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A guide to core logging for rock engineering

Core Logging Committee of the South Africa Section of The Association of Engineering Geologists

SUMMARY. A guide for the logging of borehole core for rock engineering purposes is proposed.

General acceptance of such a guide ensures that core logs will generally contain meaningful descriptions of the rock mass parameters most significant in rock engineering problems. The use of defined terms and format ensures that any reader of the log will have an appreciation of the original appearance of the core, and in particular those aspects important to rock engineering.

The proposed guide takes due cognizance of existing accepted systems of soil and rock mass description or classification and attempts to remain compatible with these wherever feasible.

Only those parameters which are commonly of interest in rock engineering are described. Qualitative descriptions depending only on visual inspection and simple mechanical field tests are used. Primary core descriptions include descriptions of colour, weathering, fabric, discontinuity surface spacing, hardness, rock name and stratigraphic horizon. This is followed, where required, by a description of the discontinuity surfaces including their type, separation, fracture filling (presence or absence), roughness and orientation. If significant an additional description of the nature of the fracture filling including moisture, colour, consistency or hardness, soil or rock type and origin is added. The significance of each of these parameters with respect to engineering behaviour is discussed and standard descriptive terms defined.

Other information commonly recorded on the borehole log, such as drilling method and size, core recovery, RQD, fracture frequency and standard tests are reviewed and techniques of presentation are suggested.

Recommendations are made for the handling and storage of rock cores. Some useful techniques for the logging of core are discussed.

1 INTRODUCTION

The purpose of the Core Logging Committee of the South Africa Section of the Association of Engineering Geologists was to prepare a guide for core logging for rock engineering purposes in South Africa.

For such a guide to be generally accepted it should fulfil the following requirements:

(a) It should be sufficiently detailed to ensure that the resulting core log contains enough information to enable reliable interpretations of geological and rock engineering conditions for most typical engineering structures.

(b) It should not be so complex as to render its use impractical or unnecessarily cumbersome.

(c) It must take due regard of such standardized procedures as may already exist and, where feasible, incorporate these with a minimum of variations.

A distinction is drawn between the borehole log and the core log. The *borehole log* includes a description of relevant data applicable to the drilling of the borehole and to the core recovered. It includes information on the drilling machine, tools and materials used, progress, difficulties encountered and tests performed. Part of the borehole log is the *core log* which is purely a description of the recovered core.

It is the core log which is the subject of this paper. A core log cannot be considered in isolation from the borehole log in which it is to be included and the parameters comprising the borehole log are therefore also given brief consideration in this paper.

The preparation of a core and borehole log presupposes that an adequate driller's record is available. Preparation and nature of the driller's record is outside the scope of this paper.

The complexity of rock, as a variable material subject to fractures and weathering, and its complicated inter-related behaviour with the structures formed in or on it, has resulted in the development of a large variety of descriptive systems for logging cores. These systems vary considerably both in the degree of complexity and nature of the parameters described.

Of necessity, the guide proposed by this Committee cannot include for all possible eventualities and in the interest of usability has been kept as simple as possible. Only those parameters which are commonly of interest in rock engineering are described using qualitative descriptions dependent only on visual inspection and simple mechanical field tests.

Where a specific investigation requires the description of additional parameters or the use of other specific or more detailed classifications or descriptions of properties, these may be added to the suggested core log.

The adoption of the proposed guide ensures that descriptions of the most commonly required rock mass parameters are included in the log in accordance with a set of standard descriptions, the interpretation of which is known to anyone who has available a copy of this paper.

2 PROPOSED METHOD OF CORE LOGGING

The purpose of the core log is to enable the person reading the log to visualize the cores (as seen by the compiler of the log) and hence to draw inferences on the likely behaviour of the actual rock mass. Only those parameters which are significant to the rock mass behaviour or which enable correlations between boreholes to be made or give a better understanding of the general geology of the site are recorded.

Whenever possible, classifications with five class intervals are adopted since the extremes, middle and two intermediate values of such a group are often self-evident. Class interval limits are defined using visual criteria or simple field tests with equipment commonly carried by the core logger (knife, geological pick, etc.).

Many boreholes start in soil or pass through soil strata. Descriptions of these soil horizons form an integral part of the borehole log. An excellent system of soil profiling has been proposed, by Jennings, et al[1] which has been widely accepted in Southern Africa. The adoption of a system of core description which is similar and compatible with the soils system would be a tremendous advantage. With such similar compatible systems the logger and reader would not be required to work to a "different set of rules" or terms of reference when comparing the soil and rock of a profile.

Unfortunately, the soil profiling system was not developed with rock descriptions in mind, and its simple extension into rock does not produce an adequate rock mass description. It has therefore been necessary to modify and adapt the soil profiling system for its application to rock. The resulting system is compatible with the soil profiling system but varies considerably in detail.

