.g. results of index tests)</td><td>Structure
Discontinuities (items as in rock description list above)
Weathered State
Additional Information (e.g. presence of voids, seepage not related to discontinuities)</td><td rowspan="2">Strength
Colour
Particle Shape/ Composition
Soil Name (based on rapid assessment of grading/plasticity)
Additional Information (e.g. degree of sample disturbance, results of index tests)</td><td rowspan="2">[Structure]
[Discontinuities] (items as in rock description list above)
Weathered State</td><td rowspan="2">Strength
Colour
Particle Shape/Composition
Soil Name (based on rapid or detailed assessment of grading/ plasticity)
Additional Information (e.g. degree of sample disturbance, mineralogy, results of index tests)</td><td rowspan="2">[Structure]
[Discontinuities] (nature, orientation, spacing, roughness, aperture, infilling)
[Weathered State]</td></tr>
<tr><td colspan="2">Additional Geological Information (e.g. geological origin, type of deposit)</td></tr>
<tr><td>Notes :</td><td colspan="6">(1) Less comprehensive descriptions may also be possible with lower quality samples (e.g. flushings, jar or bulk samples).
(2) Main descriptive items marked in square brackets may often not be applicable, depending on sample size.
(3) For soils derived from insitu rock weathering: if the original rock texture/structure is retained (i.e. saprolites), they should be described in rock terms, supplemented by additional soil terms for compactness/consistency and grading; if the rock texture/structure is completely lost (i.e. residual soils), they should be described in soil terms.
(4) Description of the orientation of discontinuities in drillcore may also be possible, depending on the ground investigation techniques used; see Geoguide 2 (GCO, 1987a).
(5) This table provides general guidance only. For further details on particular descriptive items, refer to the relevant text section.</td></tr>
</table>

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Table 2 - Classification of Rock Material Strength

Descriptive Term	Uniaxial Compressive Strength (MPa)	Approximate Point Load Strength Index Values ($I_s(50)$) for Granitic & Volcanic Rocks (MPa)	Field Identification Tests
Extremely weak	< 0.5		Easily crumbled by hand; indented deeply by thumbnail.
Very weak	0.5 - 1.25	Generally not applicable	Crumbled with difficulty by hand; scratched easily by thumbnail; peeled easily by pocket knife.
Weak	1.25 - 5		May be broken by hand into pieces; scratched by thumbnail; peeled by pocket knife; deep indentations up to 5mm made with point of geological pick; hand-held specimen easily broken by single light blow of geological hammer.
Moderately weak	5 - 12.5	0.2 - 0.5	May be broken with difficulty in two hands; scratched with difficulty by thumbnail; difficult to peel but easily scratched by pocket knife; shallow indentations easily made with point of geological pick; hand-held specimen usually broken by single light blow of geological hammer.
Moderately strong	12.5 - 50	0.5 - 2	Scratched by pocket knife; shallow indentations made by firm blow with point of geological pick; hand-held specimen usually broken by single firm blow of geological hammer.
Strong	50 - 100	2 - 4	Firm blows with point of geological pick cause only superficial surface damage; hand-held specimen requires more than one firm blow to break with geological hammer.
Very strong	100 - 200	4 - 8	Many blows of geological hammer required to break specimen.
Extremely strong	> 200	> 8	Specimen can only be chipped by blows of geological hammer.

Note : The very weak and extremely weak classes are applicable to soils derived from insitu weathering of rocks.

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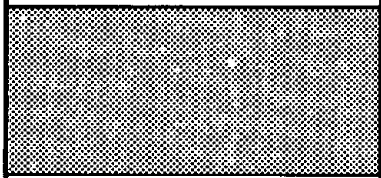
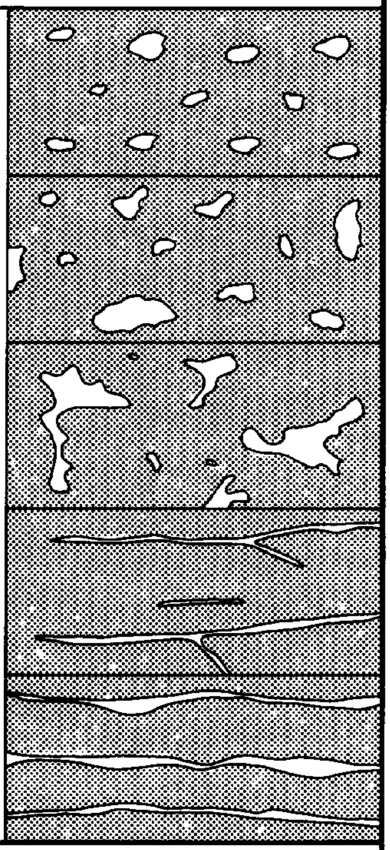
Table 3 - Colour Description Scheme

Value	Chroma	Hue
Light	Pinkish	Pink
Dark	Reddish	Red
	Yellowish	Yellow
	Orangish	Orange
	Brownish	Brown
	Greenish	Green
	Bluish	Blue
	Purplish	Purple
		White
	Greyish	Grey
		Black

Colour Distribution

Uniform	Non-uniform	
	Spotted	
	Mottled	
	Dappled	
	Streaked	
	Striped	

Notes : (1) For uniform colour distribution, choose a hue and then supplement it if necessary with a value and/or chroma.

(2) If the colour distribution is non-uniform, repeat this procedure for the two (or more) components of the distribution, employing the non-uniform descriptor to indicate which component is dominant, e.g. light pinkish grey spotted with black.

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Table 4 - Classification of Rock Material Decomposition Grades

Descriptive Term	Grade Symbol	General Characteristics for Granitic & Volcanic Rocks & Other Rocks of Equivalent Strength in the Fresh State	Additional Typical Characteristics for Specific Rock Types			
			Granite	Granodiorite	Coarse Ash Crystal/Lithic Tuff	Fine Ash Vitric Tuff
Residual Soil	VI	Original rock texture completely destroyed Can be crumbled by hand and finger pressure into constituent grains	Reddish brown Feldspars completely destroyed Quartz is only remaining primary mineral; usually dull, etched or pitted and reduced in size compared with fresh condition	Dark reddish brown Feldspars completely destroyed Quartz only remaining primary mineral; grains reduced in size compared with fresh condition	Brown or reddish brown Quartz only remaining primary mineral	Yellowish brown
Completely Decomposed	V	Original rock texture preserved Can be crumbled by hand and finger pressure into constituent grains Easily indented by point of geological pick Slakes when immersed in water Completely discoloured compared with fresh rock	Yellowish brown to reddish brown Feldspars powdery to soft Hand penetrometer shear strength index < 250 kPa Zero rebound from N Schmidt hammer	Yellowish brown to reddish brown Plagioclase feldspars powdery to soft, very easily grooved by pin Orthoclase feldspars gritty, less easily grooved Zero rebound from N Schmidt hammer	Brown to reddish brown Slakes slowly in water Mafic minerals soft, dull, dark green to brown, difficult to distinguish	Yellowish brown Slakes readily in water
Highly Decomposed	IV	Can be broken by hand into smaller pieces Makes a dull sound when struck by geological hammer Not easily indented by point of geological pick Does not slake when immersed in water Completely discoloured compared with fresh rock	Yellowish brown to yellowish orange/ brown Feldspars powdery Hand penetrometer shear strength index > 250 kPa Positive N Schmidt rebound value < 25	Yellowish brown to yellowish orange/ brown Plagioclase feldspars powdery to gritty N Schmidt rebound value 15 - 30	Yellowish brown Mafic minerals soft, dull, dark green	Yellowish grey Surface can be scratched by knife
Moderately Decomposed	III	Cannot usually be broken by hand; easily broken by geological hammer Makes a dull or slight ringing sound when struck by geological hammer Completely stained throughout	Yellowish brown Feldspars gritty Biotite not shiny N Schmidt rebound value 25 - 45	Yellowish brown Plagioclase feldspars party decomposed to gritty small pieces N Schmidt rebound value 25 - 50	Yellowish grey Mafic minerals generally not shiny, soft, black or stained dark brown	White or light grey Surface cannot be scratched by knife
Slightly Decomposed	II	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer Fresh rock colours generally retained but stained near joint surfaces	Feldspars hard to slightly gritty Orthoclase feldspars often pink Biotite slightly stained and dull around edges N Schmidt rebound value > 45	Plagioclase feldspars slightly gritty Biotite and hornblende slightly stained and dull N Schmidt rebound value 45 - 70	Light grey or greenish grey Mafic minerals shiny, hard, black, may be slightly stained and dull around edges	Grey, light grey or greenish grey Cloudy appearance
Fresh	I	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer No visible signs of decomposition (i.e. no discolouration)	Overall rock colour grey/white Feldspars hard and shiny Biotite shiny, not stained Quartz colourless or grey, glassy	Overall rock colour grey Feldspars hard and shiny Biotite and hornblende shiny; not stained Quartz colourless or grey, glassy N Schmidt rebound value > 60	Overall rock colour ranges from light greenish grey (JSM) to grey (JSM, JYT) Feldspars hard and shiny Mafic minerals shiny, hard, black Quartz colourless or grey, glassy	Overall rock colour black Glassy appearance
General Notes		(1) Not all these general characteristics are applicable to rocks whose strength in the fresh state is moderately strong or less (see Table 2). Alternative classifications may be more appropriate for such materials (see Section 2.3.4). (2) Use of geological hammer applicable mainly to materials confined in a field exposure.	(3) Based on Moye (1955), Hencher & Martin (1982) and unpublished work by the GCO. (4) Assessments of minerals applicable to medium and coarse-grained granite; may be difficult or impossible to assess in fine-grained granites.	(5) Based on Irfan & Powell (1985a,b).	(6) Based on unpublished work by the GCO. (7) JYT = Yim Tin Tsai Formation JSM = Shing Mun Formation (see HKGS maps and memoirs). (8) Mafic minerals referred to are biotite and hornblende.	(9) Based on unpublished work by the GCO.
Notes on Index Tests		(10) Slake test: samples already close to saturation moisture content are less likely to slake. (11) Feldspar alteration test: Hard = cannot be cut by knife or grooved by pin; Gritty = can be cut by knife or grooved by pin with pressure; Powdery = easily grooved by pin, can be crushed to silt fragments in fingers; Soft = easily grooved by pin, can be moulded very easily to clay in fingers. (12) N Schmidt hammer test: rebound values are for hammer held perpendicular to rock face: take initial 'seating' blows to ensure good contact and record average value from a minimum of five consecutive impacts, ignoring unusually low readings. (13) Hand penetrometer test: press instrument head slowly and smoothly into sample, take an average of ten values and divide by two to give shear strength index; test may be impractical on very small samples. (14) Test results in general may be affected by sample moisture content and degree of microfracturing.				

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Table 5 - Classification of Solid Rocks and Superficial Deposits in Hong Kong

Superficial Deposits *		Grain Size (mm)	Solid Rocks * — Sedimentary Rocks: Detrital Rocks	Sedimentary Rocks: Chemical & Biochemical Rocks	Pyroclastic Rocks
	Grain Size Term				
Boulders			Conglomerate / Sedimentary Breccia	Limestone and Dolomite, Evaporites	Pyroclastic Breccia
		200			
Cobbles					
		60			
Gravel	Coarse				Lapilli Tuff
		20			
	Medium				
		6			
	Fine				
		2			
Sand	Coarse		Sandstone		Coarse Ash Tuff
		0.6			
	Medium				
		0.2			
	Fine				
		0.06			
Silt	Mud		Siltstone (Mudstone)		Fine Ash Tuff
		0.002			
Clay	Mud		Claystone (Mudstone)	Chert	

Igneous Rocks

Grain Size Term	Acid (much quartz)	Intermediate (some quartz)	Basic (little or no quartz)
	Pegmatite		
Coarse-grained	Granite, Granodiorite	Quartz Monzonite, Quartz Syenite	Gabbro
Medium-grained	Aplite		✱, Lamprophyre
Fine-grained			✱
	Rhyolite, Rhyodacite, Dacite	Quartz Latite, Quartz Trachyte, Trachyandesite, Andesite	✱ Basalt

Metamorphic Rocks

Foliated	Non-Foliated
Schist	Fault Breccia, Quartzite, Marble
Phyllite / Mylonite	

Legend :

* Engineering soils comprise superficial deposits and any solid rock which has weathered to the condition where it can be broken down by hand into constituent grains

✱ Equivalent to Dolerite in Allen & Stephens (1971)

Note : This table is based on the classification scheme used by the Hong Kong Geological Survey.

Table 6 - Spacing of Planar Structures

Descriptive Term	Spacing
Very thick	> 2m
Thick	600 mm - 2 m
Medium	200 mm - 600 mm
Thin	60 mm - 200 mm
Very thin	20 mm - 60 mm
Thickly-laminated (sedimentary)	6 mm - 20 mm
Narrow (metamorphic and igneous)	
Thinly-laminated (sedimentary)	< 6 mm
Very narrow (metamorphic and igneous)	

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Table 7 - Discontinuity Spacing

Descriptive Term	Spacing
Extremely widely-spaced	> 6 m
Very widely-spaced	2 m - 6 m
Widely-spaced	600 mm - 2 m
Medium-spaced	200 mm - 600 mm
Closely-spaced	60 mm - 200 mm
Very closely-spaced	20 mm - 60 mm
Extremely closely-spaced	< 20 mm

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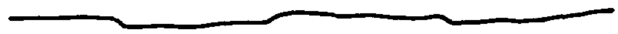
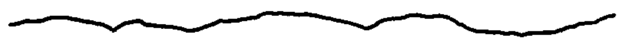
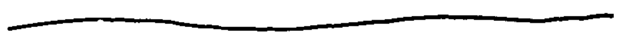
Table 8 - Unevenness (Small-Scale Roughness) of Discontinuities

Class	First Term	Second Term	Illustration
1	Rough	Stepped	
2	Smooth	Stepped	
3	Slickensided	Stepped	
4	Rough	Undulating	
5	Smooth	Undulating	
6	Slickensided	Undulating	
7	Rough	Planar	
8	Smooth	Planar	
9	Slickensided	Planar	

Notes : (1) Length of the illustrated profiles is in the range 1 to 10 metres.
(2) Vertical and horizontal scales are equal.

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Table 9 - Aperture Size

Descriptive Term	Aperture Distance between Discontinuity Walls
Wide	> 200 mm
Moderately wide	60 - 200 mm
Moderately narrow	20 - 60 mm
Narrow	6 - 20 mm
Very narrow	2 - 6 mm
Extremely narrow	> 0 - 2 mm
Tight	Zero

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Table 10 - Classification of Rock Mass Weathering Zones

Zone Description		Zone Symbol	Zone Characteristics
Residual Soil		RS	**Residual soil derived from insitu weathering; mass structure and material texture / fabric completely destroyed : 100 % soil**
Partially Weathered Rock	0/30 % Rock	PW 0/30	**Less than 30 % rock Soil retains original mass structure and material texture / fabric (i. e. saprolite)** Rock content does not affect shear behaviour of mass, but relict discontinuities in soil may do so Rock content may be significant for investigation and construction
Partially Weathered Rock	30/50% Rock	PW 30/50	**30 % to 50 % rock** Both rock content and relict discontinuities may affect shear behaviour of mass
Partially Weathered Rock	50/90% Rock	PW 50/90	**50 % to 90 % rock** Interlocked structure
Partially Weathered Rock	90/100% Rock	PW 90/100	**Greater than 90 % rock** Small amount of the material converted to soil along discontinuities
Unweathered Rock		UW	**100 % rock** May show slight discolouration along discontinuities

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Table 11 - Procedure for Rapid Identification and Description of Soils

Group	Basic Soil Type	Particle Size (mm)	Visual Identification
Very Coarse Soils	BOULDERS	200	Only seen complete in pits or exposures.
Very Coarse Soils	COBBLES	60	Often difficult to recover from boreholes.
Coarse Soils (over 65% sand and gravel sizes)	GRAVELS	Coarse 20	Easily visible to naked eye; particle shape can be described; grading can be described.
		Medium 6	Well-graded: wide range of grain sizes, well distributed. Poorly-graded: not well graded. (May be uniform: size of most particles lies between narrow limits; or gap-graded: an intermediate size of particle is markedly under-represented.)
		Fine 2	
Coarse Soils (over 65% sand and gravel sizes)	SANDS	Coarse 0.6	Visible to naked eye; very little or no cohesion when dry; grading can be described.
		Medium 0.2	Well-graded: wide range of grain sizes. Poorly-graded: not well graded. (May be uniform: size of most particles lies between narrow limits; or gap-graded: an intermediate size of particle is markedly under-represented.)
		Fine 0.06	
Fine Soils (over 35% silt and clay sizes) — MUD	SILTS	Coarse 0.02	Only coarse silt barely visible to naked eye; exhibits little plasticity and marked dilatancy; slightly granular or silky to the touch. Disintegrates in water; lumps dry quickly; possess cohesion but can be powdered easily between fingers.
		Medium 0.006	
		Fine 0.002	
Fine Soils (over 35% silt and clay sizes) — MUD	CLAYS		Dry lumps can be broken but not powdered between fingers; they also disintegrate under water but more slowly than silt; smooth to the touch; exhibits plasticity but no dilatancy; sticks to fingers and dries slowly; shrinks appreciably on drying, usually showing cracks. Intermediate and high plasticity clays show these properties to a moderate and high degree, respectively.
Organic Soils	ORGANIC CLAY, SILT or SAND	Varies	Contains substantial amounts of organic vegetable matter. Often has noticeable smell and changes colour on oxidation.
Organic Soils	PEATS	Varies	Predominantly plant remains; usually dark brown or black in colour, often with distinctive smell; low bulk density.

Particle Shape and Plasticity

Particle Shape	
Form	Equidimensional, Flat, Elongate, Flat and elongate
Angularity	Angular, Subangular, Subrounded, Rounded
Surface Texture	Smooth, Rough, Glassy, Honeycombed, Pitted, Striated

Plasticity	
Silts	Non-plastic or low plasticity
Clays	Intermediate plasticity (Lean clay); High plasticity (Fat clay)

Composite Soil Types (Mixtures of Basic Soil Types)

Scale of Secondary Constituents with Coarse Soils

Term		% of Silt or Clay
Slightly silty / Slightly clayey	GRAVEL or SAND	< 5
- silty / - clayey	GRAVEL or SAND	5 - 15
Very silty / Very clayey	GRAVEL or SAND	15 - 35

Coarse fraction may also be subdivided to give additional secondary constituent where applicable (Table 15).
For composite types described as:
clayey : fines are plastic, cohesive;
silty : fines are non-plastic or of low plasticity

Scale of Secondary Constituents with Fine Soils

Term		% of Gravel or Sand
Slightly gravelly / Slightly sandy	SILT or CLAY	< 35
- gravelly / - sandy	SILT or CLAY	35 - 65

Full explanation of the use of secondary constituents in Composite Soils is given in Tables 15 and 16.

Strength (Compactness & Consistency)

Strength Term	Field Test
Loose	By inspection of voids and particle packing
Dense	By inspection of voids and particle packing
Loose	Can be excavated with spade; 50mm wooden peg can be easily driven.
Dense	Requires pick for excavation; 50mm wooden peg hard to drive.
Very soft	Exudes between fingers when squeezed in hand.
Soft	Moulded by light finger pressure.
Firm	Can be moulded by strong finger pressure.
Stiff	Cannot be moulded by fingers. Can be indented by thumb.
Very stiff	Can be indented by thumb nail.
Compact	Fibres already compressed together.
Spongy	Very compressible and open structure.
Plastic	Can be moulded in hand, and smears fingers.

Structure and Weathering

Structural Term	Field Identification
Homo-geneous	Deposit consists essentially of one type.
Inter-stratified (Interbedded or Inter-laminated)	Alternating layers of varying types or with bands or lenses of other materials. Quantitative scale for bedding spacing may be used.
Hetero-geneous	A mixture of types.
Fissured	Breaks into polyhedral fragments along fissures. Quantitative scale for spacing of discontinuities may be used.
Intact	No fissures.
Homo-geneous	Deposit consists essentially of one type.
Inter-stratified (Interbedded or Inter-laminated)	Alternating layers of varying types. Interval scale for thickness of layers may be used.
Fibrous	Plant remains recognizable and retain some strength.
Amorphous	No recognizable plant remains.

Quantitative Scales

Scale of Bedding Spacing

Term	Mean Spacing (mm)
Very thickly-bedded	> 2000
Thickly-bedded	600 - 2000
Medium-bedded	200 - 600
Thinly-bedded	60 - 200
Very thinly-bedded	20 - 60
Thickly-laminated	6 - 20
Thinly-laminated	< 6

Scale of Spacing of Other Discontinuities

Term	Mean Spacing (mm)
Extremely widely-spaced	> 6000
Very widely-spaced	2000 - 6000
Widely-spaced	600 - 2000
Medium-spaced	200 - 600
Closely-spaced	60 - 200
Very closely-spaced	20 - 60
Extremely closely-spaced	< 20

Discontinuities (General)

For full description of individual discontinuities, use methods and terms given in Section 2.4.3

Weathering

In fine soils : describe discolouration where evident
In coarse soils : describe overall discolouration of soil and degree of decomposition of gravel and larger fragments

Colour

Colour	
Lightness	Light, Dark
Chroma	Pinkish, Reddish, Yellowish, Orangish, Brownish, Greenish, Bluish, Purplish, Greyish
Hue	Pink, Red, Yellow, Orange, Brown, Green, Blue, Purple, White, Grey, Black
Non-uniform Distribution	Spotted, Mottled, Dappled, Streaked, Striped

Select one value of lightness, chroma and hue as required, qualified by a term for non-uniform distribution where appropriate. See Table 3.

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Table 12 - Soil Strength in Terms of Compactness and Consistency

Soil Type	Descriptive Term for Compactness / Relative Density	SPT N Values (Blows / 300mm penetration)
Sands and Gravels	Very loose	0 - 4
	Loose	4 - 10
	Medium dense	10 - 30
	Dense	30 - 50
	Very dense	> 50
Soil Type	**Descriptive Term for Consistency**	**Undrained Shear Strength (kPa)**
Silts and Clays	Very soft	< 20
	Soft	20 - 40
	Firm	40 - 75
	Stiff	75 - 150
	Very stiff or hard	> 150

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Table 13 - Particle Form

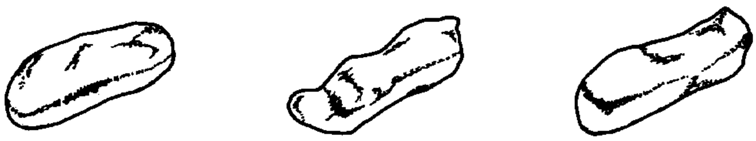
Descriptive Term	Illustration
Equidimensional	
Flat	
Elongate	
Flat and Elongate	

Table 14 - Particle Angularity

Descriptive Term	Illustration
Angular	
Subangular	
Subrounded	
Rounded	

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Table 15 - Use of Secondary Constituents for the Naming of Composite Soils

Principal Soil Type	Terminology Sequence	Term for Secondary Constituent	Percentage of Secondary Constituent
Very coarse soils (BOULDERS & COBBLES)	Secondary + constituents after principal	With a little With some With much	< 5 5 - 20 20 - 50
Coarse soils (GRAVELS & SANDS) i.e. > 65% gravel and sand	Secondary constituents before principal (excluding cobbles and boulders)	Slightly (silty, clayey or silty/clayey *) — (silty, clayey or silty/clayey *) Very (silty, clayey or silty/clayey *) AND / OR Slightly (gravelly or sandy *) — (gravelly or sandy *) Very (gravelly or sandy *)	< 5 5 - 15 15 - 35 < 5 5 - 20 20 - 50
Fine soils (SILTS & CLAYS) i.e. > 35% silt and clay	Secondary constituents before principal (excluding cobbles and boulders)	Slightly (gravelly or sandy or both *) — (gravelly or sandy *)	< 35 35 - 65

Legend :

\+ For further details, see Table 16

* Secondary soil type as appropriate; use silty/clayey when a distinction cannot be made between the two

Note : Table adapted from Norbury et al (1984).

Examples : Slightly silty/clayey, sandy GRAVEL
Slightly clayey, gravelly SAND
Very gravelly SAND
Sandy SILT
Slightly gravelly, slightly sandy SILT/CLAY

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Table 16 - Methods for Naming Soils Containing Very Coarse Material

Rapid Method for Naming Very Coarse Soils		
Principal Soil Type	**Term**	**Estimated Boulder or Cobble Content of Very Coarse Fraction**
Very coarse soils (BOULDERS & COBBLES) i.e. >50% of material is very coarse (> 60mm)	BOULDERS	> 50% is of boulder size (> 200mm)
	COBBLES	> 50% is of cobble size (60 - 200mm)
	BOULDERS may be qualified as 'cobbly' and COBBLES as 'bouldery'	

Full Method for Naming Composite Soils Containing Very Coarse Material		
Principal Soil Type	**Term**	**Composition**
BOULDERS (or COBBLES)	BOULDERS (or COBBLES) with a little finer material	< 5% finer material
BOULDERS (or COBBLES)	BOULDERS (or COBBLES) with some finer material	5%-20% finer material
BOULDERS (or COBBLES)	BOULDERS (or COBBLES) with much finer material	20%-50% finer material
FINER MATERIAL	FINER MATERIAL with many boulders (or cobbles)	50%-20% boulders (or cobbles)
FINER MATERIAL	FINER MATERIAL with some boulders (or cobbles)	20%-5% boulders (or cobbles)
FINER MATERIAL	FINER MATERIAL with occasional boulders (or cobbles)	< 5% boulders (or cobbles)
Note : When the full method is used, the name of the finer material should be given (in parentheses when it is the minor constituent, as shown below).		
Examples : Sandy GRAVEL with occasional boulders Cobbly BOULDERS with some finer material (slightly gravelly sand) BOULDERS with much finer material (silty/clayey, very sandy gravel)		

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Table 17 - Plasticity Terms Based on Liquid Limit

Descriptive Term for Plasticity	Range of Liquid Limit (%)
Low plasticity	< 35
Intermediate plasticity	35 - 50
High plasticity	50 - 70
Very high plasticity	70 - 90
Extremely high plasticity	> 90

Note : Classification in terms of plasticity is based on liquid limit, in accordance with BS 5930 (1981).

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Table 18 - Identification Features for Different Soil Types

Feature		Soil Type				
					Soils Derived from Insitu Rock Weathering	
Group	Item	Fill	Colluvium	Weathered Colluvium	Residual Soil	Saprolite
Rock Type of Boulders and Cobbles	a. Foreign, but present upslope	☆	☆	☆		
	b. Totally foreign or man-made (brick, etc.)	☆				
Relict Structure	a. Joints and veins in boulders	☆	☆	☆		☆
	b. Joints and veins persistent through matrix					☆
	c. Remnants of disrupted veins	☆	☆	☆		
	d. Layering	☆				
Texture/ Fabric	a. Uniform arrangement of rock fragments (e.g. corestones), controlled by original joint pattern					☆
	b. Jumbled arrangement of rock fragments with some point contact	☆	☆	☆		
	c. Gradational change in strength and grading from rock fragments to matrix			☆		☆
	d. Sharp change in strength and grading from rock fragments to matrix	☆	☆			
	e. Matrix mineralogy/texture different from rock fragments	☆	☆	☆		
Stratigraphic Profile	a. Overlies boulder-free zone or layer	☆	☆	☆		
Basal Features	a. Topsoil layer	☆	☆	☆		
	b. Particle alignment		☆	☆		
Springs	a. At contacts with other soils	☆	☆	☆		
Geomorphology	a. Fan- or lobe-shaped		☆	☆		
	b. Anomalous topography	☆				

Legend :

☆ Feature indicates soil type, but soil type does not always show a particular feature

Note : Table adapted from Huntley & Randall (1981).

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Table 19 - Names and Descriptive Letters for Grading and Plasticity Characteristics

Soil Compo-nents	Terms	Descriptive Name	Letter
Coarse Components	Main terms	GRAVEL	G
		SAND	S
	Qualifying terms	Well-graded	W
		Poorly-graded	P
		Uniform	Pu
		Gap-graded	Pg
Fine Components	Main terms	FINE SOIL, FINES may be differentiated into M or C	F
		SILT (M-SOIL) ✱ plots below A-line of plasticity chart of Figure 8 (of restricted plastic range)	M
		CLAY plots above A-line (fully plastic)	C
	Qualifying terms	Low plasticity	L
		Intermediate plasticity	I
		High plasticity	H
		Very high plasticity	V
		Extremely high plasticity	E
		Upper plasticity range * incorporating groups I, H, V and E	U
Organic Components	Main term	PEAT	Pt
	Qualifying term	Organic may be suffixed to any group	O

Legend:

✱ See Note 5 in Table 20

* This term is a useful guide when it is not possible or not required to designate the range of liquid limit more closely, e.g. during the rapid description of soils

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Table 20 - British Soil Classification System for Engineering Purposes

Soil Groups (1)			Subgroups and Laboratory Identification				
GRAVEL and SAND may be qualified by an additional secondary constituent for coarse fraction where appropriate (Table 15)			Group Symbol (2)(3)	Subgroup Symbol (2)	Fines (% less than 0.06mm)	Liquid Limit (%)	Name
Coarse Soils (less than 35% of the material is finer than 0.06mm)	GRAVELS (more than 50% of coarse material is of gravel size (coarser than 2mm))	Slightly silty or clayey GRAVEL	G GW GP	GW GPu GPg	0 - 5		Well-graded GRAVEL Poorly-graded/Uniform/Gap-graded GRAVEL
		Silty GRAVEL clayey GRAVEL	G-F G-M G-C	GWM GPM GWC GPC	5 - 15		Well-graded/Poorly-graded silty GRAVEL Well-graded/Poorly-graded clayey GRAVEL
		Very silty GRAVEL Very clayey GRAVEL	GF GM GC	GML, etc GCL GCI GCH GCV GCE	15 - 35		Very silty GRAVEL : subdivide as for GC Very clayey GRAVEL (clay of low, intermediate, high, very high, extremely high plasticity)
	SANDS (more than 50% of coarse material is of sand size (finer than 2mm))	Slightly silty or clayey SAND	S SW SP	SW SPu SPg	0 - 5		Well-graded SAND Poorly-graded/Uniform/Gap-graded SAND
		Silty SAND Clayey SAND	S-F S-M S-C	SWM SPM SWC SPC	5 - 15		Well-graded/Poorly-graded silty SAND Well-graded/Poorly-graded clayey SAND
		Very silty SAND Very clayey SAND	SF SM SC	SML, etc SCL SCI SCH SCV SCE	15 - 35		Very silty SAND : subdivide as for SC Very clayey SAND (clay of low, intermediate, high, very high, extremely high plasticity)
Fine Soils (more than 35% of the material is finer than 0.06mm)	Gravelly or sandy SILTS and CLAYS (35% - 65% fines)	Gravelly SILT (4) Gravelly CLAY (4)	FG MG CG	MLG, etc CLG CIG CHG CVG CEG		 < 35 35 - 50 50 - 70 70 - 90 > 90	Gravelly SILT : subdivide as for CG Gravelly CLAY (of low, intermediate, high, very high, extremely high plasticity)
		Sandy SILT (4) Sandy CLAY (4)	FS MS CS	MLS, etc CLS, etc			Sandy SILT : subdivide as for CG Sandy CLAY : subdivide as for CG
	SILTS and CLAYS (65% - 100% fines)	SILT (M-soil) CLAY (5) (6) (7)	F M C	ML, etc CL CI CH CV CE		 < 35 35 - 50 50 - 70 70 - 90 > 90	SILT : subdivide as for C CLAY (of low, intermediate, high, very high, extremely high plasticity)
Organic Soils		Descriptive letter 'O' suffixed to any group or sub-group symbol.	Organic matter suspected to be a significant constituent. Example MHO : Organic SILT of high plasticity.				
Peat		Pt Peat soils consist predominantly of plant remains which may be fibrous or amorphous.					

Notes :

(1) The name of the soil group should always be given when describing soils, supplemented, if required, by the group symbol, although for some applications (e.g. diagrams) it may be convenient to use the group symbol alone.

(2) The group symbol or sub-group symbol should be placed in brackets if laboratory methods have not been used for identification, e.g. (GC).

(3) The designation FINE SOIL or FINES, F may be used in place of SILT, M, or CLAY, C, when it is not possible or not required to distinguish between them.

(4) Gravelly if more than 50 % of coarse material is of gravel size. Sandy if more than 50 % of coarse material is of sand size.

(5) SILT (M-soil), M is material that plots below the A-line, and has a restricted plastic range in relation to its liquid limit, and relatively low cohesion. Fine soils of this type include clean silt-sized materials and rock flour, micaceous and diatomaceous soils, pumice, and volcanic soils, and soils containing halloysite. The alternative term 'M-soil' avoids confusion with materials of predominantly silt size, which form only a part of the group.
Organic soils also usually plot below the A-line on the plasticity chart, when they are designated ORGANIC SILT, MO.

(6) CLAY, C is material that plots above the A-line, and is fully plastic in relation to its liquid limit.

(7) SILT and CLAY may be qualified as slightly sandy, or slightly gravelly, or both, where appropriate (Table 15).

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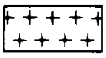
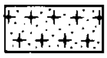
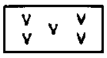
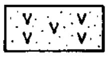
Table 21 - Symbols for Rocks and Soils

ROCKS

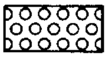
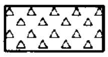
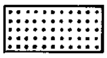
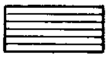
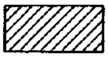
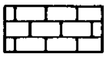
Igneous Rocks

	Granite
	Granodiorite, Syenite, Monzonite
	Gabbro, Lamprophyre
	Rhyolite
	Dacite, Latite, Andesite, Trachyte, Trachyandesite
	Basalt

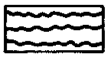
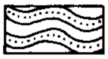
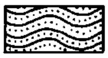
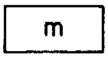
Pyroclastic Rocks

	Pyroclastic breccia
	Coarse ash tuff, Lapilli tuff
	Fine ash tuff

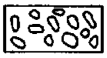
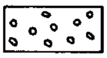
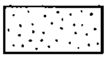
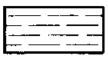
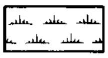
Sedimentary Rocks

	Conglomerate
	Sedimentary breccia
	Sandstone
	Siltstone
	Claystone
	Shale
	Limestone

Metamorphic Rocks

	Metamorphic rocks - regional
	Phyllite, Mylonite
	Schist
	Gneiss
	Quartzite
	Marble
	Metamorphic rocks - contact (e.g. Hornfels)

SOILS

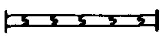
	Fill (made ground)
	Boulders and cobbles
	Gravel
	Sand
	Silt
	Clay
	Peat

Note : Composite soil types to be signified by combined symbols, e.g.

	Silty sand

Table 22 - Symbols for Borehole Records

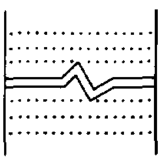

Fault

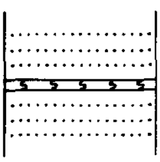

Slip surface

Shell band

Examples :


Granite faulted against gneiss


Fault in sandstone


Slip surface in sandstone

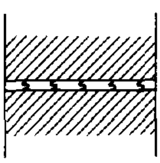

Slip surface in shale

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Table 23 - Symbols for General Planar Structures

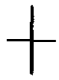
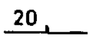
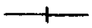
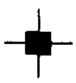
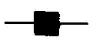
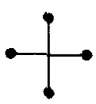
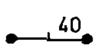
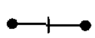
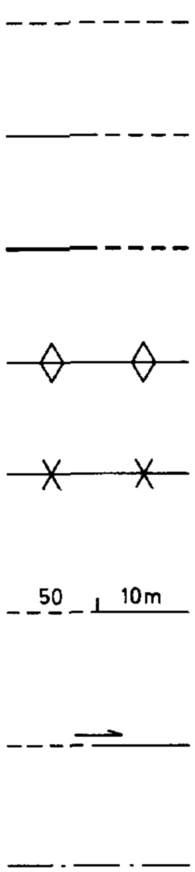
	Horizontal stratum
	Inclined stratum with dip in degrees (long axis is strike direction)
	Vertical stratum (long axis is strike direction)
	Foliation or cleavage, horizontal
	Foliation or cleavage, inclined, with dip in degrees (long axis is strike direction)
	Foliation or cleavage, vertical (long axis is strike direction)
	Joint, horizontal
	Joint, inclined, with dip in degrees (long axis is strike direction)
	Joint, vertical (long axis is strike direction)
	Flow fabric, horizontal
	Flow fabric, inclined, with dip in degrees (long axis is strike direction)
	Flow fabric, vertical (long axis is strike direction)

Table 24 - Symbols for Other Geological Structures and Boundaries



(dashed line)	Geological boundary, superficial deposit	
(thin line, broken)	Geological boundary, solid rock	broken lines denote uncertainty
(thick line, broken)	Mineral vein	broken lines denote uncertainty
(line with diamonds)	Axial trace of anticline	
(line with crosses)	Axial trace of syncline	
(fault symbol)	Fault, crossmark on downthrow side, with dip in degrees and throw in metres	broken lines denote uncertainty
(fault with arrow)	Fault, with horizontal component of relative movement	broken lines denote uncertainty
(dash-dot line)	Photogeological lineament	

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GENERAL INFORMATION

Record No.	Site	Date (Day / Month / Year)	Operator	Discontinuity Data Sheet No.
7 98	ANYWHERE	10 / 03 / 87	FT	2 of 12

NATURE AND ORIENTATION OF DISCONTINUITIES

Location: Chainage mark or No.	Type	Dip direction	Dip	Persistence	Aperture	Infilling	Consistency	Uneveness	Waviness wavelength	Waviness amplitude	Differentially weathered zone width around discontinuity (mm)	Water	Remarks
113	2	178	56	3;5	4	4	2	7	2;0	;05	150	1	
114	2	026	27	1;5	5	2	-	7	1;0	;04	50	1	
115	2	235	86	;9	7	2	-	7	-	-	20	1	
116	2	176	66	;7	6	6	5	7	-	-	40	1	
117	2	246	84	4;3	4	4	2	7	2;0	;05	120	1	
118	2	149	55	2;4	5	2	-	7	1;5	;10	30	1	
119	1	064	44	25;0	3	4	4	4	3;0	;08	200	2	300mm relative movement along fault
120	2	144	90	1;9	7	6	5	1	0;5	;05	20	1	
121	2	234	82	3;3	4	2	-	1	1;5	;03	100	1	
122	2	232	81	;4	7	2	-	7	-	-	20	1	
123	2	144	62	1;3	5	2	-	7	1;0	;05	50	1	
124	1	263	80	18;0	3	4	4	4	4;5	;20	200	3	Seepage estimate 5 litres/min

Type
0. Fault zone
1. Fault
2. Joint
3. Cleavage
4. Schistosity
5. Shear plane
6. Fissure
7. Tension crack
8. Foliation
9. Bedding

Dip direction, Dip
Expressed in degrees

Persistence
Maximum dimension of trace length on exposed face expressed in metres

Aperture
1. Wide (>200mm)
2. Mod. wide (60-200mm)
3. Mod. narrow (20-60mm)
4. Narrow (6-20mm)
5. Very narrow (2-6mm)
6. Ext. narrow (>0-2mm)
7. Tight (zero)

Nature of Infilling
0. Clean
1. Surface staining
2. Decomposed /disintegrated rock
3. Non-cohesive soil
4. Cohesive soil
5. Quartz
6. Calcite
7. Manganese
8. Kaolin
9. Other - specify

Consistency of Infilling

Soil strength	Rock strength
1. Very soft	6. Extremely weak
2. Soft	7. Very weak
3. Firm	8. Weak
4. Stiff	9. Moderately weak
5. Very stiff or hard	10. Moderately strong
	11. Strong
	12. Very strong
	13. Extremely strong

Uneveness
(small-scale roughness)
1. Rough stepped
2. Smooth stepped
3. Slickensided stepped
4. Rough undulating
5. Smooth undulating
6. Slickensided undulating
7. Rough planar
8. Smooth planar
9. Slickensided planar

Waviness
(large-scale roughness)
Express wavelength & amplitude in metres

Water
1. Dry
2. Damp/wet
3. Seepage present (estimate quantity separately in litres/sec or litres/min)

Figure 1 - Example of a Discontinuity Data Sheet

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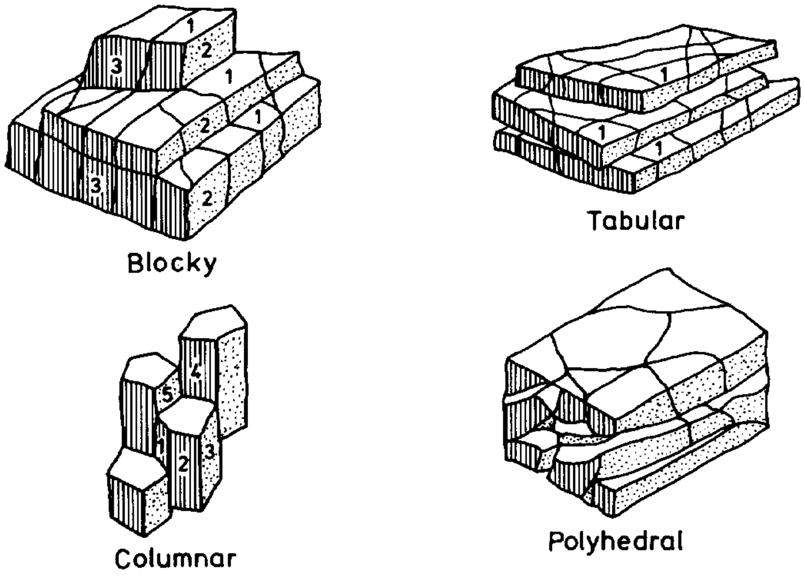
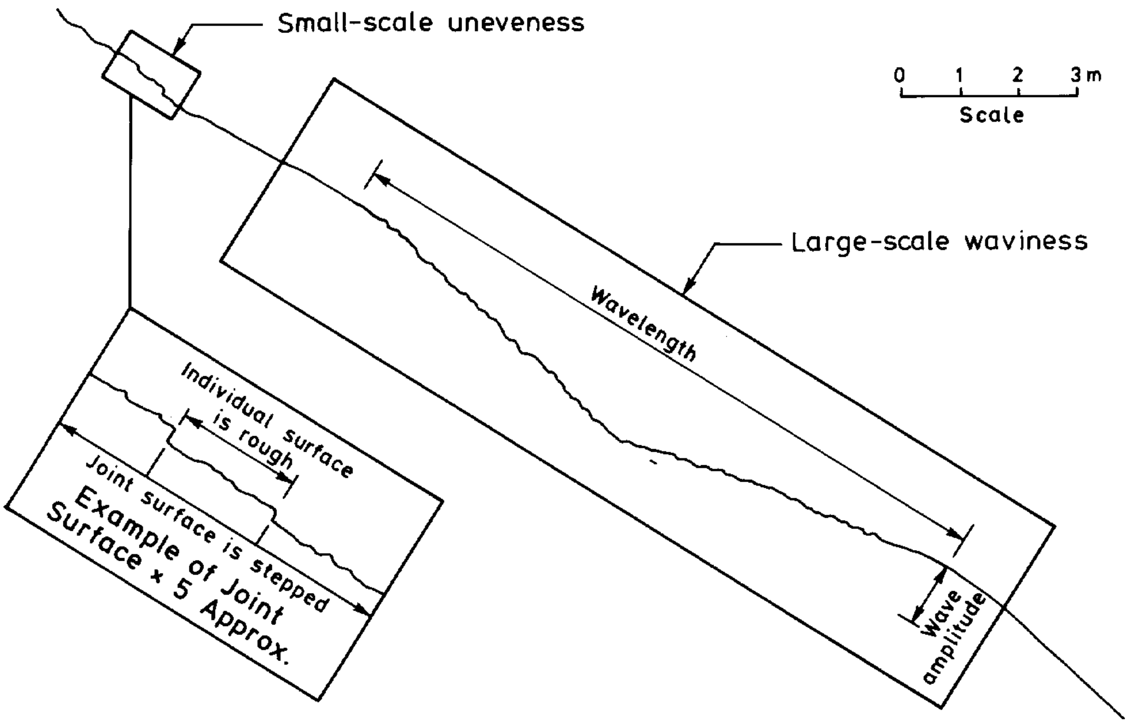


Note : Numbers in diagrams refer to discontinuity sets.

Figure 2 - Shape of Rock Blocks in a Discontinuous Rock Mass



Notes : (1) Waviness can be described by estimation / measurement of wavelength and amplitude.
(2) Uneveness can be described using the terms given in Table 8 .

Figure 3 - Scales of Discontinuity Roughness

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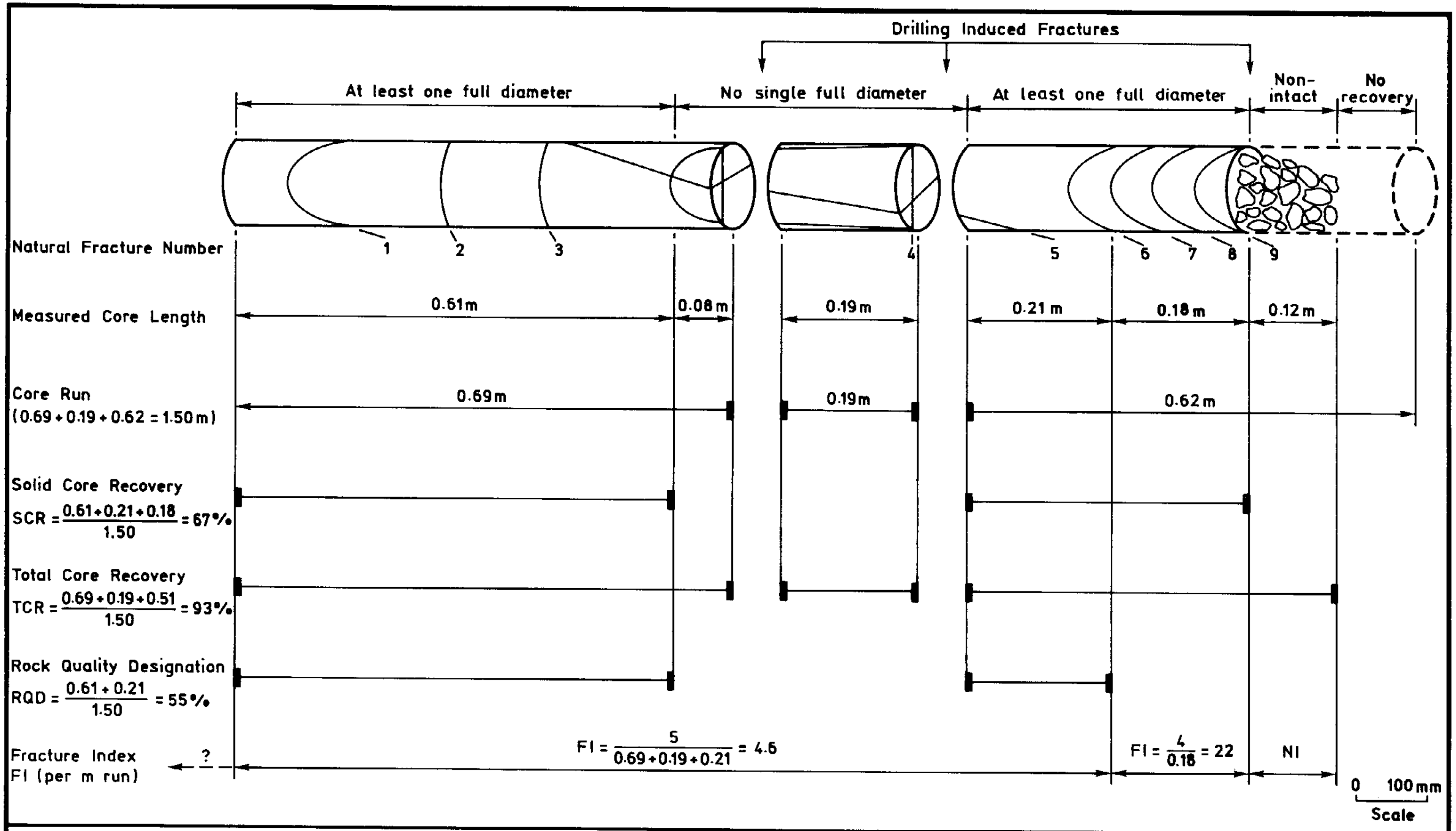

Notes : (1) All fractures shown on the core are natural unless otherwise stated.
(2) Table adapted from Norbury et al (1984).