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The core description includes not only the description of rock material, but also the discontinuity surfaces[2] that occur through it and the fracture[2] filling materials. It is recognised that while discontinuity surfaces and their filling are of great importance to rock mass behaviour they are often given a secondary role in the rock core description. A core description comprising three parts is therefore proposed:

(1) The primary description is that of the parameters affecting the basic rock mass properties.
(2) To supplement the above a description of the discontinuity surfaces may be given.
(3) Finally, a description of the fracture filling may be relevant.

Depending on the nature of the engineering problem, a decision may be made to describe only (1), the basic rock mass parameters, alternatively two or all three parts of description may be required.

The core log should be a factual description of the core. Any interpretation or assessments on the part of the core logger should clearly be distinguished from the factual information.

It is recognised that assessments and interpretations are best made when actually looking at the core in its fresh and least disturbed state. The logger of the core is therefore often in a very favourable position to make such assessments and interpretations and to exclude these from the core log is to reduce the value of the log. Such interpretations or assessments should be included in parentheses, following the factual core description.

2.1 Description of the Primary Rock Mass Parameters

In the description of the rock mass, six basic parameters were selected as being of primary importance for rock engineering purposes. These are illustrated in Table 1 in which they are compared with the descriptive parameters chosen for soil descriptions.

TABLE 1. ROCK AND SOI S: COMPARISON OF DESCRIPTIVE PARAMETERS

Soil Description	Rock Mass Description
MOISTURE	
COLOUR	COLOUR
CONSISTENCY	WHEATHERING
STRUCTURE	FABRIC AND DISCONTINUITY SURFACE SPACING
	HARDNESS
SOILTYPE	ROCK NAME
ORIGIN	STRATIGRAPHIC HORIZON

Definitions of each of these parameters are given in the following sub-sections.

It is recommended that all the parameters be described even in situations where one or more do not appear to be significant at the time of logging.

It is not intended that the logger should accept that these are the only rock mass parameters which are significant and which are to be described. In specific applications other parameters[3] may be of equal and greater importance and should be included in the descriptions. The inclusion of such additional parameters and the definitions of their application is left to the specialist core logger in question. He should, however, indicate clearly the additions to the core log that he is making.

2.1.1 Colour

Colour is one of the most obvious characteristics of a rock stratum and therefore one of the most basic and useful in the description of a rock to both the specialist and layman alike. It often provides an excellent guide for rock strata correlation and may be used to identify various "marker" horizons. Colour variation is a primary indication of weathering.

Colour is usually one of the most variable of rock characteristics and a single rock type may exhibit a large range of colours. Nevertheless, when judiciously used, it will afford a valuable indication as to the probable nature and composition of the rock.

Colours of igneous rocks are related to their rock forming minerals, the light coloured minerals, quartz, feldspar and felspathoids giving rise, for instance, to granite and syenite, while dark rock forming minerals mica, amphibole, pyroxene and olivine give rise, for instance, to dolerite and gabbro. The colour of shales and slates generally result from a pigmentation of some kind, which may be carbonaceous material or iron oxide. The colour difference in these rocks often reflects only the state of oxidation of the iron produced by the process of weathering.

Since colour varies with moisture content it is essential that all colours are described at a known moisture content. It is recommended therefore that core should be wet when described. Where descriptions are made of core at other moisture contents this should be described in accordance with Jennings et al[1] as dry, slightly moist, moist, wet, very wet. To ensure that surfaces are representative of the rock material only recently broken surfaces should be used for the description. Surfaces altered by weathering, contaminants or surface abrasion should be avoided. It is usually good practice to wash the core before commencing core description.

Every colour sensation comprises two dominant qualities; each of which may vary without disturbing the other. These qualities are firstly, the hue or name of the colour and secondly, the quality of lightness or value, whereby we distinguish a light colour from a dark one.

Colour descriptions should be kept as simple as possible and the actual terms used should, where possible, correspond with those on accepted colour charts. The use of the Munsell Colour Chart is recommended.

The rock colour is its predominant colour i.e. brown, green, red, pink, khaki. Where a secondary colour is also evident this colour can be included in the description as an adjective i.e. reddish brown, greyish green, yellowish khaki. Where significant, the colour should be further amplified by using the following descriptions for value: very light, light, medium, dark, very dark i.e. dark reddish brown, light yellowish khaki.

In many rock types especially igneous and metamorphic rocks, the rock texture may give rise to an ill-defined or variable colour. In these cases the colour of the dominant minerals or the overall ground mass should be described and the colours of secondary features should be described separately. The secondary colouration usually has a characteristic geometric pattern which may be described by one of the following terms:

banded	approximately parallel bands of varying colour.
streaked	randomly orientated streaks of colour
blotched	large irregular patches of colour (>75 mm ø)
mottled	irregular patches of colour
speckled	very small, less than 10 mm diameter, patches of colour
stained	local colour variations associated with other features, i.e. bedding, joints, etc.

An example: Light greenish grey speckled black and streaked white.

The colour of inclusions such as lenses, veins, vesicles, amygdales or discrete and large crystals should also be described if they are considered to be significant features, e.g. dark greyish brown mottled white with pink veins.

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2.1.2 Weathering

Weathering of rocks takes place under the influence of the hydrosphere and the atmosphere as a result of their instability in environments which differ from those in which they were formed. It is a process of alteration by means of mechanical, chemical and biological action which drastically affects the engineering properties of both the rock material and the rock mass. Some of the more important effects of weathering on rock is the decrease in strength, density and volumetric stability and the increase in deformability, porosity and weatherability. Weathering normally starts at the earth's surface but its development and extent depend on a large number of variables, the most important of which are the rock types, climatic environment and rock fabric. The zones of weathering are often very irregular and variable over small distances.

As it is not intended to describe or define the mechanisms of decomposition or disintegration, the more general term "weathering" is used throughout.

The classification contained in the Working Party Report of the Geological Society Engineering Group of Great Britain has been used as a basis for this guide.

TABLE 2. DEGREES OF WEATHERING

DIAGNOSTIC FEATURE / DESCRIPTION TERM	DISCOLOURATION EXTENT	FRACTURE CONDITION	SURFACE CHARACTERISTICS	ORIGINAL TEXTURE	GRAIN BOUNDARY CONDITION
UNWEATHERED	NONE	CLOSED OR DISCOLOURED	UNCHANGED	PRESERVED	TIGHT
SLIGHTLY WEATHERED	20% OF FRACTURE SPACING ON BOTH SIDES OF FRACTURE	DISCOLOURED MAY CONTAIN THIN FILLING	PARTIAL DISCOLOURATION	PRESERVED	TIGHT
MEDIUM WEATHERED	20% OF FRACTURE SPACING ON BOTH SIDES OF FRACTURE	DISCOLOURED MAY CONTAIN THICK FILLING	PARTIAL TO COMPLETE DISCOLOURATION NOT FRIABLE EXCEPT POORLY CEMETED ROCKS	PRESERVED	PARTIAL
HIGHLY WEATHERED	THROUGHOUT	-	FRIABLE AND POSSIBLY PITTED	MAINLY PRESERVED	PARTIAL SEPARATION
COMPLETELY WEATHERED	THROUGHOUT	-	RESEMBLES A SOIL	PARTLY PRESERVED	COMPLETE SEPARATION

The British system has been modified to meet the following requirements:

1. A five-fold instead of seven-fold classification system has been adopted.
2. The definitions of degrees of weathering have been altered so as to eliminate the use of the terms "weathering" or "decomposed".
3. The term "fresh" is replaced by "unweathered" in order to avoid confusion when it is not used in conjunction with other weathering terms.
4. The effect of the drilling process on the external appearance of the core is taken into account.

The definitions of weathering are as follows:

Unweathered -
No visible signs of alteration in the rock material out fracture planes may be stained or discoloured.

Slightly weathered -
Fractures are stained or discoloured and may contain a thin filling of altered material. Discolouration may extend into the rock from the fracture planes to a distance of up to 20% of the fracture spacing (i.e. less than 4o% of the core is discoloured).

Medium weathered -
Slight discolouration extends from fracture planes for a distance greater than 20% of the fracture spacing (i.e. generally greater part of the rock). Fractures may contain filling of altered material. The surface of the core is not friable (except in the case of poorly cemented sedimentary rocks) and the original texture of the rock has been preserved. Partial opening of grain boundaries may be observed.

Highly weathered -
Discolouration extends throughout the rock. The surface of the core is friable and usually pitted due to washing out of highly altered minerals by drilling water. The original texture of the rock has mainly been preserved but separation of grains has occurred.

Completely weathered -
The rock is totally discoloured and the external appearance of the core is that of a soil. Internally the rock texture is partly preserved but grains have completely separated.

Note that the boundary between soil and rock is defined in terms of strength or hardness and not in terms of weathering.

Only those sections of core which are present in the core box can be described out any core loss must be considered. The degree of weathering observed is not always representative of the section under consideration. Other properties of the rock such as rock type, core recovery, rock strength, fracture spacing and condition must be taken into account in combination with the degree of weathering to determine the true condition of the section. An approximate guide is presented in Table 2.

Where slaking of the core is observed or suspected its nature and degree should be recorded after the description of the basic parameters.

Where the assessed condition of the rock intersected in a drill run differs from that observed in the core this should be noted at the end of the core description.

An example:
Grey slightly weathered fine grained medium jointed hard rock dolerite. (Core loss and fracture filling suggest rock mass is highly weathered to spheroidal boulders. 50% boulders + 50% matrix not recovered)

2.1.3 Fabric

Fabric is the term used to describe the micro structural and textural features of the *rock material.* It is these structural or textural features which affect rock material behaviour and would therefore be accounted for in the testing of laboratory samples. Larger structural features are termed discontinuity surfaces[2]. These are of such a scale that their effects cannot be determined on laboratory specimens and they are not considered to affect the rock material properties but influence *rock mass* properties. Fabric description can usefully be subdivided into two parts, namely texture and micro structure.

(i) Texture
Rocks are composed of assemblages of minerals. The arrangement and size of the individual grains of these minerals give the rock an individual form or *texture.*

Since the size or arrangement of the individual minerals can affect the physical properties of the rock such as permeability or angle of internal friction, it is necessary to describe them so that their engineer- log significance can be assessed.