Figure 4 - Schematic Illustration of Fracture Logging Terms

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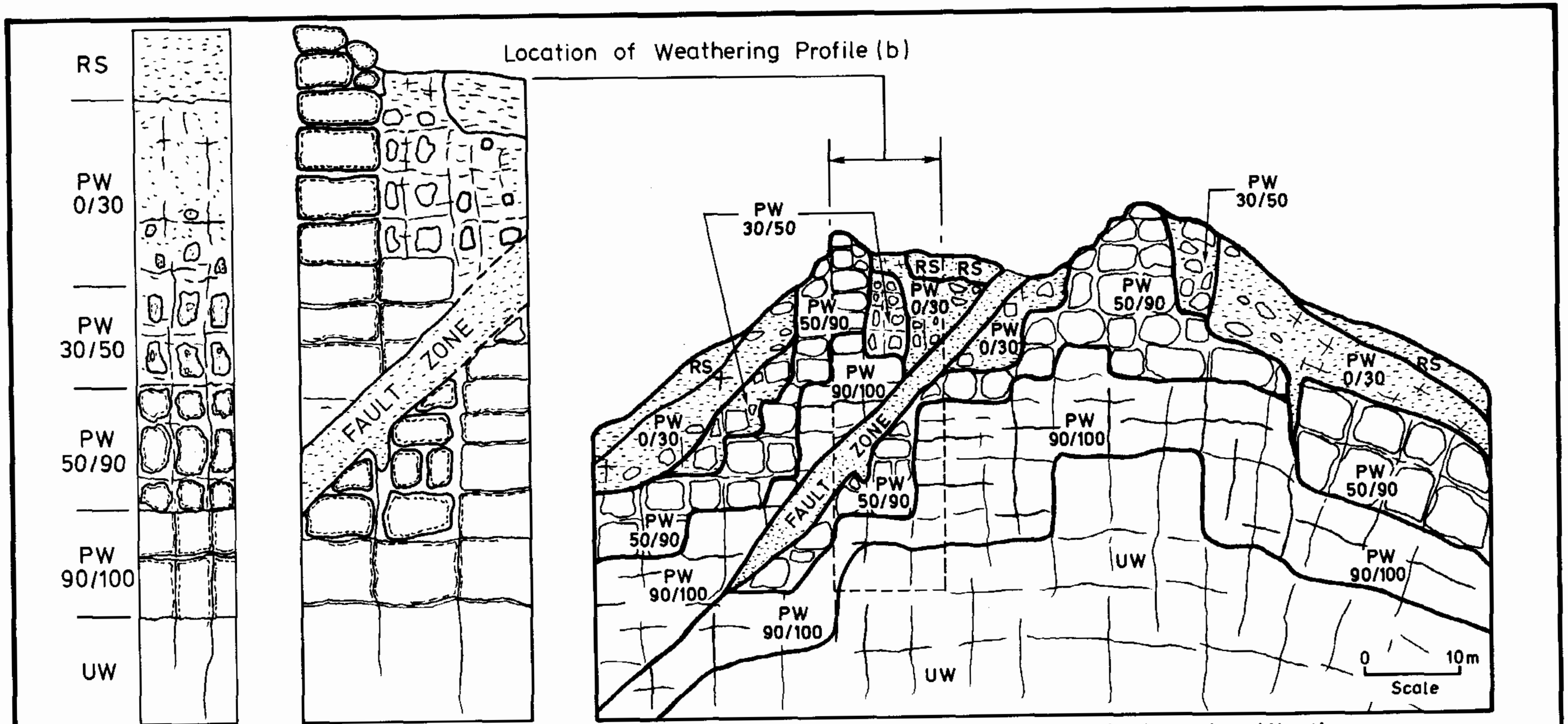

(a) Idealised Weathering Profile

(b) Example of a Complex Weathering Profile

(c) Example of a Zonal Mass Weathering Classification Applied to a Rock Mass Exposure

Legend :

UW	Unweathered Rock	PW50/90	Partially Weathered 50/90% Rock	PW0/30	Partially Weathered 0/30% Rock
PW90/100	Partially Weathered 90/100% Rock	PW30/50	Partially Weathered 30/50% Rock	RS	Residual Soil

Note : For definitions of terms, see Table 10.

Figure 5 - Mass Weathering Profiles and Zonal Weathering Classification of a Mass Exposure

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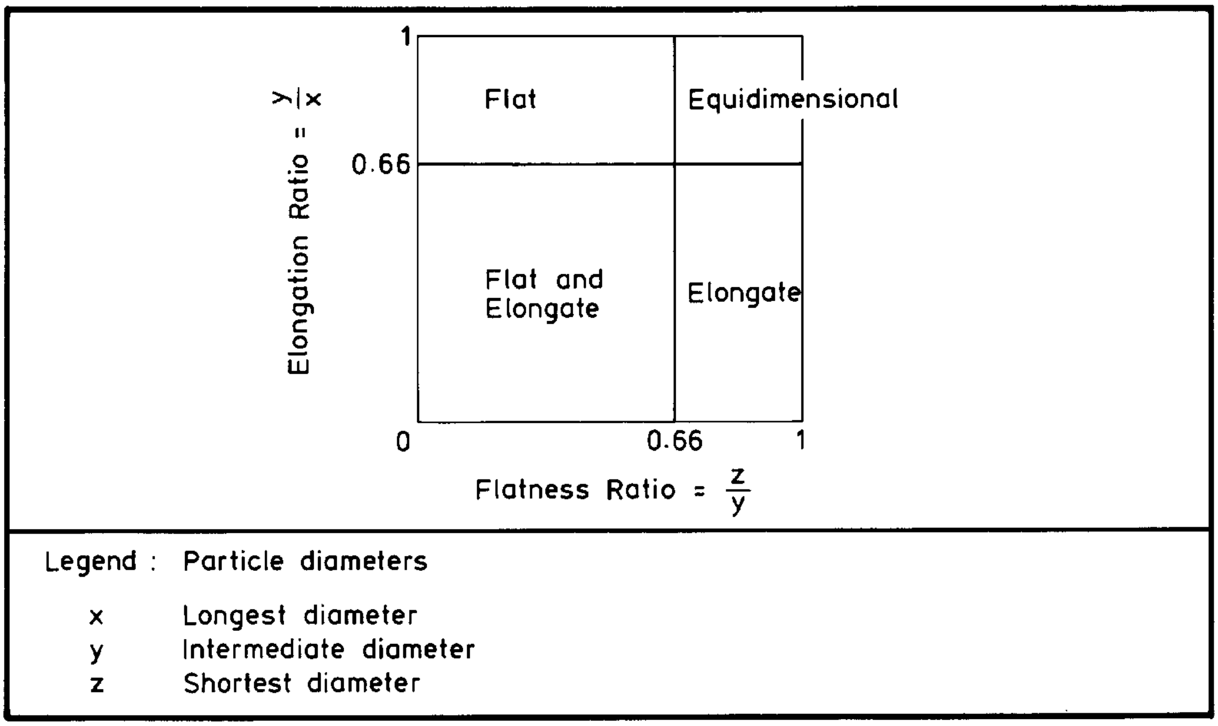

Figure 6 - Quantitative Classification of Particle Form

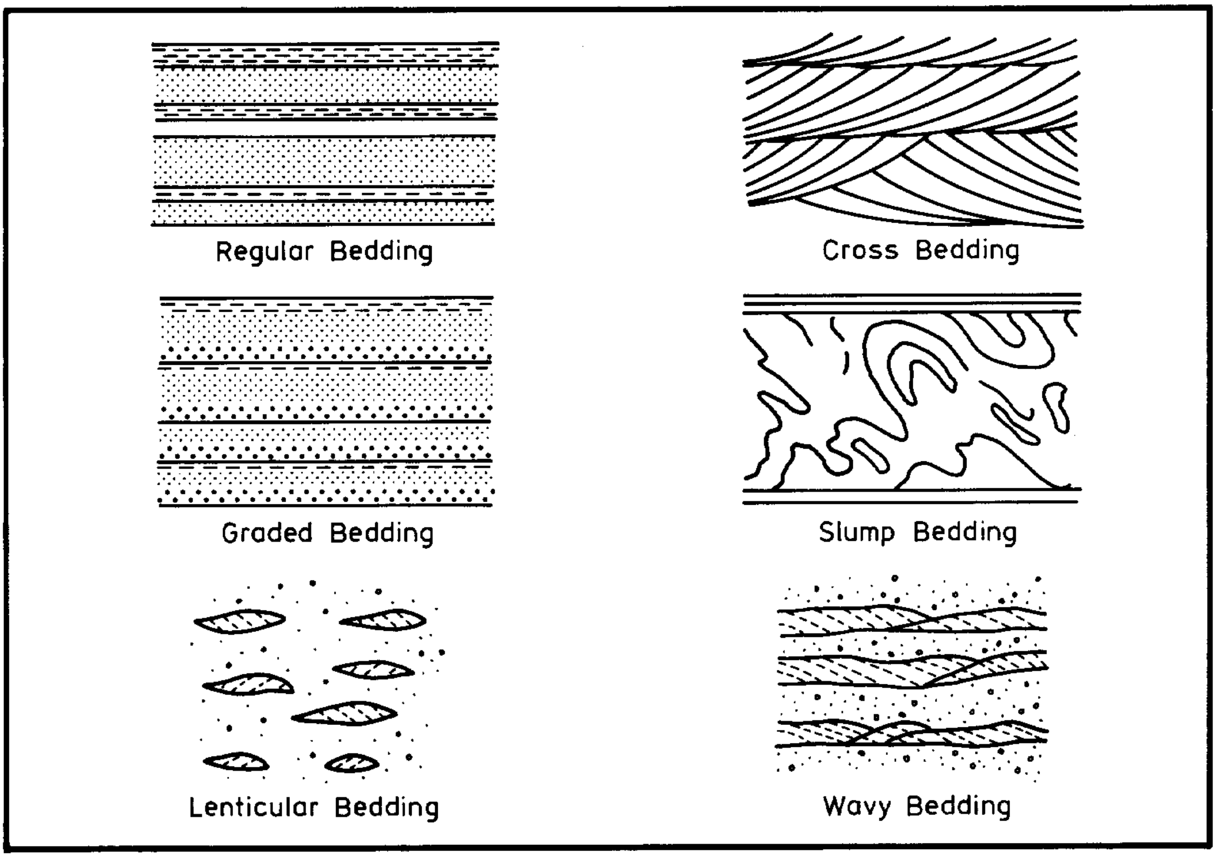

Figure 7 - Types of Bedding

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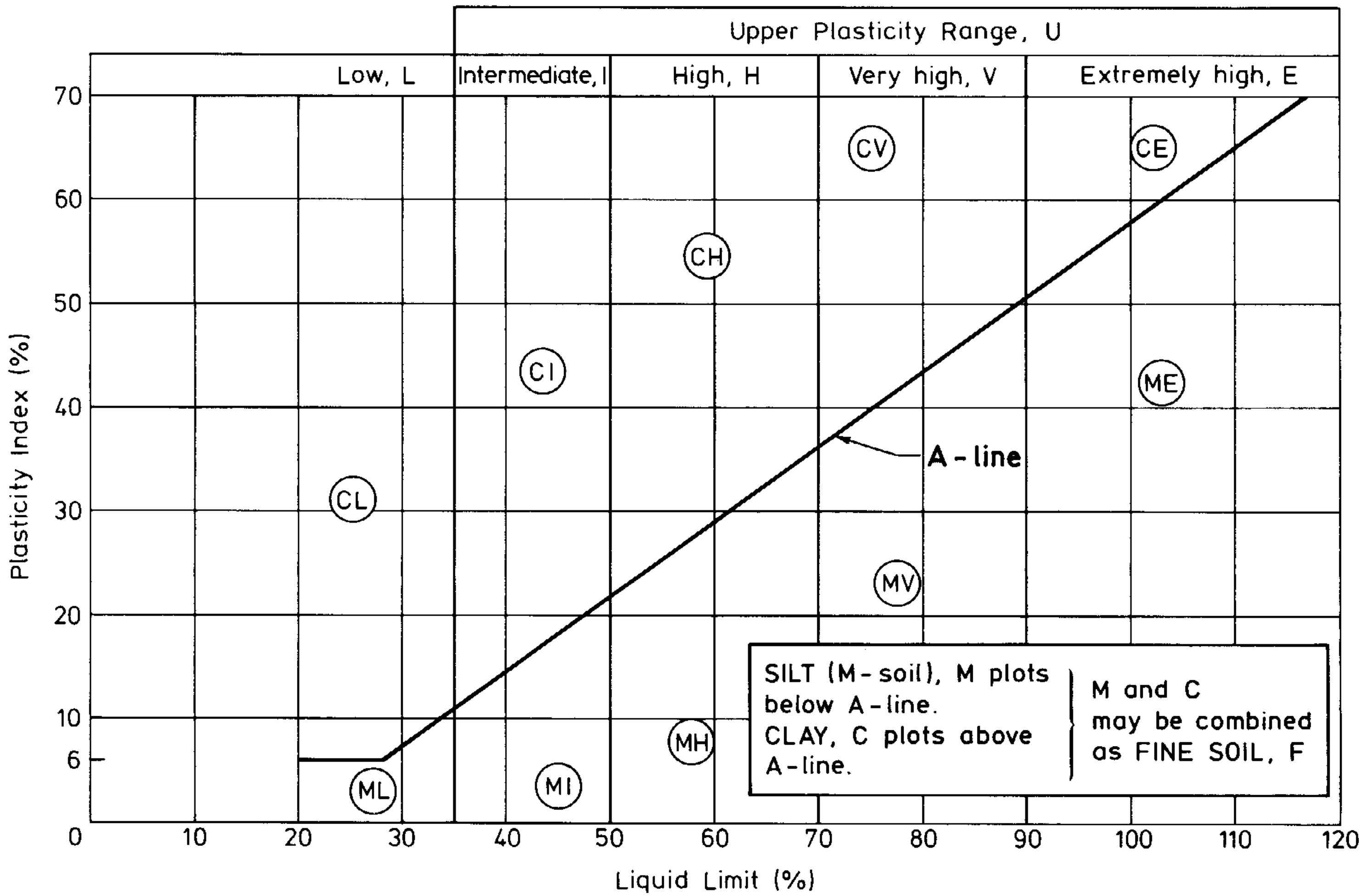

Notes: (1) The letter O is added to the symbol of any material containing a significant proportion of organic matter e.g. MHO.
(2) Plasticity measurements are made on material passing 425 μm BS sieve.

Figure 8 - Plasticity Chart for Classification of Fine Soils and the Finer Part of Composite Soils

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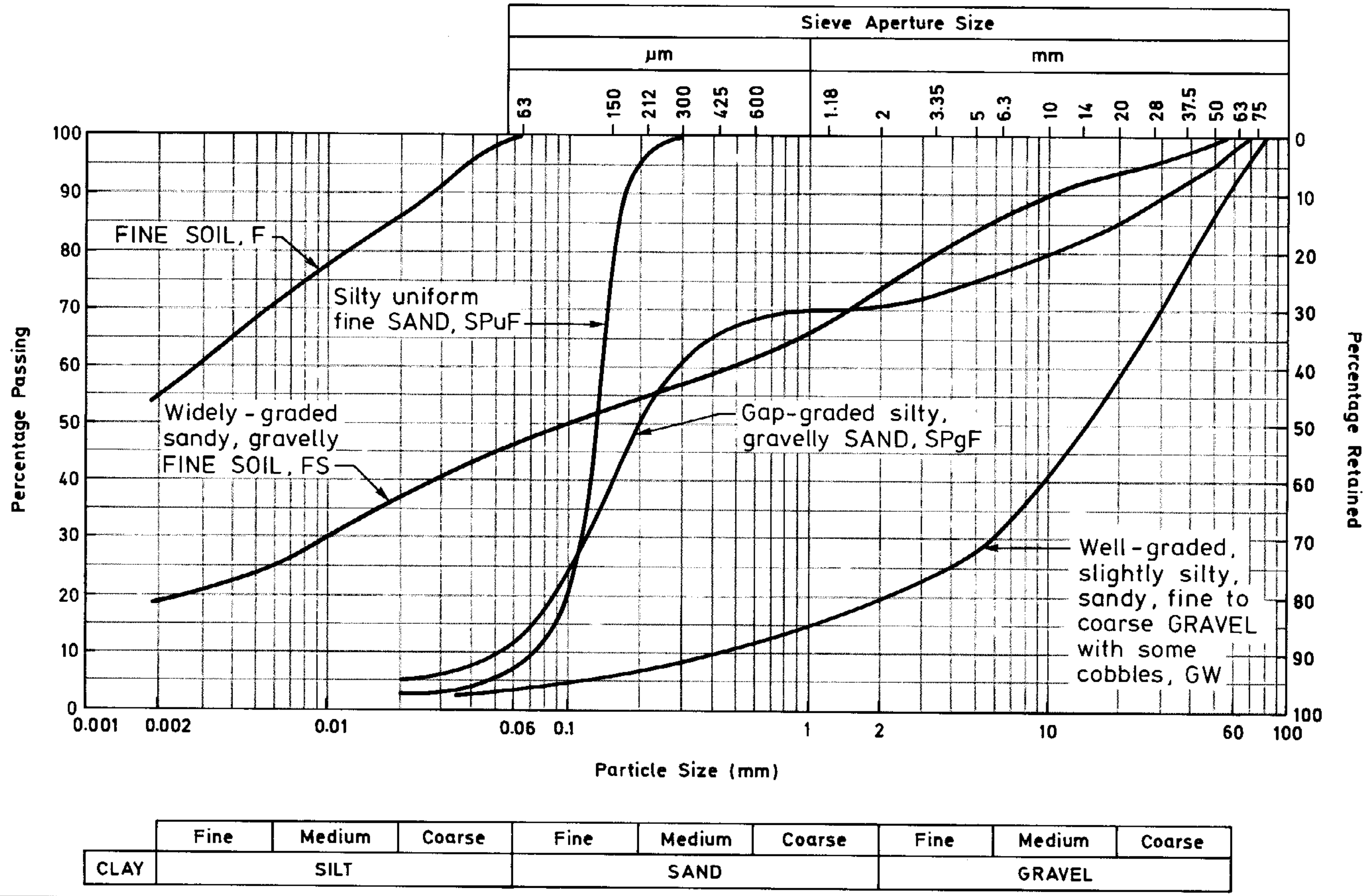

Note : Figure adapted from BS5930 (BSI, 1981).

Figure 9 - Grading Chart for Soils with Grading Curves of Selected Soil Types

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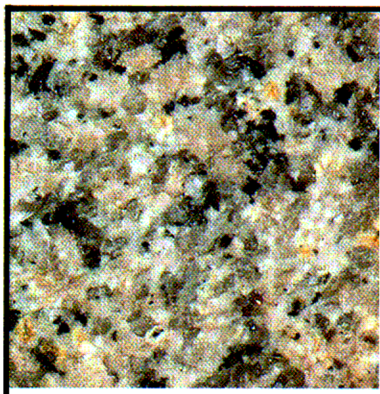
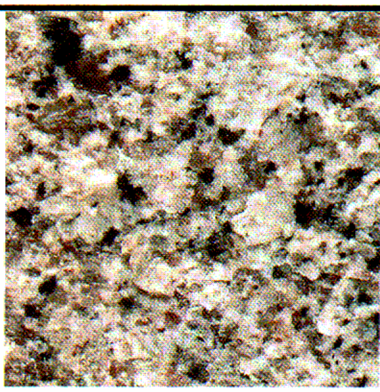
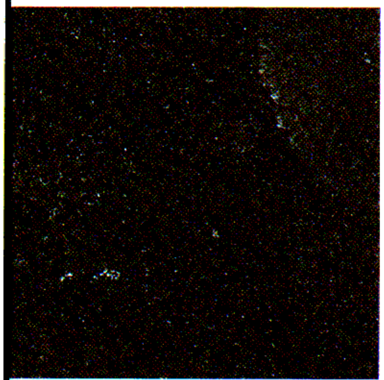
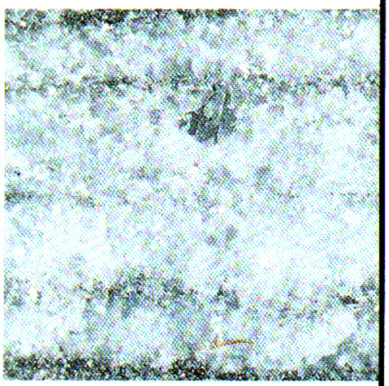

A : Equigranular

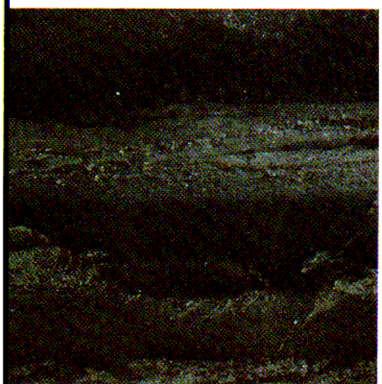

B : Inequigranular


C : Megacrystic


D : Aphanitic


E : Porphyritic


F : Crystalline


G : Cryptocrystalline

Natural scale

Note : Porphyritic texture represents a special case of megacrystic texture (see Glossary). It is rarely possible to distinguish between the two by observation alone; additional geological information on the composition of the large grains/crystals relative to the matrix is usually required.

Plate 1 - Rock Textures

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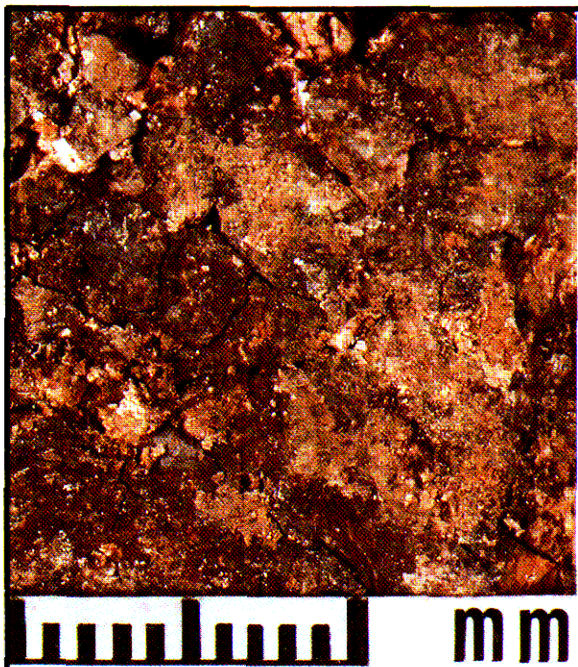

A: Microfractures Caused by General Mechanical Weathering in Highly Decomposed Granite at Kwai Chung, New Territories

B: Microfractures Caused by Recent Slope Failure in a Volcanic Residual Soil at Pun Shan Tsuen, near Tsuen Wan, New Territories

C: Curved Microfractures Caused by Mechanical Weathering (Exfoliation) in a Granite Corestone at Lung Kwu Chau Island, New Territories

D: Microfractures Caused by Tectonic Activity in Slightly Decomposed Granite at Siu Lam, New Territories

Note : For further information, see Section 2.3.3 .