The most noticeable textural feature is grain size. The majority of sedimentary rock names imply a grain size distribution and therefore a formal classification equivalent to that of soil" particle size is not considered to be necessary. The obvious exceptions are the sandstones where a grain size qualification is considered to be valuable. A five-fold grain size classification has been chosen based on visual identification using a hand lens. For metamorphic and igneous rocks the same reasoning is applicable, with a grain size qualification only being necessary in the coarser grained rocks.

The suggested terminology and grain sizes are given in Table 3.

(ii) Micro Structure -

Many rock types exhibit a definite structure characteristic of their origin. For example, bedding planes in sedimentary rocks, foliations in metamorphic rocks and flow banding in igneous rocks.

These preferentially oriented features impart to the rock material a distinct anisotropy of physical properties. It is therefore usually necessary to include their description in the core log.

It is recognised that the scale of many of these features varies from very small (and can therefore be evaluated as affecting rock material properties in the laboratory) to very large (affecting rock mass behaviour which cannot be measured by laboratory testing). The smaller scale features are therefore considered to be part of the fabric of the rock material while the larger scale features form part of the discontinuity surface pattern of the rock mass.

The boundary between *micro structure* and discontinuity surface spacing is defined here as a feature spacing of 10 mm. It is proposed that the terms defined in Table 4 be used.

TABLE 3. GRAIN SIZE CLASSIFICATION

DESCRIPTION	SIZE IN mm	RECOGNITION	EQUIV. SOIL TYPE
Very fine grained	<0,06	Individual grains cannot be seen with a hand lens	Clays & Silts
Fine grained	0,06 - 0,2	Just visible as individual grains under hand lens	Fine sand
Medium grained	0,2 - 0,6	Grains clearly visible under hand lens, just visible to the naked eye	Medium sand
Coarse grained	0,6 - 2,0	Grains clearly visible to naked eye	Coarse sand
Very Coarse Grained	>2,0 -	Grains measureable	Gravel

For very coarse grained rock the average grain size may be recorded.

2.1.4 Discontinuity Surface Spacing

Discontinuity surface is defined[2] as any surface across which some property for a rock mass is discontinuous. This includes fracture surfaces, weakness planes and bedding planes. The term is restricted only to mechanical continuity.

Fracture[2] is the general term for any mechanical discontinuity in the rock; it is therefore the collective term for joints faults, cracks etc.

Joint[2] is a break of geological origin in the continuity of a body of rock occurring either singly, or more frequently in a set or system, but not attended by a visible movement parallel to the surface of discontinuity.

Discontinuity surfaces include two major categories. Firstly features characteristic of the origin of the rock such as bedding, foliations and flow bands, and secondly features occurring as a result of tectonic rupture (fractures) such as joints, faults and shear-zones.

It is recognised that rock mass behaviour is influenced and often controlled by the discontinuities that occur within in. It is therefore necessary to include a description of these features in the core log. In the primary rock mass description only the discontinuity surface spacing is indicated. Where a more detailed description of the discontinuity surfaces is required this is given separately following the primary rock mass description.

The proposed description of discontinuity surface spacing is given in Table 4.

TABLE 4. DISCONTINUITY SURFACE AND MICRO STRUCTURE SPACING

DESCRIPTION FOR STRUCTURAL FEATURES: BEDDING, FOLIATION OR FLOW BANDING	SPACING[5] IN mm	DESCRIPTION FOR JOINTS, FAULTS, OR OTHER FRACTURES
Very thickly (bedded foliated or banded)	Greater than1000	Very widely (fractured or jointed)
Thickly	300 - 1000	Widely
Medium	100 - 300	Medium
Thinly	30 - 100	Closely
Very thinly	10 - 30	Very closely
DESCRIPTION FOR MICRO - STRUCTURAL FEATURES: LAMINATION, FOLIATIONS OR CLEAVAGE		
Intensely laminated (foliated or cleaved)	3 - 10	
Very intensely	< 3	

In the determination of discontinuity surface spacing only natural discontinuities are included. In some instances it may be necessary to record separately the spacing of man made fractures such as those caused by blasting.

Where discontinuity surfaces are parallel or sub-parallel the spacing is taken in the direction normal to the surface orientation.

An example of the two-fold spacing description could be "thinly bedded, widely fractured". This description would apply to a rock mass of sedimentary origin with a bedding plane spacing of 30 mm to 100 *mm* and a spacing between other natural breaks, most probably joints, of 300 mm - 1 000 mm.

Where the end terms are used the actual spacing should be placed behind the description e.g. very thickly banded (1,8 m) or very intensely laminated (0,5 mm).

2.1.5 Rock Hardness

In rock engineering, the rock material strength plays a dominant role. Excavation methods, permissible bearing pressures and tunnel support requirements are usually directly related to this rock property.

Rock mass strength is determined not only by the strength of the rock material but also by the discontinuities occurring in the mass.