Plate 2 - Microfractures

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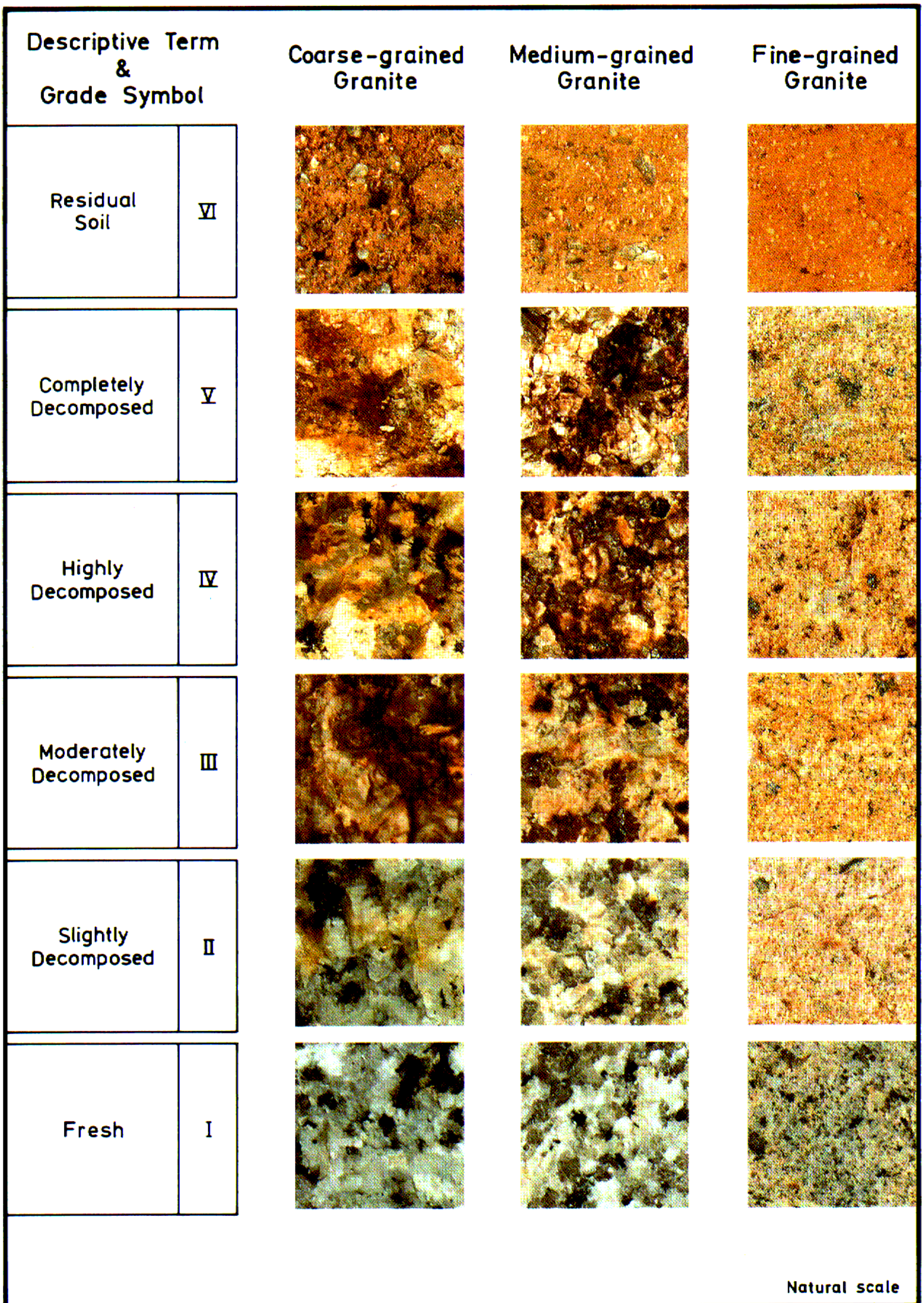

Plate 3 - Decomposition Grades of Rock Material (Sheet 1 of 2)

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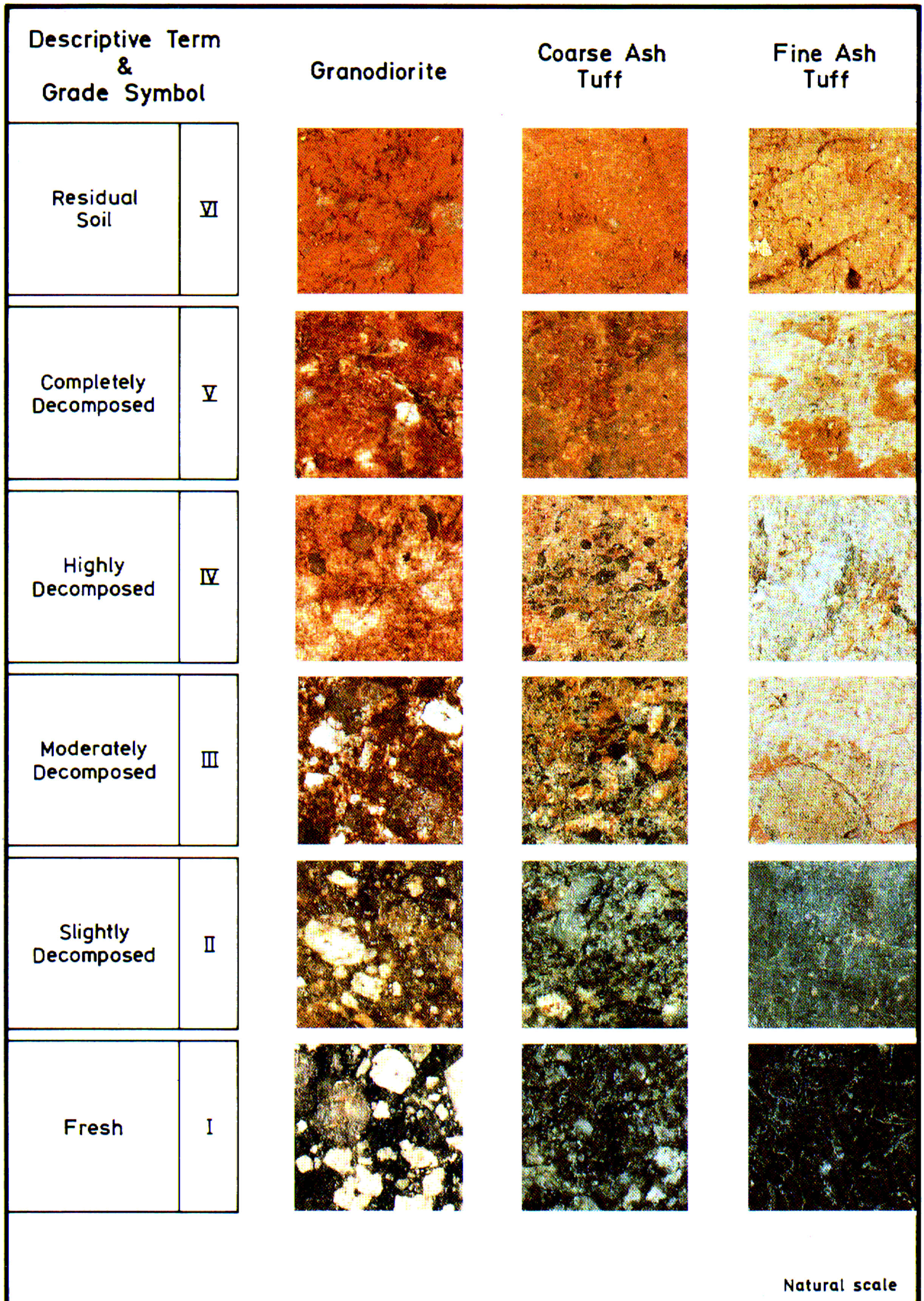

Plate 3 - Decomposition Grades of Rock Material (Sheet 2 of 2)

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A : Igneous Rock from Lai King, New Territories

B : Pyroclastic Rock from Chai Wan, Hong Kong Island

Note : For full descriptions, see Section 2.3.7.

Plate 4 - Rock Material Examples (Sheet 1 of 2)

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C : Metamorphic Rock from Tuen Mun, New Territories

D : Sedimentary Rock from Ma Liu Shui, New Territories

Note : For full descriptions, see Section 2.3.7 .

Plate 4 - Rock Material Examples (Sheet 2 of 2)

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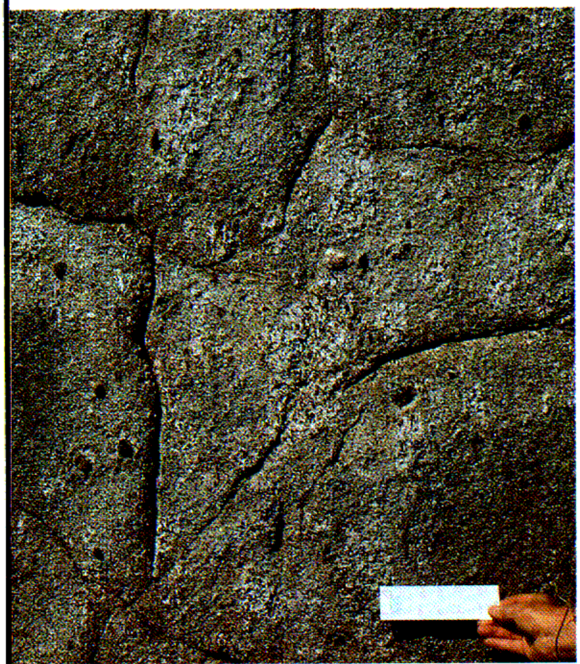
A : Bedded
(Interbedded sandstone and mudstone at Sai Kung Hoi, New Territories)

B : Laminated
(Mudstone at Ping Chau; also shows slump structure)



C : Massive
(Lapilli tuff with impersistent joints at Ting Kau, New Territories)

D : Flow-banded
(Rhyolite at Clear Water Bay Peninsula, New Territories)

Plate 5 - Rock Planar Structures (Sheet 1 of 2)

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E : Eutaxitic
(Fine ash tuff at Ap Lei Chau, Hong Kong Island; brown-stained irregular joints also visible)

F : Foliated
(Schist from Tuen Mun, New Territories as seen in drillcore)

G : Cleaved
(Phyllite at Tuen Mun, New Territories, showing slightly undulating cleavage)

H : Banded
(Schistose andesite at Tuen Mun, New Territories, showing alternating layers of different grain size / mineralogy)

Plate 5 - Rock Planar Structures (Sheet 2 of 2)

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A : Corestones in a Natural Coastal Exposure of Quartz Syenite at Tai Miu Wan, Clear Water Bay Peninsula, New Territories

B : Split Corestones in a Granite Cutslope at Wong Nai Chung Road, Happy Valley, Hong Kong Island

Plate 6 - Corestones

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A : Granite Cutslope at Jat's Incline, East Kowloon, Showing a Partially Weathered PW 30/50 Rock Mass Zone with Large Corestones Overlying a Partially Weathered PW 0/30 Rock Mass Zone

B : Cutslope in Coarse Ash Tuff at Mt. Davis, Hong Kong Island, Showing Variation in Degree of Rock Mass Weathering and Spacing / Orientation of Major Discontinuities (Vegetation and chunam surfacing obscure the relatively more weathered zones)

Plate 7 - Complex Rock Mass Exposures

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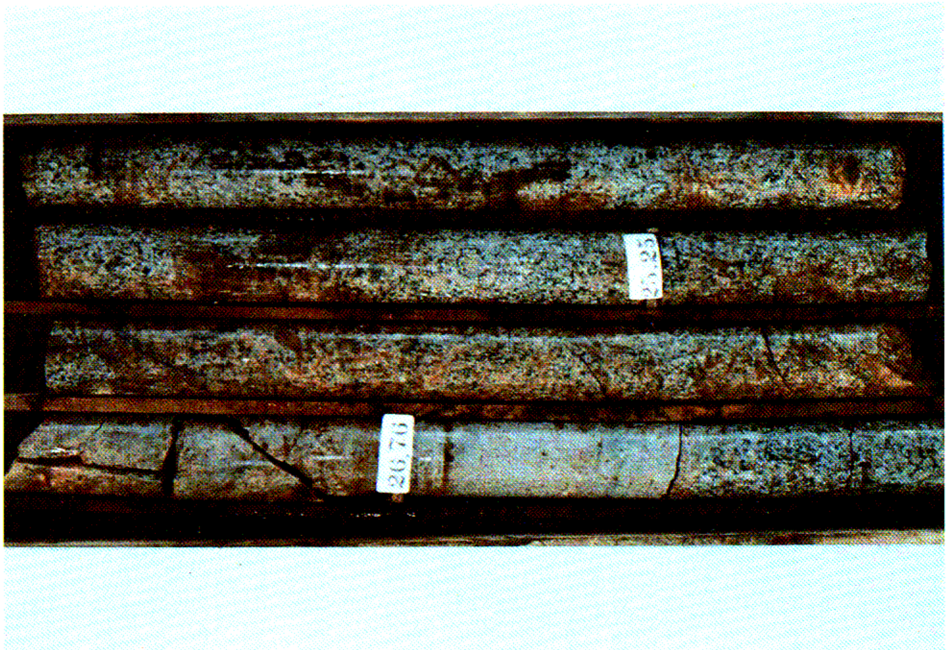
A: Pyroclastic Rock Mass Exposed in an Excavation at Chai Wan, Hong Kong Island



B: Igneous Rock Mass Sampled by Drilling at Tsim Sha Tsui, Kowloon

Note : For full descriptions, see Section 2.4.6 .

Plate 8 - Rock Mass Examples

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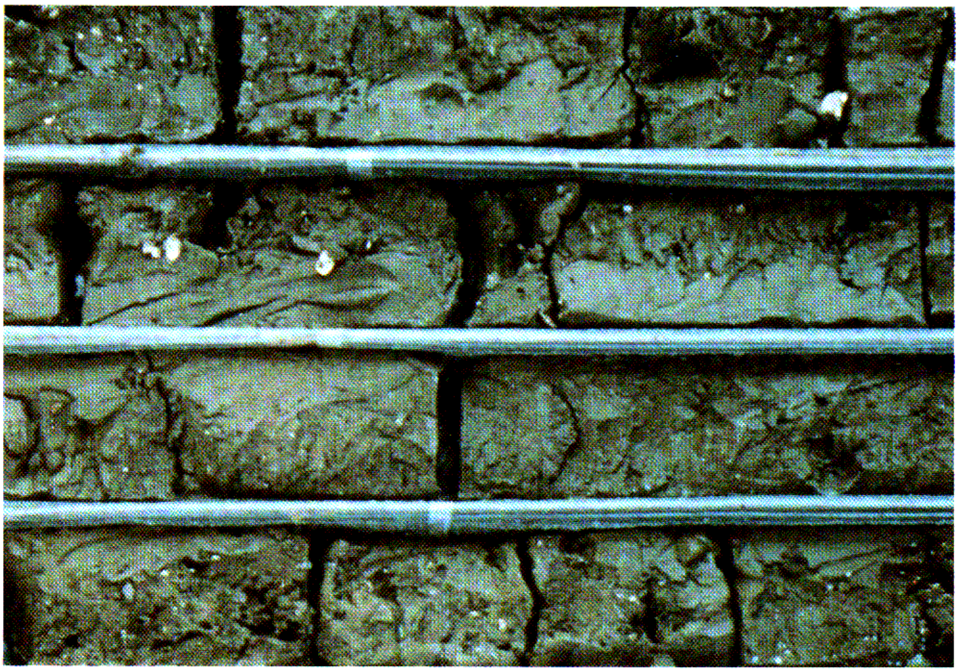
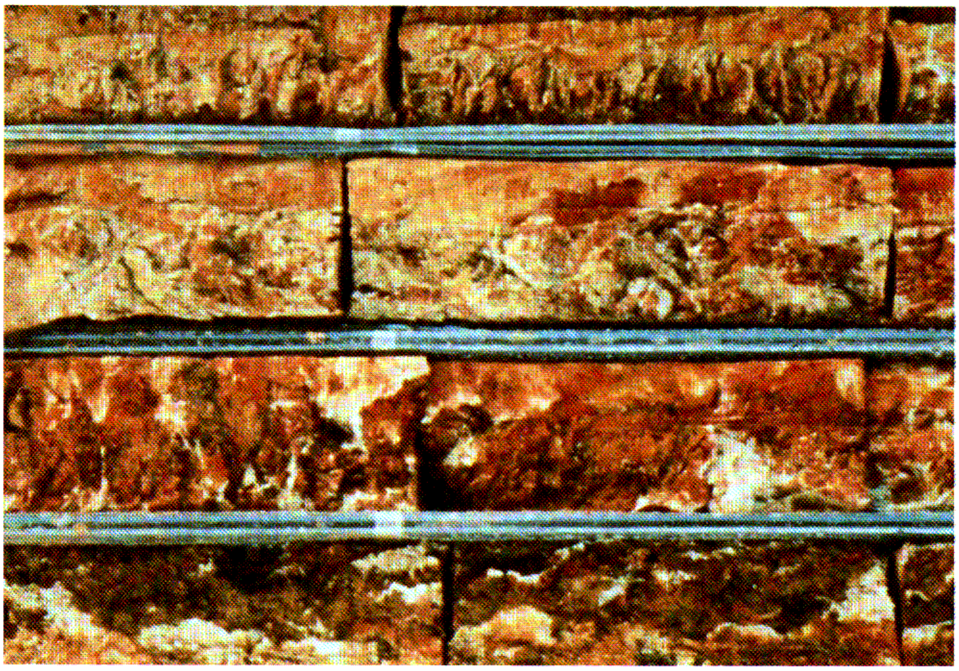
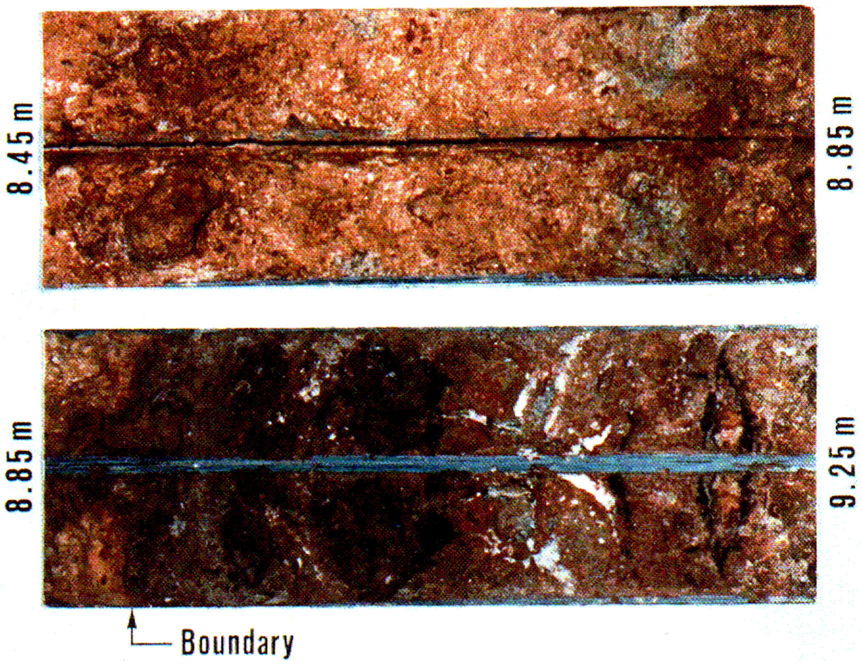


A: Uniform Grey or Greenish Grey Marine Muds Deposited in a Reducing Environment (i. e. have not been exposed to sub-aerial weathering)



B: Mottled Colours in Alluvium Underlying Marine Muds Showing the Effect of Oxidation during Previous Exposure to Sub-aerial Weathering

Plate 9 - Contrasts between Unweathered Marine and Weathered Alluvial Sediments



A: Boundary in Split Mazier Samples from Borehole at Peak Road, near Magazine Gap, Hong Kong Island (Light brown, structureless colluvium containing occasional cobbles of highly decomposed ash tuff overlying darker, variably coloured, completely decomposed ash tuff with prominent black-stained and kaolin(?)-infilled relict joints)

B: Boundary in a Trial Pit at Ngau Chi Wan, East Kowloon (Variably coloured (mottled), volcanic colluvium containing large decomposed boulders of ash tuff overlying uniform, light pinkish grey, completely decomposed medium-grained granite)

Plate 10 - Colluvium/Insitu Decomposed Rock Boundaries

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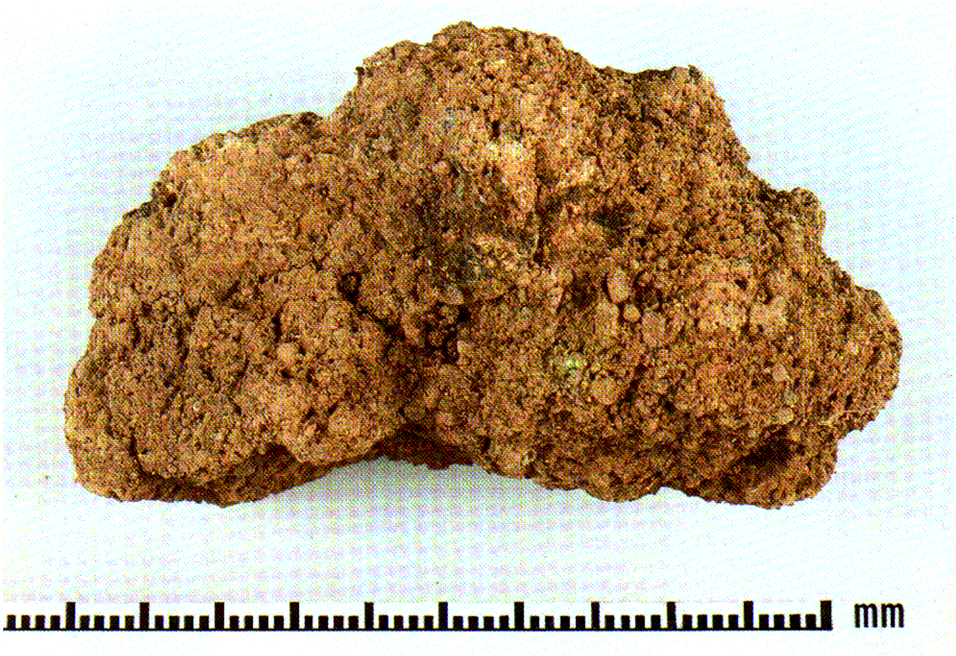
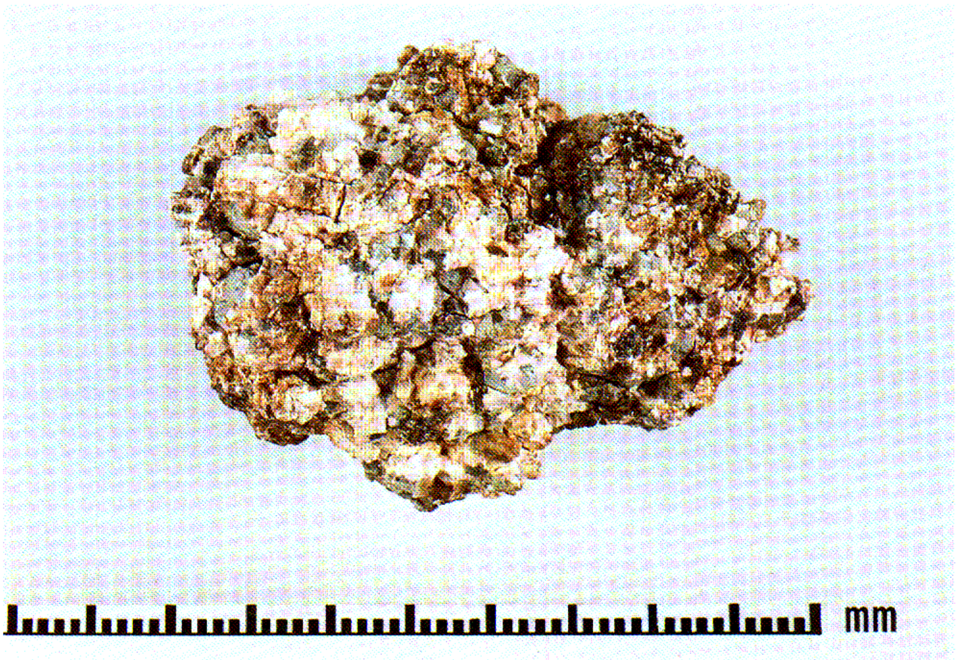


A: Hand Sample of Residual Soil from Chai Wan, Hong Kong Island



B: Hand Sample of Completely Decomposed Granite from Ho Man Tin, Kowloon

Note : For full descriptions, see Section 3.9 .

Plate 11 - Soil Examples (Sheet 1 of 4)

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C: Hand Sample of Marine Mud from Junk Bay, New Territories

D: Hand Sample of Marine Sand from Castle Peak Road, New Territories

Note : For full descriptions, see Section 3.9 .

Plate 11 - Soil Examples (Sheet 2 of 4)

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E : Field Exposure of Colluvium, Infilling a Small Valley on Ap Lei Chau, Hong Kong Island

F : Field Exposure of Alluvium in Stream Bank near Tong Yan San Tsuen, New Territories

Note : For full descriptions, see Section 3.9 .

Plate 11 - Soil Examples (Sheet 3 of 4)

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G : Exposure of Layered Fill in a Trial Pit at Peak Road, near Magazine Gap, Hong Kong Island

Note : For full descriptions, see Section 3.9 .

Plate 11 - Soil Examples (Sheet 4 of 4)

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APPENDIX A

NATURE AND OCCURRENCE OF HONG KONG ROCKS AND SUPERFICIAL DEPOSITS

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A.1 INTRODUCTION

Rocks and soils may be described for engineering purposes by the methods given in Chapters 2 and 3 respectively. The purpose of this Appendix is to explain the nature and occurrence of Hong Kong rocks and superficial deposits from the geological viewpoint.

Geological classifications of natural earth materials are based on characteristics such as lithology, chemistry, mode of formation and occurrence, and age. On the geological maps of the Hong Kong Geological Survey, a distinction is made between the solid lithified rocks, which include their insitu weathered mantles, and the transported superficial deposits. To most geologists, soil is the natural material which occurs above the lower limit of biological activity, and it is not included on the geological maps; an engineer tends to refer to this material as 'topsoil'. The differences between the engineering and geological uses of the terms 'rock', 'soil' and 'superficial deposits' are discussed in Section 1.2.1.

Solid rocks are classified into the following four broad types, based on their mode of formation :

(a) Igneous, which are crystalline or glassy rocks that are formed by the solidification of molten material known as 'magma'. They are either intrusive, solidifying beneath the earth's surface, or extrusive, erupting at the surface before cooling.

(b) Sedimentary, which are formed either from fragmented rock or material particles that have been transported by gravity, water, wind or ice, or from chemical precipitates from solutions or secretions by organisms. Sediments are often well stratified or have structures which indicate their mode of deposition.

(c) Pyroclastic, which are formed of fragments and particles of magma and pre-existing rocks that are ejected explosively from a volcano and which settle at the surface by sedimentation through air or water. These rocks share some features of both sedimentary rocks (i.e. they are fragmental and may be stratified) and igneous rocks (i.e. they are erupted at the surface).