Rock hardness, defined as the resistance to indentation or scratching may be used as an index type test which provides some measure of rock material strength. Studies conducted by Miller[4] have shown that there is a relationship between the uniaxial compressive strength and the product of hardness and density as expressed ln the following formula;

$\log\sigma_a \text{ (ult)} = 0{,}00014\ \gamma_a\ R + 3{,}16$

where γ_a = dry unit wt (lb/ft^3)
R = Schmidt hardness (L-hammer)

For the lower ranges up to medium hard rock (Table 5) hardness is more readily and consistently described in the field than is strength as it can be assessed from visual inspection and simple mechanical tests such as scratching with a knife and striking with a hammer. It has been shown by

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Jennings et al[7] that there is a correlation between hardness derived from these tests and the minimum uniaxial rock material strength. This relationship is illustrated in Figure 1 which is adapted from Jennings et al [7].

Knowing the rock type and rock material hardness, it is possible for the experienced engineer or engineering geologist to make fairly accurate estimates on rock material strength. These can be readily verified by uniaxial compressive strength or point load tests.

In view of the ease of testing and the portability of the point load test apparatus, the extensive use of point load tests, as a more precise index of strength is recommended for field use on samples with a strength of more than 25 MPa.

Experience has shown that there are two distinct ranges of rock material strength required. The engineer responsible for the design of foundations or slope stability, where stress levels are usually low, is generally particularly interested in obtaining a fairly close subdivision in the lower strength ranges[7]. The mining or tunnelling engineer on the other hand, working in environments where stress concentrations are greater and where excavation tools and techniques are of great importance, generally requires a close subdivision in the higher strength ranges[8]. To accommodate the small subdivision of the range at both ends of the scale it is necessary to adopt six classifications in the range of rock material hardness. These are defined in Table 5. These classifications and their possible uniaxial compressive strength ranges are also shown on Figure 1. It will be observed that there is a terminology change from that proposed by Jennings et al[7].

TABLE 5. CLASSIFICATION OF ROCK HARDNESS

CLASSIFICATION	FIELD TEST	RANGE OF MINIMUM COMPRESSSIVE STRENGTH (MPa)
Very soft rock	Can be peeled with a kl1ife, material crumbles under firm blows with the sharp end of a geological pick	1 to 3
Soft rock	Can just be scraped with a knife indentations of 2 to 4 mm with firm blows of the pick point	3 to 10
Medium hard rock	Cannot be scraped or peeled with **a knife,** hand held specimen breaks with firm blows of the pick	10 to 25
Hard rock	Point load tests must be carried out in order to distinguish between these classifications. These results may be verified by uniaxial compressive strength tests on selected samples.	25 to 70
Very hard rock		70 to 200
Extremely hard rock		>200