(d) Metamorphic, which are derived from pre-existing rocks by mineralogical, chemical and structural changes. Metamorphism is caused by the effects of changing temperature, pressure, shearing stress and chemical environment acting on solid rocks.

Superficial deposits commonly mantle and obscure the underlying, older solid rocks. Most superficial deposits are sediments which, because they are geologically very young, have not yet been lithified to form solid sedimentary rocks. Both solid rocks and superficial deposits can be modified by weathering.

The following sections give a brief account of each of the four broad rock types and of the superficial deposits, plus some general information on structural geology and weathering. More detailed information of specific relevance to Hong Kong can be obtained from Bennett (1984a, 1984b, 1984c) and from numerous other references given by Brand (1988). The most detailed accounts of the distribution and nature of geological materials in Hong Kong are given in the series of maps and memoirs produced by the Hong Kong Geological Survey. The geological classification of rocks and superficial deposits used in the maps and memoirs is given in Table A1. All the rock types found in Hong Kong are illustrated in Plate A1.

Additional information on geological processes, and on the geological and engineering classifications of rocks and soils, can be found in the sources listed in Sections A.9 and A.10. In particular, the importance of geological processes in engineering has been well reviewed by Blyth & de Freitas (1984) and Leggett & Karrow (1983).

As with the remainder of this Geoguide, the meanings of all the specialised geological terms used in the following sections are given in the Glossary. Most of the entries in the Glossary are based on the definitions given by Bates & Jackson (1980).

A.2 IGNEOUS ROCKS

A.2.1 Nature

Igneous rocks are formed by the solidification of magma. They may be extrusive or intrusive, and these two types are distinguished by the large-scale form of the rock mass and its relationship to adjacent rocks. As this form may not always be readily apparent, the rock names used are not dependent on mode of occurrence (e.g. it is possible to have a basalt intrusion or a basalt extrusion). The normal methods of classifying igneous rocks are based on the relative abundance of selected minerals and the chemical composition. This is often supplemented by studies of the texture, as seen in the field and under a microscope.

A.2.2 Occurrence

Intrusive igneous rocks, which are very common in Hong Kong, are usually markedly crystalline. The grain size can vary from very fine (< 0.06 mm) to coarse (> 6 mm), and may be pegmatitic (> 20 mm). The intrusions of granite found in Hong Kong usually display a wide range of grain sizes, indicating a complex cooling history. In the simplest cases, the cooling of an intrusion results in a finer-grained margin near the contacts with other rocks. Minor intrusions, which are usually very fine-grained, may occur as dykes, which are near vertical, or as sills, which are roughly flat-lying. These small intrusions cut the older rocks in which they are found.

Extrusive igneous rocks, more generally described as 'lavas', have flowed from a volcanic vent or fissure. Lavas may occur as a single flow or a succession of flows, and may be interbedded with sediments.

A.2.3 Composition

The composition of igneous rocks, which is the basis for their classification, can be described in terms of the minerals present or the chemical composition. Most igneous rocks are derived from magma rich in

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silica, so nearly all the minerals are silicates. The commonest are quartz and feldspar (felsic), which are light in colour, but distinctive dark minerals (mafic), such as biotite, can alter the appearance of a rock when present in small amounts. Thus, a simple division of the igneous rocks based on mineral content can be made in terms of colour : leucocratic (light), mesocratic (medium) and melanocratic (dark).

The most widely-used classification of the crystalline igneous rocks (Streckeisen, 1974) is based on the relative proportions of quartz (Q), alkali feldspar (A) and plagioclase feldspar (P), from which such common names as granite, granodiorite and gabbro are defined. The proportions of these minerals are obtained by modal analysis, i.e. by measuring the actual percentage mineral composition, and the results are plotted on a QAP triangular diagram (Figure A1). The very fine or glassy igneous rocks, whose individual crystals cannot be distinguished, are classified on the basis of chemical composition (Cox et al, 1979). The rock types defined, such as rhyolite, dacite and basalt, have their equivalents in the QAP classification (Streckeisen, 1980). These equivalents are given in Figure A1, but, because different methods of classification are used, the correspondence with the chemical classification is not exact.

A.2.4 Chemical Types

Igneous rocks can be grouped together in related families based on their chemical composition. If the composition is not known in detail, the following simple system of classification can be used for Hong Kong rocks :

(a) Basic rocks, which are melanocratic, with usually more than about 30% dark minerals, and 44 to 54% silica (e.g. gabbro).

(b) Intermediate rocks, which are usually mesocratic, with less than 50% dark minerals, and 54 to 62% silica (e.g. andesite and syenite).

(c) Acid rocks, which are often leucocratic, with less than 20% dark minerals and more than 62% silica (e.g. granite and granodiorite).

A.2.5 Textures

The texture of an igneous rock is concerned with the size, shape and disposition of the constituent minerals. Intrusive rocks are predominantly crystalline, with grain boundaries interlocked, while extrusive rocks, which have cooled rapidly at the surface, are partly or dominantly glassy.

The textural feature of most importance in igneous rock classification is the dominant grain size of the groundmass. The very fine-grained rocks, (aphanitic), with a grain size of less than 0.06 mm, have crystals that cannot be distinguished with the naked eye. For larger grain sizes, there is a division into fine-, medium-, and coarse-grained rock (Table A1). The very coarse-grained (pegmatitic) rocks have grains larger than 20 mm.

Within the groundmass, there are often significantly larger crystals, termed 'megacrysts'. There is a wide variety of megacrystic textures, each

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indicating a different mode of occurrence of the megacryst, for example porphyritic and xenocrystic. Megacrysts may be aligned parallel to the flow direction in a rock; this is commonly seen in the syenites and monzonites, and also in lavas and narrow dykes. Where these textural differences result in a visible layering or banding, an igneous rock is said to have a 'flow-banded' structure.

A.2.6 Alteration

At a late stage in the crystallization of an igneous rock, the release of accumulated hot liquids and gases may alter the rock extensively. A typical example is kaolinization of granite, in which the feldspar is altered to kaolinite. Alteration is usually controlled by existing discontinuities in the rock mass, and there may be a gradation from, for example, completely altered granite adjacent to a discontinuity outwards into fresh granite.

A.2.7 Named Varieties

The varieties of igneous rocks found in Hong Kong are listed below. These notes are intended to highlight the differences between varieties.

(a) Granite, which is the most widespread igneous rock type, is a leucocratic, silica-rich (acid), crystalline rock composed of quartz, feldspar and dark biotite mica. The dominant feldspar is usually alkali. Granite forms major and minor intrusions, including very narrow dykes. Aplite dykes are generally granitic in composition, and are characterised by an equigranular fine-grained texture. Pegmatite is also usually granitic in composition, but is characteristically very coarse-grained.

(b) Granodiorite is a mesocratic, silica-rich (acid), crystalline rock composed of quartz, feldspar and abundant biotite (which results in a darker colour than granite). The dominant feldspar is plagioclase. Granodiorite forms major intrusions, typically seen at Tai Po, and sometimes forms dykes.

(c) Quartz syenite is a leucocratic to mesocratic crystalline rock with intermediate silica content, in which there is less than 20% quartz. The rock is mostly feldspar, with alkali feldspar dominant. The rock occurs as intrusions, for example at D'Aguilar Peak, and as large dykes, for example at Wong Chuk Hang. Quartz monzonite is related to quartz syenite, but plagioclase and alkali feldspar are present in roughly equal amounts. Examples can be found at Tai Wai, Sha Tin.

(d) Rhyolite is the very fine-grained equivalent of granite. The megacrysts of quartz (quartzphyric) or feldspar (felsparphyric) give the different rhyolites their character. Rhyolite is found as narrow dykes, for example at Kwai Shing and the Lower Shing Mun Reservoir, and as lava flows in the Clear Water Bay Peninsula and the Sai Kung Country Park.

(e) Dacite is the mesocratic, very fine-grained equivalent of granodiorite. There are usually megacrysts of quartz and feldspar, and biotite is often clearly seen. Dacite is either associated with the rhyolite as narrow dykes, as on Tsing Yi, or forms the margin to the granodiorite. Rocks which cannot be distinguished as either rhyolite or dacite are called 'rhyodacite', and can be seen on Mt. Stenhouse, Lamma Island.

(f) Quartz trachyte is the mesocratic, very fine-grained equivalent of quartz syenite. The rock is characterised by alkali feldspar megacrysts. It occurs as dykes, for example at Aberdeen, and on the margins of quartz syenite intrusions, as at Cape D'Aguilar. Quartz latite, the very fine-grained equivalent of quartz monzonite, is a related rock.

(g) Trachyandesite is intermediate, usually melanocratic and is very fine-grained. Megacrysts of alkali feldspar are common. It is found as lava flows in the Clear Water Bay area.

(h) Andesite is intermediate, usually melanocratic or mesocratic, and is very fine-grained. Megacrysts of feldspar and mafic minerals are common. Andesite is found as lava flows within the tuffs, as at Ma Wo (Tai Po) and Tuen Mun, and as dykes, as at Tsing Lung Tau.

(i) Gabbro and its very fine-grained equivalent, basalt, are basic, melanocratic rocks composed of an intergrowth of plagioclase feldspar and mafic minerals. These rocks are commonly found as narrow dykes; for example, gabbro at Diamond Hill and basalt at Siu Lam.

(j) Lamprophyre is a basic, melanocratic rock characterised by the abundance of mafic minerals, with feldspar only present in the groundmass. It is occasionally found as narrow dykes, for example at Rennies Mill.

A.3 PYROCLASTIC ROCKS

A.3.1 Nature

Pyroclastic rocks are formed by the lithification of material which has been ejected explosively from a volcanic vent. Materials from non-explosive volcanic eruptions are lavas, which are classified as igneous rocks (see Section A.2.2). Pyroclastic rock material is composed of glass and pumice, broken crystals and rock fragments. The rock fragments may be solidified magma from the vent, or material which formed the sides of or choked the vent. The majority of the material in a pyroclastic rock is of igneous origin, but since the rock is composed of fragmental material and is sedimented, it is classified in a manner similar to that used for sedimentary rocks.

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A.3.2 Composition

The normal method of classifying pyroclastic rocks is on the basis of composition and size range of the individual components or pyroclasts (Figures A2 and A3). Pyroclastic rocks may contain sedimentary material. Rocks with roughly equal amounts of pyroclastic and primary sedimentary material are 'tuffites', and are usually given the sedimentary rock name with 'tuffaceous' as a prefix (e.g. tuffaceous sandstone).

The largest pyroclasts are blocks and bombs, and, when lithified, become 'pyroclastic breccia' and 'agglomerate' respectively (Figure A3). Lapilli, equivalent in sediment grain size to gravel, are lithified to a 'lapilli tuff', less commonly called 'lapillistone'. Ash, which is equivalent in grain size to sand and mud, is lithified to 'coarse ash tuff' and 'fine ash tuff' respectively. It is very common to find poorly-sorted rocks containing a mixture of different-sized pyroclasts, and these are covered by the names 'tuff-breccia', 'lapilli-ash tuff' and 'ash-lapilli tuff'. When the composition is known in greater detail, it is possible to refine this nomenclature to give such rocks as 'lapilli-coarse ash tuff' and 'coarse ash-fine ash tuff'.

Pyroclastic rock names are qualified by a term which reflects the composition of the dominant variety of pyroclast. This is either 'vitric' (glass), 'crystal' or 'lithic', but in rocks older than Tertiary (c. 60 million years) it is very unlikely that glass will survive, as it rapidly becomes stable and microcrystalline. Therefore, in the pyroclastic rocks of Hong Kong, which are Jurassic in age (much older than the Tertiary), the term 'vitric' is used to describe fragments that are recognized from their shape and texture to have been glass when the rock was first deposited. An example of such a rock is eutaxite, a variety of vitric tuff, which is found, for example, on Mt Kellett and Razor Hill. The terms 'crystal' and 'lithic' refer to pyroclasts composed of crystals (or crystal fragments) and rock fragments respectively.

A.3.3 Types

Pyroclastic fragments are created by the explosive expansion of gases in a magma, by fragmentation of adjacent magmatic rocks from previous volcanic eruptions, or by the break-up of the basement rocks under the volcanic vent or fissure. On ejection from the vent or fissure, the fragments become either 'fallout deposits' or 'pyroclastic flow deposits', as follows :

(a) Fallout deposits have many structures that resemble those of sedimentary rocks. They are generally well-sorted when deposited in water, with well-defined, rapidly alternating beds. Such deposits are found in Hong Kong, but they are rare, only being seen at Lai Chi Chong, Sham Chung and Clear Water Bay.

(b) Pyroclastic flow deposits are formed of hot, gaseous, dense masses of material that move rapidly away from a volcanic vent. The material is usually a highly concentrated mixture of gases and solids. The resultant deposit may be stratified, but in Hong Kong it more usually forms massive, poorly-sorted units of great thickness. Most of the thick sequences of poorly-sorted tuffs in Hong Kong originated as pyroclastic flow deposits. However, the process of welding, in which

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there is viscous deformation of vitric fragments, can result in marked planar fabrics, which is a characteristic of eutaxite. When water has de-stabilised an existing unlithified pyroclastic deposit, the resulting water-transported, poorly-sorted material is known as a 'laharic' deposit. Both pyroclastic flows and, to a lesser extent, lahars are found in Hong Kong; the latter, for example, at Hong Lok Yuen.

A.4 SEDIMENTARY ROCKS

A.4.1 Nature

Sediment is produced by the weathering and erosion of pre-existing rocks, or by chemical or biochemical precipitation. Sedimentary rocks produced by the lithification of the transported products of weathering are termed 'detrital' sedimentary rocks. Those produced by chemical precipitation or biochemical action are 'chemical' and 'biochemical' sedimentary rocks; for example, salt deposits and limestone. Generally, when a sediment has been deposited but not lithified, it is called a 'superficial deposit' (see Section A.6).

Sediments, and the rocks produced from them, are classified on the basis of the size of the constituent particles, mineralogical composition and origin. The system adopted by the Hong Kong Geological Survey is based on the 2-6 grain size divisions which are commonly used for the engineering description of soils (Table A1).

A.4.2 Detrital Sedimentary Rocks

A.4.2.1 Types

Detrital sedimentary rocks are divided on the basis of grain size into 'rudaceous' (gravelly), 'arenaceous' (sandy) and 'argillaceous' (clayey and silty).

A.4.2.2 Rudaceous Rocks

Lithified deposits of gravel, which may include cobbles and boulders, are called 'conglomerate' when the particles are rounded, and 'sedimentary breccia' when they are angular. The coarse particles may all be one type of rock, or they may be derived from more than one source rock. The matrix, which is subordinate, is either sand or silt and may be cemented. Conglomerates can be found at Harbour Island and at Brides Pool, and sedimentary breccias on Yim Tin Tsai in Tolo Harbour. Sedimentary breccia is so-called to distinguish it from fault breccia, pyroclastic breccia and other genetic types.

A.4.2.3 Arenaceous Rocks

Lithified deposits of material in which sand is the dominant grain size are sandstones. There is commonly fine material (silt or clay) between the sand grains, and when the amount of this finer matrix is less than 15%, the sandstone is called an 'arenite'. When the matrix exceeds 15%, the rock is a 'wacke'. The cement which binds the sand particles together to form a rock is either silica, iron oxides, clay or carbonates.

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Arenaceous rocks in Hong Kong can be split into the following four main types :

(a) Quartzose sandstone is nearly all quartz, cemented by silica. It is generally well-sorted, well-rounded and clay-free, probably being composed of material that has travelled a long way from the source rock. Examples can be seen on Bluff Head.

(b) Feldspathic sandstone contains many feldspar grains, indicating relatively rapid erosion and deposition close to the source. Examples can be seen at The Chinese University and Tai Po Kau.

(c) Lithic sandstone is very variable, containing recognizable fragments of other rocks. Although usually associated with rivers, it can be deposited in any environment. Examples can be seen at Sham Chung and on Yim Tin Tsai.

(d) Calcareous sandstone is a sandstone cemented by calcareous material in which the clasts are not themselves calcareous. An example is the beach rock containing tuff clasts and calcareous cement found at Tau Chau, Repulse Bay.

A.4.2.4 Argillaceous Rocks

Both siltstone and claystone can be recognized in Hong Kong, but, because of the difficulty in distinguishing grain sizes of lithified material, it is usual to restrict the term 'siltstone' to rocks composed of the coarser silt grains, and to use 'mudstone' or 'shale' for all finer mixes. Mudstones are non-fissile, while shale is fissile; shale should not be confused with slate, which has a metamorphic fissility (cleavage). Apart from fissility, the important characteristics of the argillaceous rocks are colour, sedimentary structures and non-clay material (e.g. sand grains, organic matter, fossils). Good examples of siltstones are found on Ping Chau. Mudstones can be seen at Fei Ngo Shan, and graphite-bearing mudstones can be found on Mo To Chau.

A.4.3 Chemical and Biochemical Sedimentary Rocks

A.4.3.1 Types

The dominant types of chemical and biochemical rocks are limestones (calcium carbonate) and dolomites (calcium magnesium carbonate). There are also siliceous rocks and evaporites in this group.

A.4.3.2 Limestone and Dolomite

Although essentially chemical or biochemical in origin, these rocks may contain fragmented material, e.g. broken calcareous fossils. Non-carbonate material, such as sand grains and chert, may also be present in small amounts. Limestone occurs in Hong Kong beneath the alluvium in the Yuen Long area.

Most of the limestone has been metamorphosed to marble. Dolomite is found offshore from Ma Shi Chau and possibly in the Ma On Shan mine.

A.4.3.3 Chert

Chert is an organic or inorganic precipitate of silica; the silica is mostly cryptocrystalline quartz, but may be amorphous in part (opal). Impurities in chert give it different colours, and flint is synonymous with one of the darker varieties. Chert is either bedded or nodular; nodular chert is common in limestone, and bedded chert can be found on Ping Chau. Chert lenses associated with pyroclastic rocks are found on the western shores of Junk Bay.

A.4.3.4 Evaporites

Evaporites include gypsum, anhydrite and halite. They are often associated with mudstones and siltstones, forming in shallow basins which are periodically flooded and dried out; this association can be seen on Ping Chau, although only evaporite mineral pseudomorphs can be seen.

A.5 METAMORPHIC ROCKS

A.5.1 Nature

Metamorphism describes the process of production of new minerals, structures and textures in pre-existing rocks, excluding the processes of weathering. There are three types of metamorphism, based on the variables of pressure due to depth of burial, temperature, strain resulting from stress applied during deformation, and fluid pressure :

(a) thermal or contact metamorphism, characterised by high temperature, low pressure and low strain,

(b) dynamic metamorphism, characterised by high strain and high fluid pressure, and

(c) regional metamorphism, characterised by high temperature and high pressure.

These three types overlap considerably, but thermal and dynamic metamorphism are restricted to localised areas, respectively, along the edges of large intrusions and on narrow thrusts and faults.

A.5.2 Contact Metamorphism

Both heat and hot fluids from a large intrusion of igneous rock affect a narrow belt of country rock surrounding the intrusion. Thermal metamorphism takes place within this contact aureole, affecting different country rocks in different ways. Mudstones and impure carbonates show the greatest mineralogical changes, e.g. the mudstones at The Chinese University which have been affected by the major granite intrusion in the Sha Tin area. The least affected are those possessing mineral assemblages which are stable at temperatures as high as those of the intruding granite, e.g. sandstones and vitric tuffs on Victoria Peak.

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In mudstones, these changes start as spotting of the rock, often caused by new mineral growth, while close to the intrusion complete recrystallisation gives a hornfels, a hard glassy rock with no fabric. Thermally metamorphosed limestones become marbles, as at Yuen Long, and skarns (calcium-bearing silicate minerals), as reported in the Ma On Shan mine. Sandstones become quartzite, e.g. at Sandy Bay, but impurities in the sediment can give small quantities of new minerals such as sillimanite, andalusite and muscovite, e.g. behind Belcher's Street, Kennedy Town.

A.5.3 Dynamic Metamorphism

The high shear stress in fault zones results in crushing of the wall rocks, allowing mobile fluids to develop high fluid pressures. Temperatures can be raised locally, but there is no regional heating. The processes and rock types associated with faulting can be split into three types :

(a) Brittle faults, which give cataclasites such as fault breccia and fault gouge. These rocks are non-foliated, and can be seen in places such as Lai Chi Kok and northwest Tai Lam Country Park.

(b) Ductile faults, which give mylonites, i.e. finely crystalline rocks containing survivor megacrysts. These rocks are generally foliated, and can be seen throughout the granite of the Castle Peak area. When green (chlorite-rich) and shiny, they are called 'phyllites', e.g. in the Lok Ma Chau Formation sediments of Mouse Island, Tuen Mun.

(c) Ductile flow, which gives metamorphic rocks characterised by a penetrative foliation such as schist. Examples of schist can be seen within the metatuffs of the northern New Territories.

Although thrusts and faults are limited in width, often a large number of them can be found in belts several kilometres wide. Shear stresses and fluid pressures in these belts can lead to the formation of such minerals as sericite (fine muscovite), pyrite and calcite. All these features can be found in the northern New Territories.

A.5.4 Regional Metamorphism

Regional metamorphism is achieved by ductile flow under high temperature and pressure in broad belts of folded or sheared rocks. A broad belt of metamorphic rocks, which includes schists, metatuffs and phyllites, occurs in the southern part of Guangdong Province and extends into the northern New Territories.

A.6 SUPERFICIAL DEPOSITS

A.6.1 Types

Superficial deposits are those sediments that have not been lithified to form rocks. The classification of superficial deposits and sedimentary rocks is essentially the same. The most important types of superficial deposits in Hong Kong are mass wasting deposits or colluvium (see below), fluvial deposits, and marine deposits. Some small quantities of organic deposits are also found.

A.6.2 Mass Wasting Deposits

In Hong Kong, mass wasting deposits (commonly called 'colluvium') are predominantly debris flow deposits and comprise heterogeneous mixtures of sediment and rock. They are formed by the rapid downslope movement of saturated masses of material, predominantly by flow (i.e. the moving mass does not contain discrete shear or slide surfaces and has the general appearance of a body that has behaved as a fluid). Other types of slope movement (e.g. rock slides, debris slides) and slow soil creep also contribute to the formation of mass wasting deposits. These deposits usually collect in valleys and at the bases of slopes, for example in the Mid-levels area. The deposits frequently grade into river deposits (alluvium) or marine deposits at the foot of a slope.

Some other, less common, types of mass wasting deposit are boulder fields and screes. Boulder fields are accumulations of boulders on a slope, which result from large pieces of rock being weathered and eroded from outcrops higher upslope, or by the eluviation of fines from a weathered mantle or from sheets of boulder-rich debris flow deposits. Boulder fields commonly grade downslope into boulder streams along valleys and depressions. Examples can be seen at Cape D'Aguilar and Lin Fa Shan. 'Talus' or 'scree' is coarse material which has weathered and fallen from a rock face and accumulated on or at the base of a slope; good examples can be seen below Lion Rock.

A.6.3 Fluvial Deposits

These deposits are collectively known as 'alluvium'. In Hong Kong two ages of fluvial deposition are recognized; Holocene alluvium, found next to existing rivers and stream courses, and older alluvium, found in higher terraces and offshore beneath the Holocene marine deposits. Both are composed of similar materials, dominantly silt, but with significant amounts of sand, gravel and clay. The older alluvium is evidence of a more extensive floodplain. Examples can be seen around Yuen Long and Shek Kong. A widespread development of this older alluvium occurs offshore, beneath marine deposits, which indicates a much lower sea-level at the time of its deposition. Small patches of alluvium can also be found on high ground, where a natural constriction in an upland valley has resulted in the valley being infilled by locally reworked colluvial debris.

A.6.4 Marine Deposits

Marine superficial deposits in Hong Kong have accumulated on older alluvial deposits and the pre-Holocene eroded rock surface. The commonest material is a light or dark grey, or greenish grey, mud. Deposits of sand are also found on the floors of contemporary deep-water channels and in other areas of strong currents. Older sand deposits can also be found buried beneath mud. Close to the present coastline, the most distinctive marine deposits are sand beaches, which are accumulations of fluvially-derived sand washed onto the shore by waves and currents. Storm beaches and raised beaches are two other beach types, but these are much less common. The former are the result of unusually high waves (e.g. due to typhoons) and the

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latter are remnants of older beaches associated with periods of higher sea-level. Estuarine fans and deltas of sand and silt are other types of distinctive marine deposit. Examples of beach deposits, estuarine fans and a delta can be found at Lung Kwu Tan, Tai Po and Nim Wan respectively.

A.6.5 Organic Deposits

The main type of organic deposit in Hong Kong is peat, which is a dark accumulation of organic material that has not fully decayed because of its very high moisture content. Peat is derived from organic debris which has accumulated in poorly-drained level sites. There is usually some sediment within the peat, and the depositional environment is often similar to that of river deposits. Peat can be found interbedded with sediments south-west of Yuen Long.