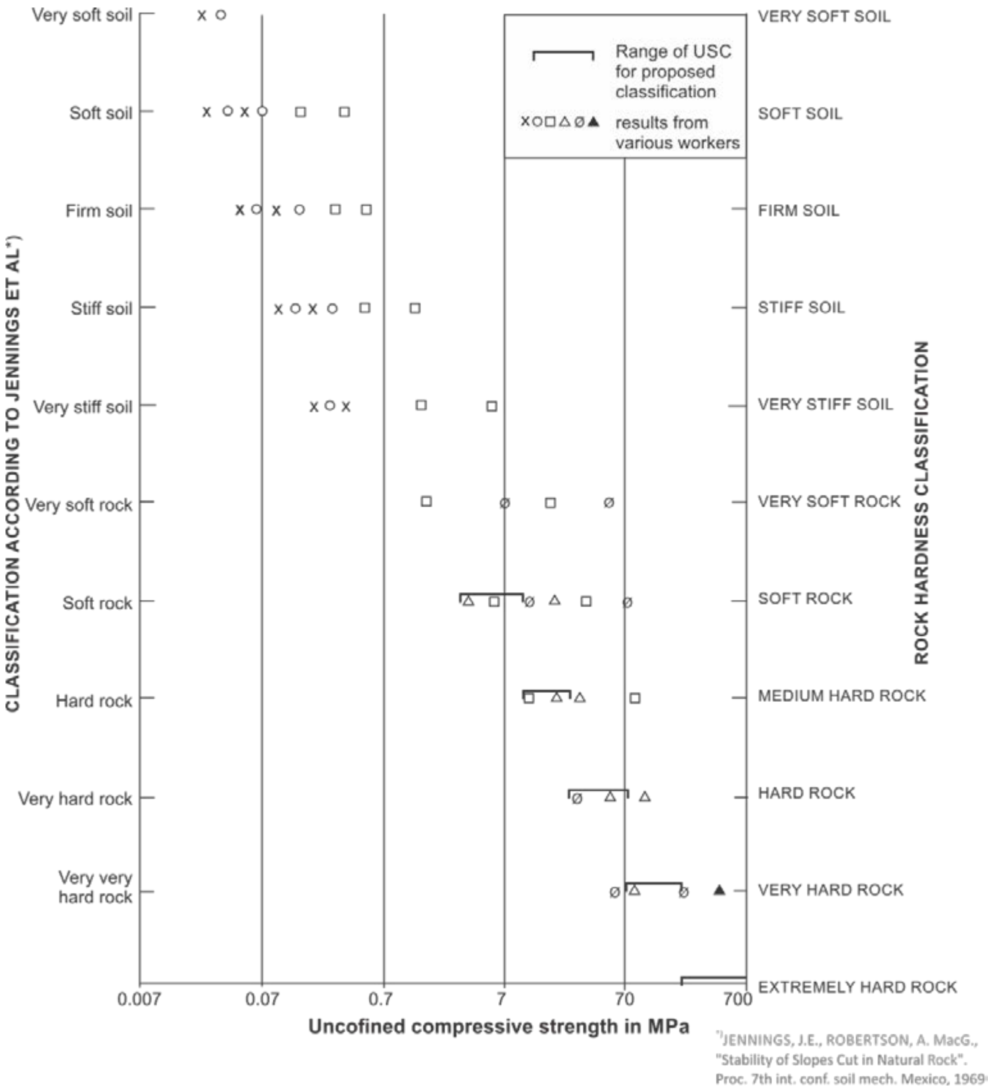

FIGURE 1. PROPSED ROCK HARDNESS CLASSIFICATION

2.1.6 Rock Type and Stratigraphic Horizon

Rock name or type is most significant in core logging. Not only does it identify the rock but it also provides an immediate picture of the likely engineering behaviour of the rock.

Problems posed by construction on, in or through mudstone, schist, dolerite or granite are vastly different. From previous experience the design engineer may recognise the effect that weathering produces on mudstones on exposure; he may identify the problems caused by sound dolerite boulders in a soft clay matrix; he would appreciate the significance of widely spaced weak joints in a massive granite.

It is recommended that the individual core logger should identify and classify rock cores in terms of standard conventions. Rocks are classified chemically, petrographically or in terms of their origin, depending on the purpose of the classification.

When classified in terms of origin, there are three rock types, namely igneous, metamorphic and sedimentary. Standard classification charts for igneous, metamorphic and sedimentary rocks, usually based on mineralogy and texture, are readily available in most geological textbooks.

From an examination of the rock core, and knowing the regional geology, it is relatively easy to make the primary division and to apply a purely descriptive name to the rock. Simple descriptive names are usually sufficient. More precise identification may have to be accomplished with a microscope.

The stratigraphic horizon from which the core was taken is often of engineering significance; for example the slaking characteristics of the Beaufort mudstones. It also indicates what other rock types that may·be anticipated on the site. The stratigraphic horizon is recorded following the rock type. It is usually sufficient to record this once per core log.

Examples of the primary core rock descriptions are:

(i) Light yellowish green streaked grey unweathered intensely laminated widely fractured medium hard rock mudstone, Ecca Group, Karoo Supergroup[9].

(ii) Dark greyish green speckled white slightly weathered very fine grained medium fractured very hard rock amygdaloidal andesite, Ventersdorp Supergroup.

2.2 Description of the Discontinuity Surfaces

The engineering behaviour of rock masses is often controlled by the discontinuity surfaces which occur within them. Discontinuity surface frequency or spacing is often the most effective feature to use singly to convey the effect of the discontinuities on rock mass behaviour. It is therefore selected for inclusion in the primary rock mass description. It is not necessarily the most significant feature controlling rock mass behaviour of any particular type.· The extent of joints and their separation may control permeability while orientation and fracture filling may be more significant to shear failure.

Depending on the nature of the engineering problem for which the core logging is being done, a number of other discontinuity surface features may be described in the core log. These are:

(i) Discontinuity surface type- or origin
(ii) Separation - of fracture walls
(iii) Filling - its presence or absence
(iv) Roughness -or the nature of the asperities on the fractures
(v) Orientation

In view of the disturbance of fracture filling and core orientation in the drilling process and the limited extent of any discontinuity surface exposed in the core, the accuracy or validity of the discontinuity surface descriptions made from core is often dubious. The use of special drilling techniques (core orientation) or exploratory methods (down-the-hole periscope or cameras) may be warranted.

The primary description of the rock mass properties may be followed by a description of the discontinuity surfaces which occur within it, which is in turn may be followed by a description of the fracture filling. Where individual discontinuity surfaces are recognisable as significant features, such as faults, shear zones or narrow dykes, they may be described singly. Where they are observed to fall into distinct groups, that is, joint sets, with distinctly different group properties, each group may be described separately.

The extent and complexity of the discontinuity surface description is at the discretion of the core logger. Sufficient detail should be included to enable a valid assessment of the rock mass behaviour to be made for the specific engineering problem at hand, but unnecessary and often costly detail should be avoided. It should be borne in mind that the cost of logging is small by comparison with the cost of recovering the core and that the core log is often more durable than the core.

2.2.1 Discontinuity Surface Type

Discontinuity surfaces are any surfaces across which there is a discontinuity of physical properties. Only those surfaces which have occurred as a result of natural geological processes are described. Fractures resulting from the drilling process or subsequent to core removal from the borehole are not described.