A.7 STRUCTURAL GEOLOGY

A.7.1 General Aspects

Geological structures in rocks and superficial deposits can be divided into faults and other fractures, and folds. Associated with folds are minor structures such as foliations, lineations and mineral fabrics.

A.7.2 Faults and Other Fractures

Rock fractures (discontinuities) are the commonest of geological structures, and can be defined as surfaces in a rock mass across which the cohesion of the rock material is lost. The two most important types of fracture are faults and joints. Where there has been visible movement along the surface, the fracture is a 'fault', otherwise it is a 'joint'. This distinction is somewhat arbitrary, since nearly all fractures involve some movement, however slight.

At or near the surface, faults can be classified into three types, depending on the orientations of the principal stresses :

(a) normal faults, with the maximum compressive stress vertical,

(b) low-angle reverse faults or thrusts, with the maximum compressive stress horizontal, and the minimum vertical, and

(c) strike-slip or wrench faults, with the maximum and minimum compressive stresses both horizontal.

Faults are often found arranged in sets (i.e. in groups with similar orientation). Major faults may have associated minor faults. Fault planes vary from single shear planes, which may be polished and smoothed, to fault zones in which the associated rocks are broken to fault breccia or fault gouge, or converted to a mylonite (see Section A.5.3).

Another feature associated with faulting is 'slickensiding'. Slickensides are polished and finely striated surfaces that result from friction along a fault plane. Although slickensides are used as movement direction indicators, they are not reliable. At best they only indicate the direction of movement during their formation, which may not be the main movement phase.

Joints commonly develop in regularly-spaced sets, which may be geometrically related to tectonic stress and the form of the rock body. However, it is virtually impossible to establish the relative ages of joints of different orientations, which makes systematic analysis difficult. The following three main types of jointing can be recognized :

(a) Tectonic joints, which are regular sets produced by regional compression or extension. Their orientation can give an indication of the stress field. They are related in origin to faults or folds, and there is often a symmetrical arrangement of these three features. In Hong Kong, such joints are well displayed in the granites, particularly at Castle Peak.

(b) Cooling joints, which result from the contraction of an igneous, pyroclastic or other heated rock body. These joints may form polygonal columns which have their axes perpendicular to the surface of the hot rock mass, but they may also be parallel to the surface of the body. A well-known example is the marked columnar jointing in the trachyandesites and welded tuffs in the High Island area of the Sai Kung peninsula.

(c) Unloading or sheeting joints, which result from expansion of the rock mass as the confining pressure is reduced, usually by erosion. These joints are usually parallel or near-parallel to the erosional surface, and are well displayed on Po Toi Island, at Cape D'Aguilar and at Siu Lam.

The surfaces of joints can vary widely in texture and may have been altered, weathered, or coated with minerals. Individual joints are usually reasonably straight, but may be curved or show sharp changes in direction. Joints close to the surface may be opened by weathering and infilled by superficial deposits or the products of insitu weathering.

A.7.3 Folds

A fold is a curve or bend in the rock structure, and its recognition requires the presence of a planar feature such as rock stratification, foliation or cleavage. Although a relatively homogeneous rock mass, such as a granite intrusion, may be folded, if there are no planar markers within the rock mass the fold cannot be seen. Fold structures may be complex when the rocks have been affected by more than one period of folding.

Folds are classified by attitude into three main types :

(a) synclines, which are folds that close downwards, with the beds younging towards the centre,

(b) anticlines, which are folds that close upwards, with the beds younging away from the centre, and

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(c) neutral folds, which are folds that close sideways.

The geometry of folds can be described further by the angle of dip of the axial plane from vertical to horizontal (using the terms 'upright', 'inclined', 'overfolded' and 'recumbent'), and by the angle between the opposing fold limbs from 0° to over 120° (using the terms 'gentle', 'open', 'close', 'tight' and 'isoclinal'). These terms are defined in the Glossary.

Major folds may be many kilometres across, as is the Tolo Channel Anticline, or hundreds of metres across, as are those found on Victoria Peak. Minor folds, visible in small exposures, often mirror the form of the major folds and are then called 'parasitic' folds. Good examples of these folds can be seen on Ma Shi Chau.

A.8 WEATHERING

A.8.1 General Aspects

Weathering is the process responsible for the breakdown and alteration of materials near the earth's surface. In igneous, pycroclastic and metamorphic rocks, it is the response of rocks to lower temperatures and stresses than those that prevailed at the time they were formed. In most sedimentary rocks, whose constituent minerals have previously been weathered to some extent, it is chiefly the response of the cementing agent in the rock to atmospheric conditions (i.e. the presence of oxygen and weak acids). In superficial deposits, the weathering of individual minerals may still be continuing at the present. The weathering process can be divided into the two main categories :

(a) mechanical weathering (or disintegration), which is caused by stresses, from both within the rock and as applied externally, that disrupt the rock fabric, and

(b) chemical weathering (or decomposition), which involves chemical reactions that transform minerals to more stable forms in the new environment.

The susceptibility of different rock types to disintegration and decomposition may differ markedly. Where two or more rock types are present together, e.g. where there is an igneous intrusion into another rock, relatively more weathered rock may occur beneath or adjacent to less weathered rock, and such a sequence may be repeated.

Weathering profiles may be of considerable age on a geological time scale. Consequently, they do not necessarily reflect the response of the rocks to the present climate. Also, they may have been partly removed by subsequent erosion. Rock exposed in a recent excavation may be affected by subsequent mechanical or chemical weathering effects, or both, under prevailing climatic conditions.

A.8.2 Mechanical Weathering

Mechanical weathering is brought about chiefly by changes of stress and temperature at or near the exposed rock surface. The important physical processes involved are expansion of water on freezing in rock pores or cracks,

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reduction in confining stress by erosion of overlying material, and differential expansion of the rock or rock minerals when strongly heated by insolation. The expansion of certain minerals in joints is also caused by chemical reactions such as hydration and oxidation, so that in some respects mechanical and chemical weathering are not easily separated and produce similar effects. A common form of mechanical weathering is exfoliation, which is the scaling or peeling-off of flakes and curved shells of rock blocks, as can be seen at To Kwa Wan. The biological components of mechanical weathering include breakdown of rocks by plant roots and animals.

A.8.3 Chemical Weathering

Chemical weathering is brought about mainly by the action of substances dissolved in rainwater and circulating groundwater. The intensity of chemical weathering is controlled by the rates of decomposition of individual minerals and the removal of decomposed minerals from the rock. Silicate minerals, the most important rock-forming group, are broken down by hydrogen ion introduction, oxidation of ferrous to ferric ions, and hydration. Clay minerals are the chief residual products of feldspar decomposition, while clay, chlorite and limonite are produced from the decomposition of mafic minerals such as biotite. These products are commonly removed by eluviation and erosion, which allows the process of chemical weathering to progress. The biological components of chemical weathering include changes in soil pH and the formation of complex organic-mineral substances.

In limestone or marble, solution is the dominant aspect of chemical weathering. Distinctive landforms are produced, notably 'karst' topography. This is characterised by sinkholes, caves and underground drainage, and has been found buried beneath superficial deposits at Yuen Long.

A.8.4 Weathering Features

The following examples of weathering features are found in Hong Kong :

(a) Weathered mantle, which is the entire depth of the weathering profile, excluding any transported material at the top.

(b) Weathering front, which is an essentially planar surface at the downward limit of active weathering within the rock mass. A sharp well-defined weathering front is a relatively rare feature, but good examples can be seen on Tai Tam Reservoir Road.

(c) Colour banding, and the more structured spheroidal weathering, which are caused by alternating enrichment and depletion of iron oxides. Colour banding can be seen in sediments on the west side of Three Fathoms Cove.

(d) Joint hardening, caused by the migration and deposition of ferromagnesian minerals, which makes the joints stand out on erosional surfaces. Examples can be seen at Ma Shi Chau and on the east side of Deep Bay.

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(e) Weathering pits, caused by the preferential weathering of different lithologies, e.g. mudstone lapilli in tuff, or of different crystals in homogeneous rocks such as granite. Examples can be seen in the tuffs north of Tsuen Wan and in granite on Hammer Hill.

(f) Mineral boxwork, which is similar to joint hardening, but in this case the hard substance is an unaltered iron mineral deposit. This can be seen in the granodiorite of Cape D'Aguilar.

(g) Tors and corestones, which are piles of jointed rocks (tors), for example as at To Kwa Wan, or single blocks (corestones). However, the term 'corestone' should be applied only to blocks within the weathered mantle which are not in contact with solid rock.

(h) Solution grooves and basins, which are normally associated with soluble rocks such as limestone, but may also develop on siliceous rocks. Examples can be seen in granite on Hammer Hill and in tuff in the Tai Po Kau Nature Reserve.

(i) Karst topography, described under chemical weathering in Section A.8.3.

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Table A1 - Classification of Solid Rocks and Superficial Deposits in Hong Kong

Superficial Deposits		Grain Size (mm)	Solid Rocks: Sedimentary Rocks – Detrital Rocks	Sedimentary Rocks – Chemical & Biochemical Rocks	Pyroclastic Rocks	Igneous Rocks	Igneous – Acid	Igneous – Intermediate	Igneous – Basic	Metamorphic – Foliated	Metamorphic – Non-Foliated
Boulders			Conglomerate / Sedimentary Breccia	Limestone and Dolomite, Evaporites	Pyroclastic Breccia		Pegmatite				
		200									
Cobbles											
		60									
Gravel	Coarse				Lapilli Tuff	Coarse-grained	Granite; Granodiorite	Quartz Monzonite; Quartz Syenite	* Gabbro; Lamprophyre		Fault Breccia; Quartzite; Marble
		20									
	Medium										
		6									
	Fine					Medium-grained			*		
		2									
Sand	Coarse		Sandstone		Coarse Ash Tuff	Fine-grained	Aplite		*	Schist	
		0.6									
	Medium										
		0.2									
	Fine										
		0.06									
Silt	Mud		Siltstone; Mudstone		Fine Ash Tuff		Rhyolite; Rhyodacite; Dacite	Quartz Latite; Quartz Trachyte; Trachyandesite; Andesite	* Basalt	Phyllite / Mylonite	
		0.002									
Clay	Mud		Claystone	Chert							

Legend :

* Equivalent to Dolerite in Allen & Stephens (1971)

Note : This table is based on the classification scheme used by the Hong Kong Geological Survey.

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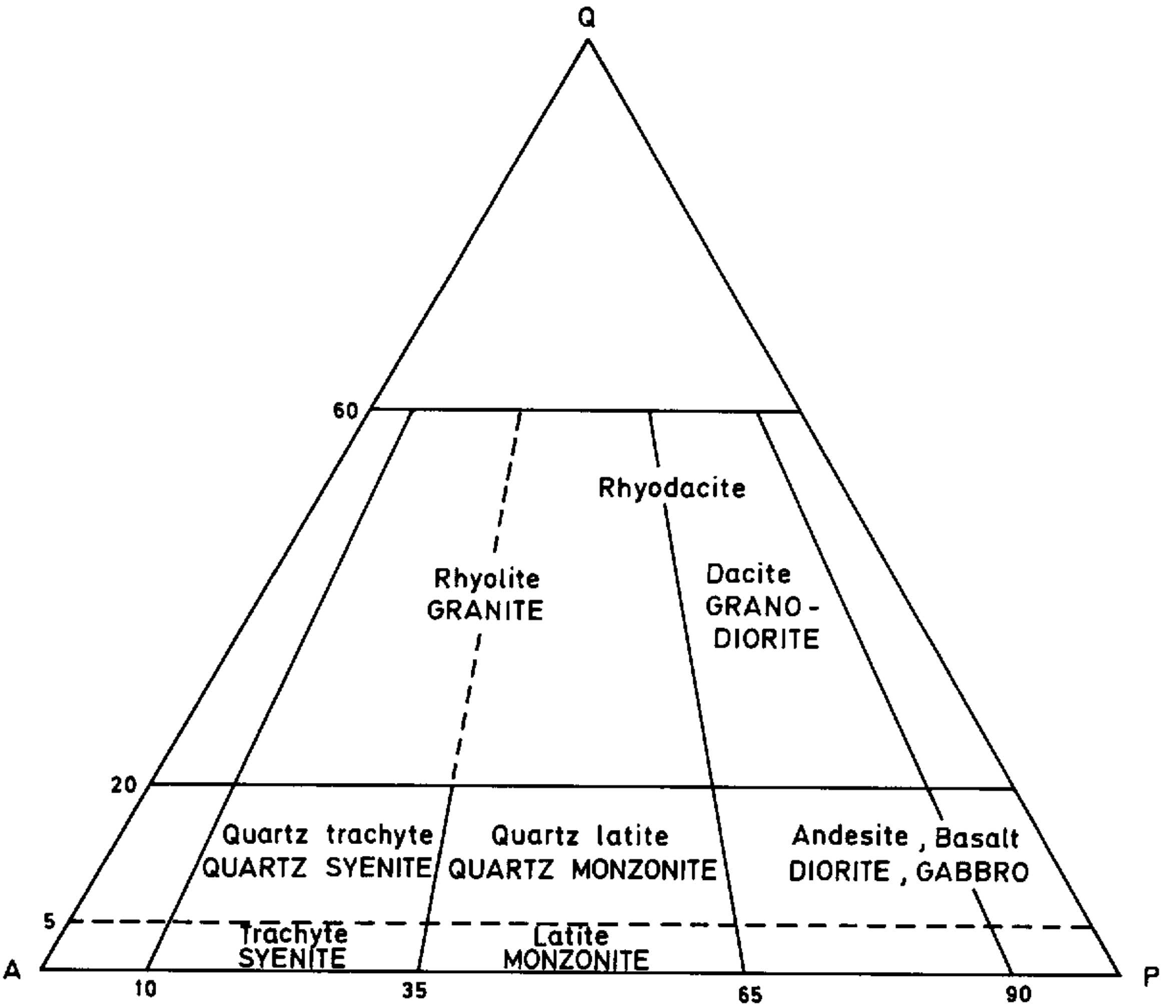

Legend :

Q	Silica minerals
A	Alkali feldspar
P	Plagioclase feldspar

Notes : (1) Plutonic in capitals; volcanic in lower case .
(2) Classification after Streckeisen (1974, 1980).

Figure A1 - Classification of Hong Kong Igneous Rocks

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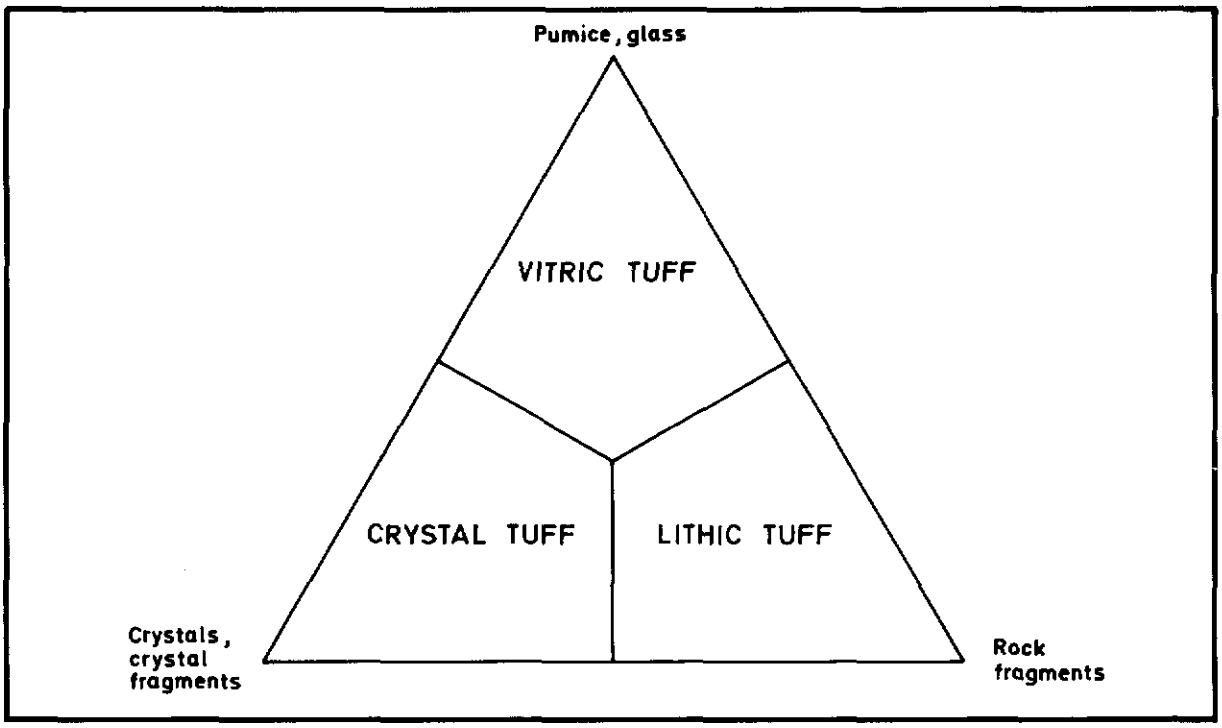
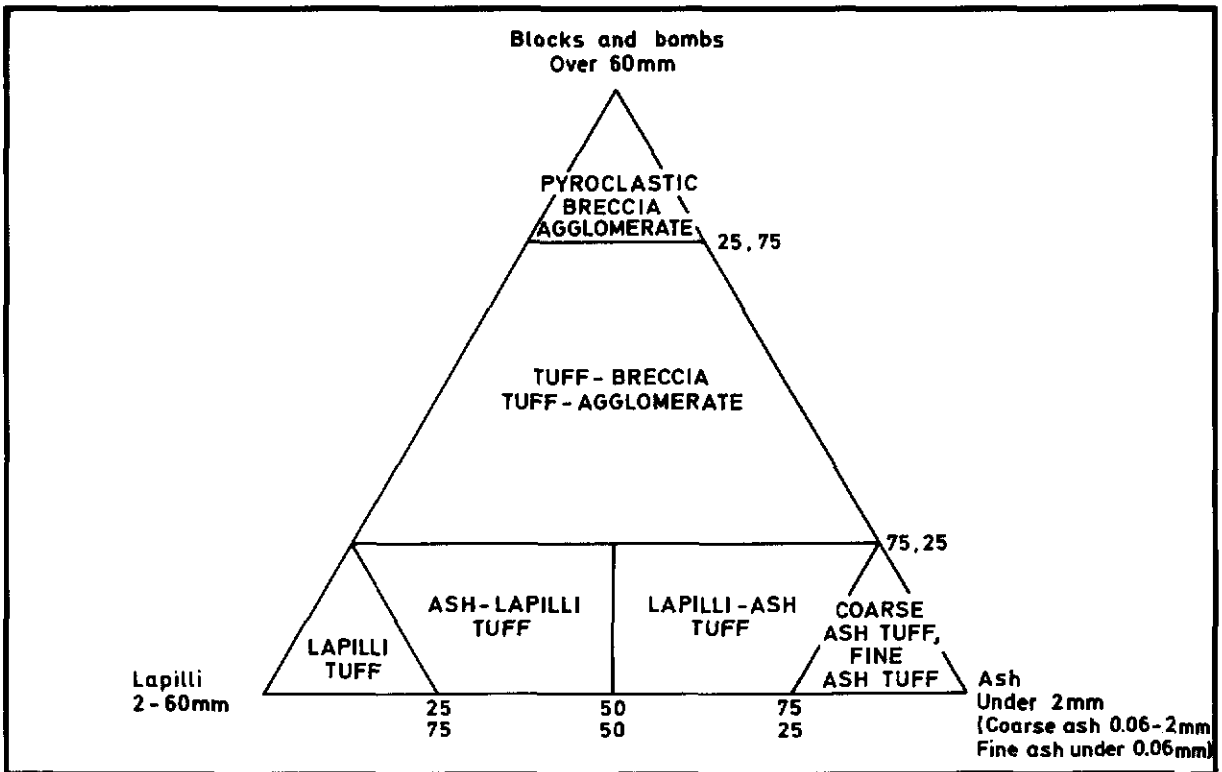


Figure A2 - Pyroclastic Rock Composition



Note : Figure adapted from Fisher and Schmincke (1984).

Figure A3 - Pyroclastic Rock Names

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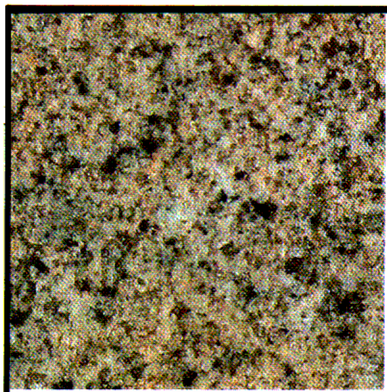
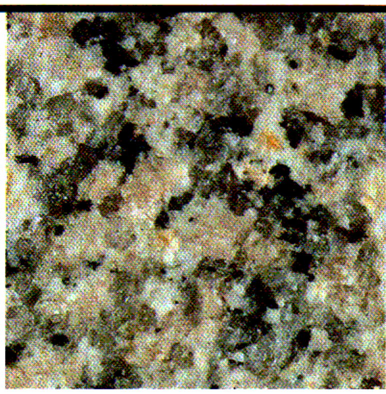
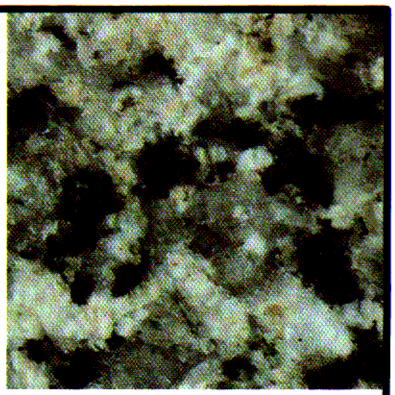


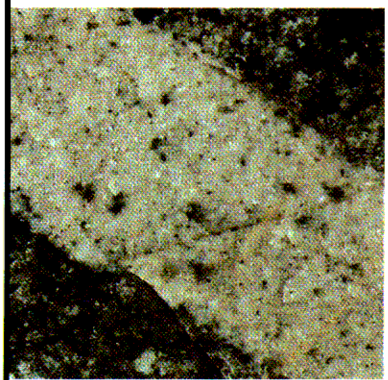
A: Fine-grained Granite



B: Medium-grained Granite

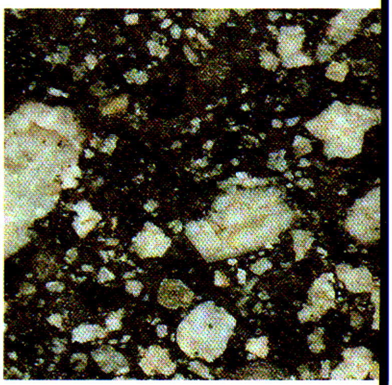


C: Coarse-grained Granite

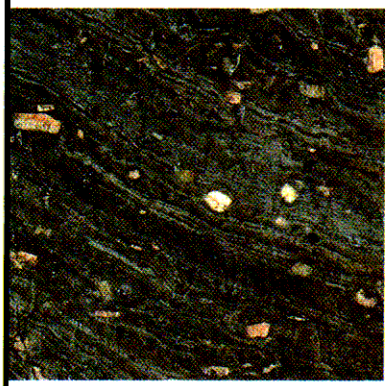


D: Aplite
(intruding granodiorite)