The properties of a discontinuity surface (extent, separation, filling, roughness, waviness and orientation) are often characteristic of its origin. Recognition of surface type in terms of its origin can therefore be extremely useful. For example bedding planes clearly have a much greater extent than cross joints in the same sedimentary rock.

A comprehensive description of fracture types and their properties has been published by Price[10]. Classification of discontinuity surfaces from the information contained in the core is usually limited to the more obvious surface types. These may be divided into two main categories:

(i) Discontinuity surfaces originating during the rock forming processes such as *bedding planes* in sedimentary rocks, *flow banding* in igneous rocks, *foliation* in metamorphic rocks and *lithological contacts* between rocks of different types or ages. Such discontinuity surfaces are usually of great extent with considerable uniformity of properties.

(ii) Fractures due to local overstress of the rock material producing rupture surfaces. The stress source may be tectonic, producing *shear* or *tension joints, normal, thrust* or *transverse faults* or *shear zones.* Where such tectonic joints occur in sedimentary rocks they are often referred to collectively as *bedding joints* or *cross joints* depending on whether they are parallel to or cut across bedding planes. Where stress occurs as a result of overburden removal or cooling, *exfoliation* and *cooling joints* result. Where fracturing has been accompanied by the intrusion of magma or the deposition of secondary materials, terms such as *dykes, sills* and *veins* may be appropriate.

The competent core logger should be aware of the different discontinuity surface types and be able to associate with each its origin and typical properties.

Discontinuity surfaces may occur singly (such as geological contacts) or in multiple sets (such as joint sets). Single features should be described individually while multiple features may be described collectively.

2.2.2 Separation

The separation between fracture surfaces controls the extent to which the opposing surfaces can interlock. In the absence of interlocking of the fracture walls the fracture filling controls entirely the shear strength along the fracture. As the fracture separation decreases the asperities of the fracture walls tend to become more interlocked and both the filling and rock material contribute to the fracture shear strength.

The shear strength along the fracture is therefore dependant on the degree of separation, presence or absence of filling materials, nature of asperities or roughness of the fracture walls and the nature of the filling material. The first three of these are included in the discontinuity surface description. The latter is included, where necessary, in a description of the filling material which follows the discontinuity surface description.

From a description by Piteau[11] the effect of degree of separation and filling can be classified as follows:

(i) With no separation (no filling) the sliding plane passes entirely through or along wall rock: the shear strength is entirely dependent on the properties of the wall rock.

(ii) Slight separation (filling appears as a stain): The filling or separation is considered only as modifying the friction angle

(iii) Appreciable separation (filling measurably thick) but still appreciable interlocking of the wall asperities: The shear strength will be a complex combination of filling and all rock material strengths.

(iv) Complete separation with no interlock of wall asperities: the filling material determines the fracture shear strength.

The suggested terminology for the separation of fracture walls is shown in Table 6.

TABLE 6. DESCRIPTION OF SEPARATION OF FRACTURE WALLS

DESCRIPTION	SEPARATION OF WALLS IN mm
Closed	0
Very narrow	0 – 0,1
Narrow	0,1 - 1
Wide	1 - 5,0
Very wide	5 – 25⁺

⁺Where separation is more than 25 mm, the fracture should be described as a major fracture.

2.2.3 Fracture filling (Presence or Absence)

All materials occurring between the fracture walls are referred to as fracture filling. The term includes in-situ weathered materials, fault zone materials and foreign materials either deposited or intruded between the fracture surfaces.

Only the presence or absence of fracture filling is noted in the discontinuity surface description. Where applicable a separate description of the fracture filling is given after the discontinuity surface description.

The suggested terminology to be used to indicate the present or absence of fracture filling materials is given in Table 7.

TABLE 7. TERMINOLOGY FOR PRESENCE OR ABSENCE OF FRACTURE FILLING MATERIALS

DESCRIPTION	DEFINITION
Clean	No fracture filling material
Stained	Colouration of rock only. No recognisable filling material
Filled	Fracture filled with recognisable filling material

2.2.4 Roughness

Asperities which occur on fracture walls interlock, if the fractures are clean and closed, and inhibit shear movement along the mean fracture surface. This restraint on movement is of two types. Small high angle asperities are sheared off during shear displacement and effectively increase the peak shear strength of the fracture. Such asperities are termed roughness. Large low angle asperities cannot be sheared off and "ride" over one another during shear displacement, changing the initial direction of shear displacement. Such large order asperities are termed waviness and cannot be reliably measured in core.

Roughness asperities usually have a base length and amplitude measured in terms of millimetres and are readily apparent on a core sized exposure of a fracture. The applicable descriptive terms are defined in Table 8.

TABLE 8: ROUGNESS CLASSIFICATION

CLASSIFICATION	DESCRIPTION
Smooth	Appears smooth and is essentially smooth to the touch. May be slickensided.
Slightly Rough	Asperities on the fracture surfaces are visible and can be distinctly felt
Medium Rough	Asperities are clearly visible and fracture surface feels abrasive
Rough	Large angular asperities can be seen. Some ridge and high side angle steps evident.
Very Rough	Near vertical steps and ridges occur on the fracture surface

Where slickensides are observed the direction of the slickensides should be recorded after the standard discontinuity surface description.