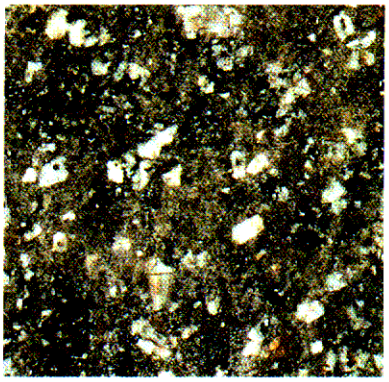
E: Pegmatite



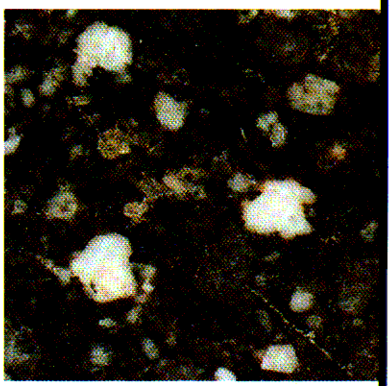
F: Granodiorite



G: Rhyolite



H: Rhyodacite



I: Dacite

Natural scale

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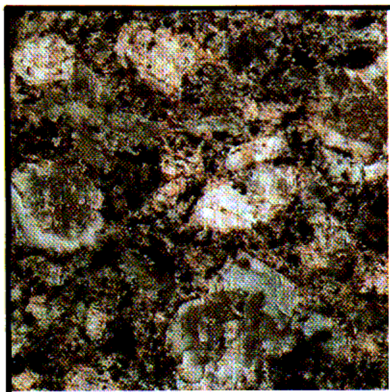
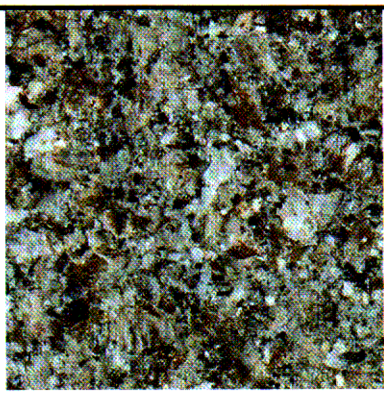
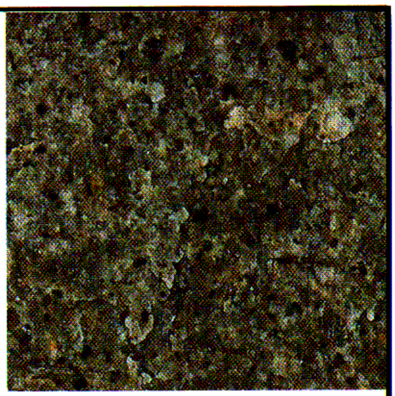
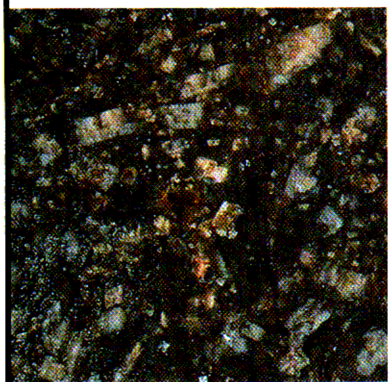
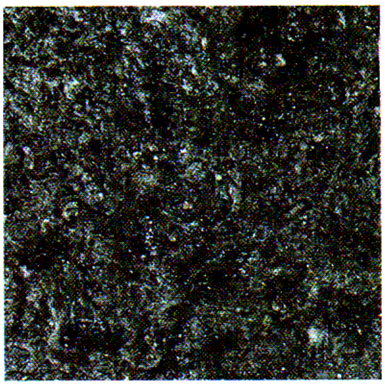
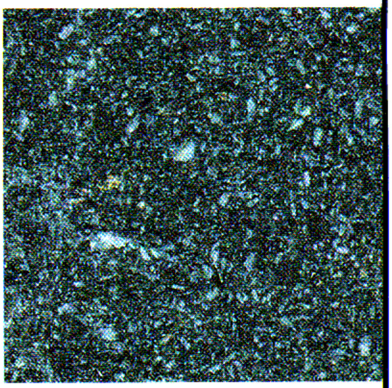

J : Quartz Monzonite

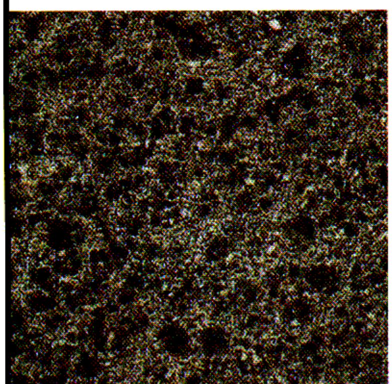

K: Quartz Syenite

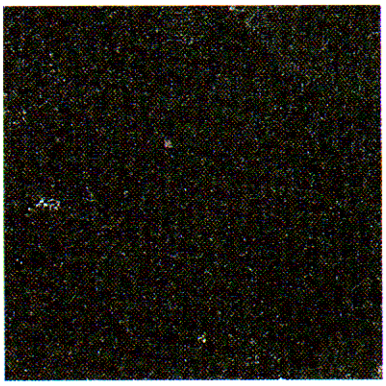

L: Quartz Latite

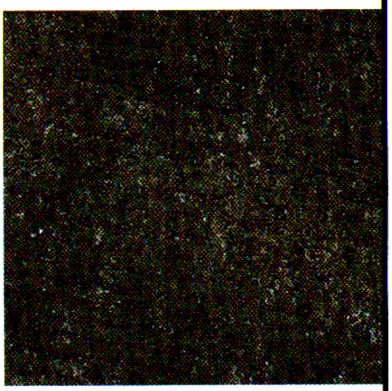

M: Quartz Trachyte


N: Trachyandesite


O: Andesite


P: Gabbro


Q: Basalt


R: Lamprophyre

Natural scale

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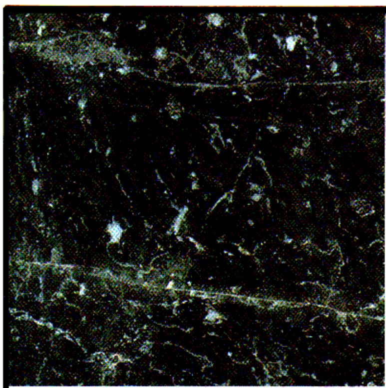
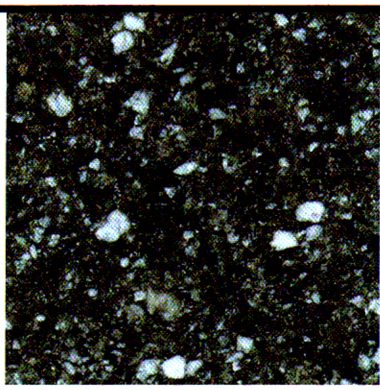
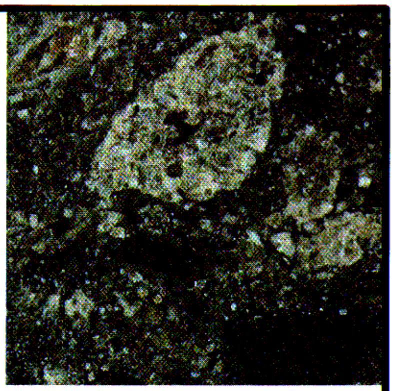


S: Fine Ash Tuff

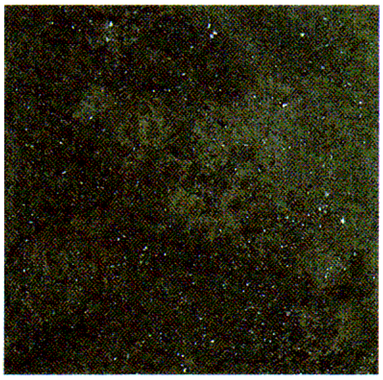


T: Coarse Ash Tuff

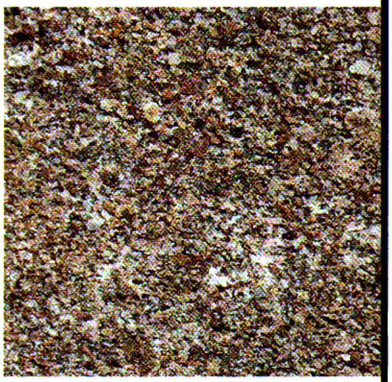


U: Lapilli Tuff

V: Pyroclastic Breccia (× 1/2)



W: Mudstone



X: Sandstone

Y: Conglomerate

Z: Sedimentary Breccia

AA: Chert

Natural scale

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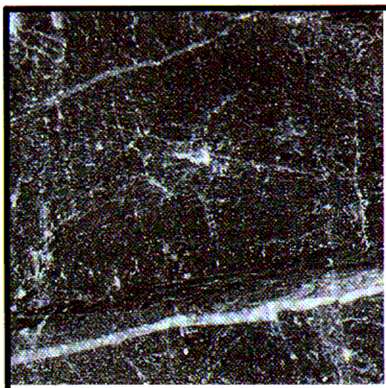
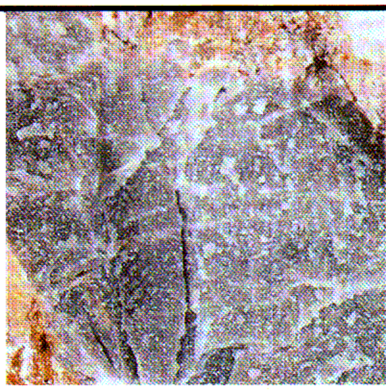


AB: Limestone

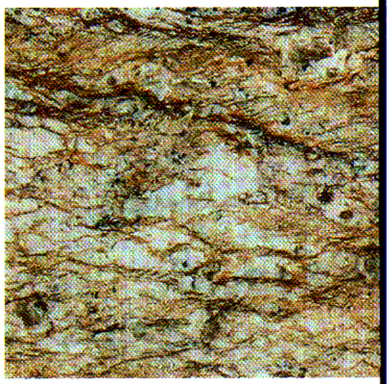


AC: Dolomite

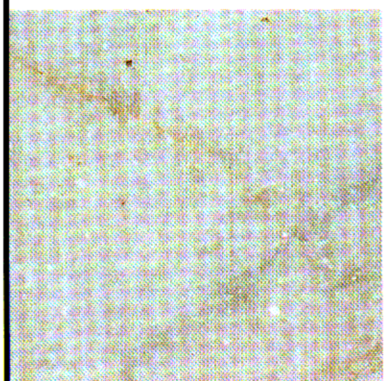
AD: Evaporite

AE: Mylonite

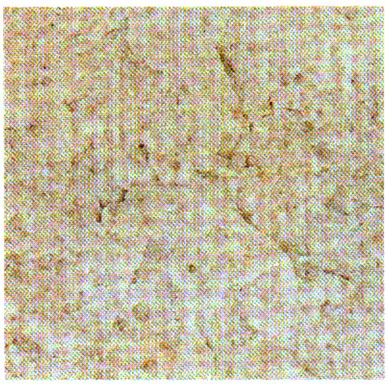
AF: Phyllite



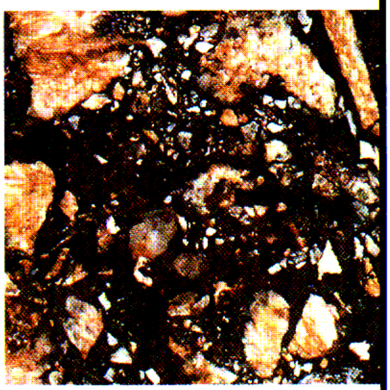
AG: Schist



AH: Marble



AI: Quartzite



AJ: Fault Breccia

Natural scale

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GLOSSARY

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Acid. Chemical term for an igneous rock containing more than 62% silica and usually less than 20% dark minerals. (Contrast with 'intermediate' and 'basic').

Agglomerate. Pyroclastic rock composed predominantly of rounded bombs of material greater than 60 mm average dimension. (Contrast with 'pyroclastic breccia').

Alkali feldspar. Group of feldspars composed of mixtures, or mixed crystals, of potassium feldspar ($KAlSi_3O_8$) and sodium feldspar ($NaAlSi_3O_8$). (See 'feldspar').

Alluvium. Detrital material of any grain size transported and deposited during comparatively recent geological time by a river or stream.

Amorphous. Term for a mineral or other substance that lacks crystalline structure and has no characteristic external form. Structural term for an organic soil with no recognizable plant remains.

Andalusite. Brown, yellow, green, red or grey silicate mineral which occurs in thick, nearly square prisms in schists, gneisses and hornfelses.

Andesite. Dark-coloured, very fine-grained, intermediate igneous rock. Often occurs in the form of lava flows. Commonly contains megacrysts of plagioclase feldspar and mafic minerals.

Angular. Shape term for a rock particle with sharp edges and corners.

Anhydrite. White or light-coloured mineral consisting of calcium sulphate ($CaSO_4$). Essentially a slightly harder and less soluble form of gypsum.

Anticline. Fold in the form of an arch whose core contains the stratigraphically older rocks.

Aphanitic. Textural term for a rock in which the individual constituents are not visible to the naked eye.

Aplite. Light-coloured, equigranular, fine-grained igneous rock of granitic composition. Very uniform and smooth-textured appearance. Commonly occurs in the form of narrow dykes.

Arenaceous. Term for a sedimentary rock composed wholly or predominantly of sand-sized grains.

Arenite. Arenaceous sedimentary rock containing less than 15% silt and clay material. (Contrast with 'wacke').

Argillaceous. Term for a sedimentary rock composed wholly or predominantly of silt- and/or clay-size particles.

Ash. Pyroclastic rock material of sand-, silt- and clay-size (i.e. $<$ 2 mm), subdivided into coarse ash for sand-size and fine ash for silt- and clay-size. Descriptive term for tuff composed wholly or predominantly of these grain sizes.

Aureole. Zone surrounding an igneous intrusion in which the country rock shows the effects of thermal or contact metamorphism.

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Axial plane. Plane that connects the points of maximum curvature of the bedding planes or other structural rock surfaces in a fold.

Banded. Structural term for a rock with alternating layers of material of differing colour or texture, possibly of differing mineral composition also.

Basal. Pertaining to, situated at, or forming the base of a geological structure. 'Basal layer' refers to the lowest layer in a layered rock or soil.

Basalt. Dark coloured, very fine-grained igneous rock composed mainly of plagioclase feldspar and mafic minerals. Often occurs in the form of lava flows. The very fine-grained equivalent of gabbro.

Basic. Chemical term for an igneous rock containing 44 to 54% silica and usually more than 30% dark minerals. (Contrast with 'acid' and 'intermediate').

Bedded. Structural term for a sedimentary rock or superficial deposit formed, arranged or deposited in layers or beds > 20 mm thick.

Biotite. Black, dark brown or dark green mineral of the mica group. Forms distinctive shiny thin prisms or flakes. Very common in crystalline igneous and metamorphic rocks.

Block. Rock fragment derived from the sides of a volcanic vent. Commonly angular or subangular. Restricted to pyroclasts > 60 mm diameter. Also a more general term for individual pieces of rock bounded by discontinuities in a rock mass.

Blocky. Shape term for a rock mass with three approximately orthogonal and equally-spaced joint sets, such that individual rock blocks tend to be roughly equidimensional.

Bomb. Partly molten material from a volcanic vent which solidifies in flight or shortly after landing. Restricted to pyroclasts > 60 mm diameter.

Boulders. Rock fragments greater than 200 mm in size.

Breccia. Coarse-grained rock composed of angular broken rock fragments held together by a mineral cement or in a fine-grained matrix. (Contrast with 'conglomerate'). May be of sedimentary or pyroclastic origin, or may be formed by crushing of any type of rock in a fault zone.

Cataclastic. Term for the structure of a rock which has been broken up severely by strong dynamic metamorphism or faulting. Common features are bent, broken or ground-up minerals. 'Cataclasite' is the name for any rock showing cataclastic structure.

Calcareous. Term applied to a rock containing an appreciable amount of calcium carbonate, e.g. calcareous sandstone.

Calcite. White, light grey, yellow or blue, common carbonate mineral : the carbonate of calcium ($CaCO_3$). Glassy appearance. Effervesces in hydrochloric acid. The principal constituent of chalk and most limestones.

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Carbonate. Term applied to a mineral compound characterised by an ionic structure of CO_3^{-2}. Calcite and dolomite are examples of carbonate minerals. Also applied to a rock consisting chiefly of carbonate minerals. Limestone and dolomite are examples of carbonate rocks. (See also 'calcareous').

Cemented. Term for a sedimentary rock whose grains are bound together in a coherent mass by mineral cements. Most cements are chemically precipitated. The most common cements are iron oxides, silica (quartz, opal, chalcedony), carbonates (calcite, dolomite) and clay minerals.

Chalcedony. Silica mineral which is the cryptocrystalline variety of quartz. Has a wide range of colours. Several varieties used as semi-precious stones (e.g. jasper, carnelian, agate, onyx).

Chert. Hard, dense, dull to slightly shiny, cryptocrystalline sedimentary rock consisting of organic or inorganic precipitates of silica. Occurs commonly as small irregular lumps in limestones and dolomites, but may also form extensive bedded deposits.

Chlorite. Group of platy micaceous minerals, usually green in colour and containing much ferrous iron. Often associated with and resembling biotite; crystals cleave into small thin flakes. Widely distributed in low-grade metamorphic rocks, or found as alteration products of ferromagnesian minerals in any rock type.

Chroma. Brilliance or intensity of a colour.

Clastic. Term for a rock composed of broken fragments that are derived from pre-existing rocks or minerals and that have been transported from their places of origin.

Clay. Soil particles smaller than 0.002 mm in size.

Claystone. Sedimentary rock composed predominantly of clay-size particles. Texture and composition similar to shale, but lacks fine lamination or fissility. (See also 'mudstone').

Cleavage. Property or tendency of a rock to split easily along aligned, usually closely-spaced fractures produced by metamorphism or deformation. Cleavage planes are secondary features and may differ in spacing and orientation from primary rock structures such as bedding. Also used to describe the breaking of a mineral along its crystal planes.

Close fold. Fold with an inter-limb angle between 30° and 70°.

Cobbles. Rock fragments 60 to 200 mm in size.

Cohesion. Property of a soil which exists by virtue of natural attraction between some fine soil particles, and which enables the soil to form a coherent mass, and to remain as such without the application of external forces.

Cohesive. Term for a soil which possesses cohesion. (Contrast with 'granular').

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Colluvium. Deposits formed by the downslope movement of earth materials essentially under the action of gravity. Typical colluvial deposits in Hong Kong are structureless, mixed accumulations of soil and rock fragments originally deposited on and at the base of natural slopes.

Columnar. Shape term for a rock mass with typically five to seven joint sets of similar dip that combine to form parallel columns of rock. (See also 'columnar jointing').

Columnar jointing. Parallel prismatic rock columns, polygonal (often six-sided) in cross-section, caused by contraction during cooling. Common in basic lavas but also found in other igneous and pyroclastic rocks.

Conglomerate. Coarse-grained sedimentary rock composed of rounded to subangular fragments larger than 2 mm average dimension set in a sand or finer-grained matrix which is often cemented. (Contrast with 'sedimentary breccia').

Consistency. Degree of resistance of a fine-grained soil to flow or to deformation in general.

Cooling joint. Joint formed by the cooling of an igneous, pyroclastic or other heated rock body.

Country rock. Rock intruded by and surrounding an igneous intrusion.

Cross bedding. Structure formed by a series of bedding planes inclined at an angle to the main planes of stratification in a sedimentary deposit. Planes are usually curved and truncated in cross-section by overlapping sets.

Cryptocrystalline. Textural term for a rock consisting of crystals that are too small to be recognized and distinguished separately under an ordinary microscope.

Crystal. Homogeneous solid chemical element or compound having a regular atomic structure expressed by symmetrically-arranged external plane faces. Term for a pyroclastic rock composed predominantly of pyroclasts in the form of crystals or crystal fragments.

Crystallinity. Degree to which crystals are developed in a rock, especially in igneous rocks.

Dacite. Medium-coloured, very fine-grained, acid igneous rock. The very fine-grained equivalent of granodiorite. Often contains megacrysts of quartz and feldspar.

Dappled. Term for non-uniform colour distribution of a rock or soil where the secondary colour constituent forms irregularly-shaped blotches or marks of widely differing size.

Decomposition grade. Class assigned to rock material on the basis of its degree of decomposition (chemical weathering), in terms of physical characteristics such as strength, discolouration, slakeability, presence or absence of original rock texture, and decomposition state of individual minerals.

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Detrital. Term for a rock or sediment formed of fragmental material which is derived from older rocks and moved from its place of origin by weathering and erosion.

Dolerite. Dark-coloured, medium-grained, basic igneous rock with the same composition as basalt and gabbro, but with a texture of intergrown plagioclase and pyroxene.

Dolomite. Generally white, sometimes slightly yellow, brown, pink or grey carbonate mineral : the carbonate of calcium and magnesium ($CaMg(CO_3)_2$). Forms curved, saddle-like crystals. Also, the term for a carbonate sedimentary rock of which more than 50% consists of the mineral dolomite. (Contrast with 'calcite' and 'limestone').

Dyke. Sheet- or table-like body of intrusive igneous rock which cuts across the bedding or other structural planes of the country rock.

Elongate. Shape term for a rock particle in which the longest diameter is much greater than the intermediate or shortest diameter. Expressed quantitatively as 'flatness ratio' > 0.66 and 'elongation ratio' < 0.66.

Elongation ratio. Ratio of the intermediate to longest diameters of a particle.

Eluviation. Downward movement of soluble or suspended material in a soil or superficial deposit by groundwater percolation.

Equidimensional. Shape term for a rock particle in which the three diameters are of approximately equal length. Expressed quantitatively as 'flatness ratio' > 0.66 and 'elongation ratio' > 0.66.

Equigranular. Textural term for a rock characterised by crystals or grains of the same size or approximately the same size.

Eutaxitic. Structural term for some pyroclastic rocks characterised by a streaked or banded appearance, due to pumice clasts or other material being stretched out whilst still in a hot viscous state, and subsequently preserved by welding.

Evaporite. Sedimentary rock consisting of minerals resulting from the evaporation of saline water.

Exfoliation. Process by which thin, curvilinear scales or shells of rock are successively spalled or stripped away from the bare surface of a rock mass or boulder under the action of mechanical and/or chemical weathering and release of confining pressure by erosion. Often results in a rounded rock mass. Commonly seen in granite corestones.

Extrusive. Term for an igneous rock that has been erupted onto the earth's surface (e.g. rocks formed from lava flows). Also applies to all pyroclastic rocks. (Contrast with 'intrusive').

Fan. Gently-sloping mass of detrital material deposited at locations of abrupt decrease in slope gradient. Forms a part-cone shape in cross- section and is fan-shaped in plan. Of alluvial or colluvial origin.

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Feldspar. Group of abundant alumino-silicate rock-forming minerals of general composition $MAl(Al,Si)_3O_8$ where M is commonly potassium, sodium or calcium. Crystals are usually white or nearly white (but frequently coloured by impurities), translucent, and possess good cleavage in two directions intersecting at or near 90°. They occur commonly in many rock types and decompose readily to clay.

Feldsparphyric. Textural term for a rock containing large megacrysts of feldspar, e.g. feldsparphyric rhyolite.

Feldspathic. General term for any rock or other mineral aggregate containing feldspar.

Felsic. General term for light-coloured minerals (e.g. quartz, feldspars, muscovite), or an igneous rock composed chiefly of these minerals. (Contrast with 'mafic').

Ferromagnesian. Term for any rock-forming minerals containing iron or magnesium.

Fibrous. Structural term for organic soils like peat which contain recognizable fibres, i.e. plant remains composed generally of elongated stems and roots. (Contrast with 'amorphous').

Fissility. Property possessed by some rocks, such as shale, of splitting easily into thin layers along closely-spaced, approximately planar, parallel surfaces. Its presence distinguishes shale from mudstone.

Fissure. Open crack or fracture in a rock or soil mass. Also used to describe a volcanic vent in the form of a crack.

Flat. Shape term for a rock particle in which the shortest diameter is much smaller than the intermediate or longest diameter. Expressed quantitatively as 'flatness ratio' < 0.66 and 'elongation ratio' > 0.66.

Flat and elongate. Shape term for a rock particle in which the longest, intermediate and shortest diameters are all of significantly different size. Expressed quantitatively as 'flatness ratio' < 0.66 and 'elongation ratio' $<$ 0.66. (Contrast with 'equidimensional').

Flatness ratio. Ratio of the shortest to intermediate diameters of a particle.

Flint. Dark grey or black variety of chert.

Flow-banded. Structural term for a rock formed by alternating layers of different colour, composition and/or texture as a result of the flow of molten rock. Most common in igneous rocks, but sometimes visible in pyroclastic flow deposits.

Foliated. Structural term for the layered, planar arrangement of the constituent grains of a rock formed by flattening of minerals due to metamorphism.

Friable. Term for a soil that crumbles very easily in the hand.

Gabbro. Dark-coloured, fine- to coarse-grained, basic intrusive igneous rock composed principally of plagioclase feldspar and mafic minerals.

Gentle fold. Fold with an inter-limb angle between 120° and 180°.

Glassy. Shape term for a rock particle with a surface texture that looks and feels like glass or quartz. Surface is typically shiny, straight or smoothly curved and lacks distinct crystal shapes.

Gneiss. Coarse-grained foliated rock formed by regional metamorphism, in which bands of granular minerals alternate with bands of flattened, elongated minerals showing preferred orientation parallel to the banding.

Gouge. Fine-grained (silt- and clay-size) material formed of rock ground down by severe earth movement. Commonly found in fault zones and known as 'fault gouge'. Also known as 'rock flour'. Does not behave as a silt/clay if the original rocks are not argillaceous.

Graded bedding. Structure evident in a bedded sedimentary deposit in which each layer shows a gradual and progressive change in particle size, usually from relatively coarse at the base of the bed to relatively fine at the top (e.g. fine sand grading to clay, cobbles grading to coarse sand).

Grading. Particle size distribution, defined as the percentages of the various grain sizes present in a soil as determined by sieving and sedimentation (BSI, 1975).

Granite. Light coloured, fine- to coarse-grained, acid igneous rock composed principally of alkali feldspar, quartz and biotite, with some plagioclase feldspar. Commonly forms both major intrusive bodies and minor intrusions such as dykes.

Granodiorite. Medium-coloured, fine- to coarse-grained, acid igneous rock composed principally of plagioclase feldspar, quartz and abundant biotite, with some alkali feldspar and hornblende. Typically contains more mafic minerals than granite.

Granular. Engineering term for a cohesionless soil, i.e. one which cannot form a coherent mass. (Contrast with 'cohesive'). Geological term for the texture of a rock that consists of mineral grains of approximately equal size.

Graphite. Grey to black, opaque, shiny, six-sided mineral. A naturally-occurring crystalline form of carbon. Common as crystals or thin flakes in veins and in many metamorphic rocks.

Gravel. Soil particles 2 to 60 mm in size.

Groundmass. Relatively fine-grained glassy or crystalline material between the megacrysts in a megacrystic igneous rock. Also known as the 'rock matrix'.

Gypsum. White or colourless soft mineral composed of hydrous calcium sulphate ($CaSO_4.2H_2O$). The commonest sulphate mineral. Often forms extensive beds of evaporite interstratified with limestone, shale and clay.

Halite. Evaporite mineral composed of sodium chloride (NaCl). Also known as 'rock salt' or 'common salt'.

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Halloysite. Clay mineral made up of very small hollow tubes, as shown by the electron microscope.

Holocene. Most recent part of geological time, from the end of the Pleistocene (approximately 8 000 to 10 000 years ago) to the present.

Honeycombed. Shape term for a rock particle with a very uneven surface texture characterised by visible pores or cavities. Commonly caused by preferential weathering and erosion of different minerals.

Hornblende. Black, dark green or greenish black, ferromagnesian silicate mineral. Crystals may be granular, fibrous or columnar. Primary constituent of many acid and intermediate igneous rocks, and a common metamorphic mineral in gneiss and schist.

Hornfels. Glassy, generally very fine-grained, rock produced by contact metamorphism. Shows no cleavage, schistosity or alignment of minerals.

Hue. Basic colour or a mixture of basic colours.

Hydration. Chemical reaction that results in the transfer of water from the fluid phase into the structure of a mineral.

Hydrothermal activity. Circulation of hot fluids and gases, usually associated with movement of magma. Fluids often contain various minerals in solution which precipitate in rock joints and fissures.

Igneous. General term for any rock formed by the solidification of magma.

Inclined fold. Fold whose axial plane is inclined from the vertical. One fold limb is commonly steeper than the other, but the steeper limb is not overfolded.

Inequigranular. Textural term for a rock characterised by a mixture of crystals or grains of significantly different sizes.

Insitu. Originally two Latin words (in situ) meaning 'in place' or 'in its original position'. Compressed here to a single word for convenient English usage. Distinguishes rocks and soils found in their original position of formation, as opposed to transported materials.

Interbedded. Structural term for beds in a sedimentary deposit with mean spacing > 20 mm lying between, or alternating with, other beds of different character (e.g. sand with interbedded clay).

Interlaminated. Structural term similar to 'interbedded', except applied to very thin beds with mean spacing < 20 mm.

Intermediate. Chemical term for an igneous rock containing 54 to 62% silica and usually less than 50% dark minerals. (Contrast with 'acid' and 'basic').

Interstratified. General structural term for sedimentary deposits consisting of alternating layers of different character. Covers both 'interbedded' and 'interlaminated'.

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Intrusive. Term for an igneous rock that has been forced into pre-existing rocks and solidified from magma underground. (Contrast with 'extrusive').

Isoclinal fold. Fold whose limbs are parallel (i.e. the inter-limb angle is 0°).

Isotropic. Term for rock and soil with the same physical properties in all directions.

Jurassic. Period of geological time between approximately 190 and 135 million years ago.

Kaolin. Group of clay minerals derived mainly by alteration of alkali feldspars and micas. Appearance is that of a soft, white or nearly white nonplastic clay. Commonly occurs as a thin coating or filling in joints in igneous rocks, but extreme alteration may convert whole rock mass to kaolin.

Kaolinized. Alteration term for a rock containing minerals, especially feldspars and micas, replaced by, or altered to, kaolin as a result of hydrothermal activity.

Karst topography. Topography characterised by sinkholes, caves, solution features and large underground drainage systems. Common in limestones, rare in other rocks.

Lahar. Mudflow in volcanic material. Caused by water saturation (e.g. by intense rainfall) of unlithified lava or pyroclastic deposits on the flanks of a volcano.

Laminated. Structural term for a sedimentary rock or superficial deposit formed, arranged or deposited in very thin layers < 20 mm thick.

Lamprophyre. Dark-coloured, very fine- to coarse-grained, basic rock characterised by high percentages of mafic minerals which often form megacrysts in a finer matrix of similar minerals plus altered feldspars.

Lapilli. Pyroclastic rock material of gravel size (i.e. 2 to 60 mm). Descriptive term for tuff composed wholly or predominantly of this grain size.

Laterite. Residual soil, usually reddish in colour, rich in secondary oxides of iron and/or aluminium. A product of intensive insitu rock weathering through leaching of more soluble elements. Common in tropical areas with strong seasonal rainfall.

Lava. General term for molten extrusive magma erupting non-explosively from a volcanic vent or fissure. Also, the term for the rock solidified from this magma.

Leaching. Separation and removal of the soluble constituents in a rock by the natural action of percolating groundwater.

Lenticular bedding. Beds in a sedimentary rock or superficial deposit formed by discontinuous lens-shaped bodies of one material surrounded by another type of material, e.g. sand lenses in a clay deposit. Lenses are usually double convex in cross-section.

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Leucocratic. Light-coloured as applied to igneous rocks. Most fine- to coarse-grained acid rocks are leucrocratic. (Contrast with 'mesocratic' and 'melanocratic').

Limb. One flank or side of a fold. A simple fold has two limbs.

Limestone. Sedimentary rock composed wholly or predominantly of calcium carbonate, mainly in the form of the mineral calcite.

Limonite. Usually dark brown or yellowish brown (may be yellow, red or nearly black), amorphous hydrated iron oxide material (ferric oxide). A very common weathering (oxidation) product of all iron-bearing minerals.

Lineation. General term for any rock structure arranged in lines. Also, the term for the appearance of stretched-out, flattened minerals in metamorphic rocks.

Liquid limit (LL). Moisture content at which a soil passes from the plastic to the liquid state, as determined by the liquid limit test (BSI, 1975).

Lithic. Relating to or made of existing rock fragments. Term for a tuff composed predominantly of fragments of previously-formed rocks.

Lithified. Term for a rock which has been converted into a coherent solid mass from a newly-deposited loose sediment by such processes as cementation, compaction, and crystallization. Lithification may occur concurrent with, soon after or long after deposition.

Lobate. Term for a long, rounded, tongue-like shape. Often applicable to the shape of colluvial deposits.

Macrostructure. Structural features of a soil mass which can be identified by the naked eye. (Contrast with 'microstructure').

Mafic. General term for dark-coloured, ferromagnesian minerals, or an igneous rock composed chiefly of these minerals. (Contrast with 'felsic').

Magma. Molten rock material formed within the earth. Solidifies at or near the earth's crust to produce extrusive and intrusive igneous rocks. Extrusive magma becomes 'lava'.

Marble. Generally light coloured (often stained by impurities), fine- to coarse-grained crystalline metamorphic rock consisting mainly of recrystallized calcite and/or dolomite. Metamorphosed limestone.

Massive. Structural term for an igneous or metamorphic rock with homogeneous texture over large areas, i.e. with no layering, foliation or other planar structures. May also be applied to sedimentary rocks with no evidence of stratification (i.e. no bedding or lamination).

Matrix. Finer-grained material enclosing, or filling the spaces between, the larger grains or particles in a mixed sedimentary rock or superficial deposit. Synonymous with groundmass in an igneous rock.

Megacryst. Any crystal or grain in an igneous or metamorphic rock that is significantly larger than the surrounding groundmass or matrix. A general, non-genetic term.

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Megacrystic. General textural term for a rock containing megacrysts. (See also 'porphyritic' and 'xenocrystic').

Melanocratic. Dark-coloured, as applied to igneous rocks. All basic rocks are melanocratic. (Contrast with 'leucocratic' and 'mesocratic').

Mesocratic. Medium-coloured (i.e. composed of roughly equal amounts of light and dark constituents), as applied to igneous rocks. Most intermediate rocks are mesocratic. (Contrast with 'leucocratic' and 'melanocratic').

Meta-. Prefix used with an igneous, pyroclastic or sedimentary rock name to indicate that the rock has been partially metamorphosed, e.g. metatuff.

Metamorphic. General term for any rock formed by mineralogical, chemical, and structural adjustment of pre-existing rocks due to changed physical and chemical conditions (excluding near-surface weathering and cementation effects).

Microcrystalline. Textural term for a crystalline rock with crystals that are too small to be seen by the naked eye, but which can be distinguished separately under an ordinary microscope.

Microfractures. General term for all small-scale discontinuities in the rock fabric. Includes cracks, fissures and planes of separation through or between individual grains.

Microstructure. Structural feature of a soil mass which cannot be identified completely by the naked eye; the use of a microscope is required for full assessment. (Contrast with 'macrostructure').

Mineral. Naturally occurring inorganic element or compound with an orderly internal structure, and characteristic chemical composition and physical properties.

Mineral boxwork. Weathering feature resulting from hard mineral deposits formed in rock joints standing out prominently on a weathered surface.

Mineralised. Alteration term for a rock containing new minerals formed either by conversion of existing minerals, or by filling of discontinuities with new substances.

Mottled. Term for non-uniform colour distribution of a rock or soil where the secondary colour constituent forms blotches or marks of approximately equal size.

Mudstone. Sedimentary rock composed predominantly of silt- and/or clay-size particles. A more general term than 'siltstone' or 'claystone'.

Muscovite. Colourless, yellow or light brown mineral of the mica group. Forms distinctive shiny thin prisms or flakes. Very common in gneisses and schists, and some acid igneous rocks.

Mylonite. Very fine-grained crystalline metamorphic rock with streaked or banded texture produced by shearing and fracturing of original grains during intense dynamic metamorphism.

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Neutral fold. Fold with its axial plane more or less horizontal. Neither an anticline nor a syncline.

Nodule. A small, irregular, rounded lump of a mineral or rock, usually contrasting in composition with the material in which it is embedded e.g. nodular chert in limestone.

Normal fault. Dipping fault in which the overlying face or wall appears to have moved downward relative to the underlying face. The angle of the fault is usually 45° to 90°.

Opal. Amorphous silica mineral. Softer, less dense, less transparent and lacks crystalline structure compared with quartz. Occurs in nearly all colours. Transparent coloured varieties used as gemstones.

Open fold. Fold with an inter-limb angle between 70° and 120°.

Overfolded. Term for a fold, or the limb of a fold, that has tilted beyond the perpendicular.

Oxidation. Chemical weathering process involving the reaction between rocks and atmospheric oxygen, the oxygen usually being dissolved in water. The main products are oxides and hydroxides. Iron is the mineral most obviously affected; iron oxidation products are characteristically brown, red and yellow in colour. (Contrast with 'reduction').

Parasitic fold. Small fold on the limb of a larger fold.

Pegmatite. Light coloured, very coarse-grained igneous rock, generally of granitic composition. Commonly occurs as irregular dykes or veins, especially around the edges of large intrusions.

Phyllite. Fine-grained metamorphic rock with well-developed slightly undulating cleavage. Commonly green, grey or reddish brown in colour. Chlorite and sericite crystals often form a distinctive shiny, smooth surface on cleavage faces.

Pitted. Shape term for a rock particle with an uneven surface texture characterised by numerous small depressions. Commonly caused by preferential weathering and erosion of different minerals.

Plagioclase feldspar. Group of sodium-calcium feldspars of general composition $(Na,Ca)Al(Si,Al)Si_2O_8$. (See 'feldspar').

Plasticity. Property which enables a soil or other material to be deformed continuously and permanently without rupture.

Plastic limit (PL). Moisture content at which a soil becomes too dry to be in a plastic condition, as determined by the plastic limit test (BSI, 1975).

Pleistocene. Geological time period between approximately 2 million and 8 000 to 10 000 years ago, i.e. immediately prior to the Holocene.

Plutonic. Pertaining to, or the general term for, any rock formed at considerable depth below the earth's surface by crystallization of magma and/or by chemical alteration.

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Polyhedral. Shape term for a rock mass with no consistent joint sets, such that individual rock blocks usually vary widely in shape and size.

Porphyritic. Textural term for an igneous rock containing large crystals (phenocrysts) that are compatible in composition and mode of formation with the groundmass or matrix in which they occur. (Contrast with 'xenocrystic').

Pseudomorph. Mineral which occurs in the crystal form of another mineral as a result of alteration, or solution and replacement, within the same crystal shape.

Pumice. Light-coloured glassy rock formed from acid lava. Contains abundant voids or cavities, which means it is often sufficiently buoyant to float on water.

Pyrite. Light brown or dark yellow iron sulphide mineral (FeS_2). Often forms cube-shaped, striated crystals with a bright metallic surface. Common in veins and fault-zone rocks. Often mistaken for gold.

Pyroclast. Individual rock fragment or particle ejected explosively from a volcanic vent. Classified by size into fine ash, coarse ash, lapilli, blocks and bombs.

Pyroclastic. General term for any rock composed of material ejected explosively from a volcanic vent.

Pyroxene. Groups of mafic silicate minerals. Commonly appear as dark green or black prismatic crystals displaying cleavage in two directions parallel to the crystal faces and intersecting at approximately 90°.

Quartz. Colourless (often coloured by impurities), glassy, hard mineral composed of crystalline silica (SiO_2). Commonly appears either as six-sided transparent crystals or as a dense crystalline mass lacking distinctive shape. Very common in all types of rocks and mineral veins.

Quartzite. A non-foliated metamorphic rock consisting mainly of quartz. Formed by recrystallization of sandstone due to contact or regional metamorphism.

Quartz latite. Medium-coloured, very fine-grained, intermediate igneous rock. The very fine-grained equivalent of quartz monzonite.

Quartz monzonite. Medium-coloured, fine- to coarse-grained, intermediate igneous rock containing roughly equal amounts of plagioclase and alkali feldspar.

Quartzphyric. Textural term for a rock containing large megacrysts of quartz, e.g. quartzphyric rhyolite.

Quartz syenite. Medium-coloured, fine- to coarse-grained, intermediate igneous rock. Feldspar component is predominantly alkali feldspar.

Quartz trachyte. Medium-coloured, very fine-grained, intermediate igneous rock. The very fine-grained equivalent of quartz syenite.

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Quaternary. Geological time period from approximately two million years ago up to the present. Split into two parts : the Pleistocene and the Holocene.

Recrystallization. Formation of new crystalline mineral grains in a rock due to metamorphism or processes involving percolating groundwater. New crystals may have the same or a different composition from the original crystals.

Recumbent fold. Overturned fold whose axial plane is horizontal or nearly horizontal.

Reduction. Chemical process whereby oxygen is removed in rocks and the leached parts of soils. Related to the continuous presence of water, which makes oxygen scarce, e.g. by reducing ferric iron (Fe_2O_3) to ferrous iron (FeO). Characteristic colours of reduced soils are greens and greys. Often associated with strong bacterial activity in the soil. (Contrast with 'oxidation').

Regular bedding. Alternating layers of materials of different grain size in a bedded sedimentary deposit. Grain size within each layer is essentially uniform.

Residual soil. Soil derived from insitu rock weathering in which all trace of the original rock texture, fabric and structure has been destroyed. (Contrast with 'saprolite'; represents a more advanced stage of weathering than saprolite).

Reverse fault. Dipping fault in which the overlying face or wall appears to have moved upward relative to the underlying face. Fault plane usually dips at a low angle.

Rhyodacite. Medium-coloured, very fine-grained, acid igneous rock. Intermediate in composition between rhyolite and dacite. Contains less alkali feldspar than rhyolite and less plagioclase feldspar than dacite. Often contains megacrysts of quartz and feldspar.

Rhyolite. Medium-coloured, very fine-grained, acid igneous rock. The very fine-grained equivalent of granite. Often contains megacrysts of quartz and feldspar.

Rind. Discoloured, relatively thin, often loose and flaky outer layer on the surface of a boulder or rock block caused by weathering.

Rough. Shape term for a rock particle with a surface texture that feels uneven, corrugated or lumpy, i.e. that lacks smoothness.

Rounded. Shape term for a rock particle with markedly rounded edges and corners.

Rudaceous. Term for any sedimentary rock composed wholly or predominantly of gravel and larger-sized grains.

Sand. Soil particles 0.06 to 2 mm in size.

Sandstone. Sedimentary rock composed predominantly of sand-size particles.

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Saprolite. Soil derived from insitu rock weathering which retains evidence of the original rock texture, fabric and structure. (Contrast with 'residual soil').

Schist. Medium- to coarse-grained, foliated, crystalline metamorphic rock. Splits readily into flakes or slabs due to parallel arrangement of most of the constituent minerals. Coarser and more undulating foliation compared with 'phyllite'; finer and often not banded compared with 'gneiss'.

Schistocity. Foliation in schist or other coarse-grained crystalline metamorphic rocks due to the parallel, planar arrangement of platy and prismatic mineral grains (e.g. mica).

Sedimentary. General term for any rock formed by the deposition of sediment, i.e. solid, fragmented material transported by gravity, wind, water or ice, or material accumulated by chemical precipitation or secretion by organisms.

Sericite. White, fine-grained mineral of the mica group. Similar composition to muscovite. Common in fault gouge and other rocks associated with dynamic metamorphism.

Shale. Mudstone with a finely-laminated depositional structure that gives the rock fissility, or the tendency to break into thin layers parallel to the lamination planes.

Shear plane. Surface along which differential movement has taken place parallel to the surface.

Shear zone. Belt of rock of significant thickness that has been crushed and contorted by shear movement.

Sheeting joint. Joint formed by pressure release due to removal of overlying rock by weathering and erosion. Also called an 'unloading joint'.

Silica. Silicon dioxide (SiO_2). Occurs naturally as crystals (e.g. quartz), in cryptocrystalline form (e.g. chalcedony) and in amorphous form (e.g. opal). Combined in silicates as an essential constituent of many minerals.

Silicate. Compound material consisting of one silicon and four oxygen atoms arranged in triangular pyramids, either isolated or joined through one or more of the oxygen atoms to form chains, sheets or three-dimensional structures with metallic elements such as aluminium. Silicate minerals are the most common rock-forming compounds and make up approximately 95% of the earth's crust.

Siliceous. Term for a rock containing abundant silica.

Sill. Table-like body of intrusive igneous rock that conforms to the bedding or other planar structures of the country rock in which it is intruded.

Sillimanite. Brown, grey, light green or white silicate mineral. Forms long needle-like crystals. Often found in high temperature, contact-metamorphosed sedimentary rocks.

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Silt. Soil particles 0.002 to 0.06 mm in size.

Siltstone. Sedimentary rock composed predominantly of silt-size particles. (See also 'mudstone').

Skarn. Thermally metamorphosed impure limestone characterised by presence of silicate minerals containing calcium.

Slaking. Breaking-up or disintegration of a rock or soil when saturated with or immersed in water.

Slate. Fine-grained metamorphic rock with a very well-developed parallel cleavage. Splits into very thin plates or flakes. Most slates are metamorphosed shales.

Slickenside. Smooth striated surface caused by friction during relative movement of rock along the surface (e.g. along a fault plane). Striations are normally low linear grooves and ridges parallel to the direction of movement. Surface often appears shiny or polished.

Slump bedding. Beds in a sedimentary deposit which have been disturbed or deformed by slumping of the newly-deposited sediment under water, usually on a sloping surface.

Smooth. Shape term for a rock particle with a surface texture that feels even, with no lumps or corrugations, i.e. lacks roughness. Results from, for example, being water-worn or the clean fracture of very fine-grained rock.

Solution. Chemical weathering process in which minerals are dissolved by percolating or static groundwater, e.g. removal of calcium carbonate in limestone or chalk by carbonic acid (weakly acid rainwater).

Sorted. Term for a loose sediment or sedimentary rock composed of particles of essentially uniform size. 'Well-sorted' refers to very uniform sorting. (Contrast with 'poorly-sorted'). Note 'sorted' in geological use is the opposite of 'graded' in engineering use.

Spotted. Term for non-uniform colour distribution of a rock or soil where the secondary colour constituent forms small rounded spots.

Stratified. General structural term for a sedimentary rock or superficial deposit formed, arranged or deposited in layers or beds of any thickness. (See also 'bedded' and 'laminated').

Streaked. Term for non-uniform colour distribution of a rock or soil where the secondary colour constituent forms elongated, discontinuous, sometimes branching, lines.

Striated. Shape term for a rock particle with a surface texture characterised by a series of fine, parallel grooved lines. Caused, for example, by slickensiding in a fault zone.

Strike. Direction in which a horizontal line can be drawn on a structural rock surface.

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Strike-slip fault. Fault on which the movement is parallel to the strike of the fault.

Striped. Term for non-uniform colour distribution of a rock or soil where the secondary colour constituent forms elongated, continuous, nonbranching lines.

Structural domain. Portion of a rock mass characterised by a relatively uniform arrangement of discontinuities.

Subangular. Shape term for a rock particle with slightly sharp (slightly angular) edges and corners.

Subrounded. Shape term for a rock particle with slightly rounded edges and corners.

Syncline. Fold in the shape of a basin whose core contains the stratigraphically younger rocks.

Tabular. Shape term for a rock mass with a single, dominant, flat-lying joint set, such that the mass consists of a series of table-like sheets of rock.

Tectonic activity. Movements of the outer part of the earth's crust. Some associated geological features are earthquakes, major faults and folds, tectonic joints and certain rock types such as mylonite.

Tectonic joint. Joint formed by tectonic activity. The orientation of tectonic joints is usually controlled by the directions of the principal regional stresses.

Tertiary. Geological time period between approximately 60 and 2 million years ago.

Throw. Amount of vertical displacement on a fault.

Thrust. Low-angle reverse fault with a dip of less than 45°.

Tight fold. Fold with an inter-limb angle between 0° and 30°.

Trachyandesite. *Usually dark-coloured, very fine-grained, intermediate igneous* rock. Commonly contains megacrysts of alkali feldspar.

Tuff. General rock name for all lithified pyroclastic rocks composed of rock fragments of gravel or finer size (< 60 mm). Subdivided according to dominant grain sizes into lapilli, coarse-ash and fine-ash types.

Tuffaceous. Term for a sedimentary rock containing up to 50% tuff material.

Tuffite. Mixed sedimentary/pyroclastic rock containing roughly equal amounts of sedimentary material and tuff material.

Unloading joint. (See 'sheeting joint').

Upright fold. Fold whose axial plane is vertical or near-vertical.

Value. Relative lightness of a colour. Grey has a neutral value, white the highest value and black the lowest.

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Vein. Mineral filling a fault, joint or other fracture in a rock; the vein is formed later than the host rock. Commonly has a table- or sheet-like form. Often associated with alteration of the host rock. Most veins are of igneous origin.

Vent. Opening at the earth's surface through which volcanic materials are extruded.

Vesicle. Cavity of variable shape in a lava, formed by the entrapment of a gas bubble during the solidification of the lava.

Vitric. Term for a pyroclastic rock composed predominantly of volcanic glass fragments.

Volcanic. General term for any extrusive igneous or pyroclastic rock.

Wacke. Arenaceous sedimentary rock containing more than 15% silt and clay. A 'dirty' sandstone. (Contrast with 'arenite').

Wavy bedding. Beds in a sedimentary deposit with markedly undulating bedding surfaces, i.e. the bed surfaces are not straight as in regular or graded bedding.

Weathering pit. Small shallow depression or basin in an otherwise flat or evenly sloping rock surface, caused by preferential weathering of specific rock fragments or crystals in rocks composed of mixtures of different fragments or crystals.

Weathering rind. (See 'rind').

Weathering zone. Portion of a rock mass delineated on the basis of its degree of weathering in terms of, for example, relative proportions of rock and soil.

Welded tuff. Vitric tuff (i.e. with a high proportion of glass fragments) that has been compacted by the squeezing together of its glass fragments under the combined action of heat retained by its particles, weight of overlying material and hot gases within the rock.

Wrench fault. (See 'strike-slip fault').

Xenocrystic. Textural term for an igneous rock containing large crystals (xenocrysts) that are foreign in origin compared with the groundmass or matrix in which they occur. (Contrast with 'porphyritic').

Young. Used as a verb meaning to face or to present the younger aspect of one rock formation toward another, e.g. if formation B is geologically younger than formation A, A can be said to "young" towards B.

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