2.2.5 Orientation

The two necessary and sufficient conditions for the definition of the orientation of a particular plane are its dip and dip direction.

There are at present a number of specialised methods that can be used to obtain the dip and dip direction of discontinuity surfaces in drill core. One method is to remove an orientated core from the rock mass using a special core orienter barrel. Alternatively the discontinuity surface orientation can be measured in the wall of the borehole using an orientated borehole periscope, camera or devices capable of taking an impression so the borehole sides. Where a feature of known dip and dip direction, i.e. bedding, intersects the core at an angle this may be used to orientate the core. A further method requires the presence of at least one easily identifiable marked band and the use of a minimum of three boreholes. This latter method enables three dimensional geometry, usually aided by stereographic projection, to be used to establish the attitude of the maker horizons. The above methods are costly and are only employed where the attitude of the discontinuity is critical to the solution of the problem.

The dip of a particular surface is the maximum angle between the plane containing the surface and the horizontal and is recorded in degrees from 0^{o} to 90^{o}.

The dip direction is the compass bearing, from true north, of the direction of maximum dip and is recorded in degrees (e.g. 045^{o} and not NE) measured clockwise from north.

A complete definition of the orientation of any one surface is given by recording the dip and dip direction, for example: 30^{o} at 036^{o} would indicate a surface dipping at 30^{o} from the horizontal with the direction of maximum dip having an orientation of 36^{o} measured clockwise from true north. A note should be made when the reading refers to true or magnetic north.

Discontinuity surfaces rarely exist in isolation and usually occur in sets. It is the definition of a number of sets and their relationship to each other that is necessary for design purposes. The definition of these sets and their orientation is simplified if all the field readings are plotted on a stereogram. The stereographic plot enables the distribution of individual discontinuity surfaces to be seen and permits the definition of discontinuity surface sets and their orientation.

On the core log the dip and dip direction of each discontinuity surface set is recorded at the end of the discontinuity surface description.

Examples of discontinuity surface descriptions are as follows:

(i) Bedding joints are narrow oxide stained slightly rough dipping 30^o at 145^o.

(ii) Set "A" cross joints are closed clean very rough dipping 10^o at 270^o.

2.3 Description of the Fracture Filling

The influence of fracture filling is two-fold.

(a) Depending on the thickness, the filling prevents the interlocking of the fracture asperities.

(b) It possesses its own characteristic properties, that is, shear strength, permeability and deformational characteristics.

The effect of the former can be deduced from the description of the fracture separation and fracture roughness. For the effect of the latter to be assessed, the nature of the infilling materials must be adequately described.

The following parameters should be described.

Moisture
Colour
Consistency or Hardness
Soil or Rock Type
Origin

Moisture, consistency, soil type and origin should be described in accordance with soil profiling techniques as described by Jennings et al[1]. Colour, hardness and rock type should be described as indicated under the appropriate sections in this paper. Where porosity is important, an estimate of the porosity should be given; as a percentage.

It should be remembered that the drilling technique employed to recover rock cores may not be suited to the recovery of relatively thin bands of softer material within the rock mass. Recovery of fracture filling may therefore be only partial and recovered material may be disturbed. Where drilling muds or fluids are used this may contaminate the filling materials and moisture conditions are altered by drilling water.

3 THE BOREHOLE LOG

The borehole log serves to describe not only the rock core produced by drilling but also any other relevant information which may be obtained from the drilling process, and from tests on cores or in boreholes.

Data relative to the borehole, the tools and materials used to form it, the casing installed for sidewall support and the tests conducted in it are significant in as much as they greatly influence the condition of the core recovered, or provide indications of rock or soil mass properties. Such information is obtained from the drillers record and forms an integral part of the borehole log.

In the description of the borehole core it is usually advantageous to include a number of other parameters or indices. These indices, for example "Rock Quality Designation" (RQD) and "Standard Penetration Blow Count" (N), have been correlated with rock and soil behavioural characteristics and are indicative of certain rock and soil mass properties.

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3.1 Layout of Log Sheet

Illustrated in Figure 2 is a typical borehole log sheet of a form suggested for general purpose usage. Where specific requirements necessitate additional information, this can be added at the logger's discretion.

The information recorded on such a log is as follows:

(i) Borehole Number - This number should be used only once on any site and kept as simple as possible.

(ii) Location
- (a) Project - Name of Project e.g. Alrode Brewery
- (b) Site - Particular site e.g. Workshops
- (c) Location - Grid reference or chainage
- (d) Elevation given above M.S.L. and orientation if not vertical.

(iii) Drilling Technique
- (a) Machine - Make of machine with model number
- (b) Drilling method and size; including type of flush, core barrel and bit.

(iv) Contract Details
- (a) Contractor
- (b) Driller
- (c) Project Number - Consultants reference
- (d) Name of Logger
- (e) Date of logging
- (f) Date drilling started and drilling completed.

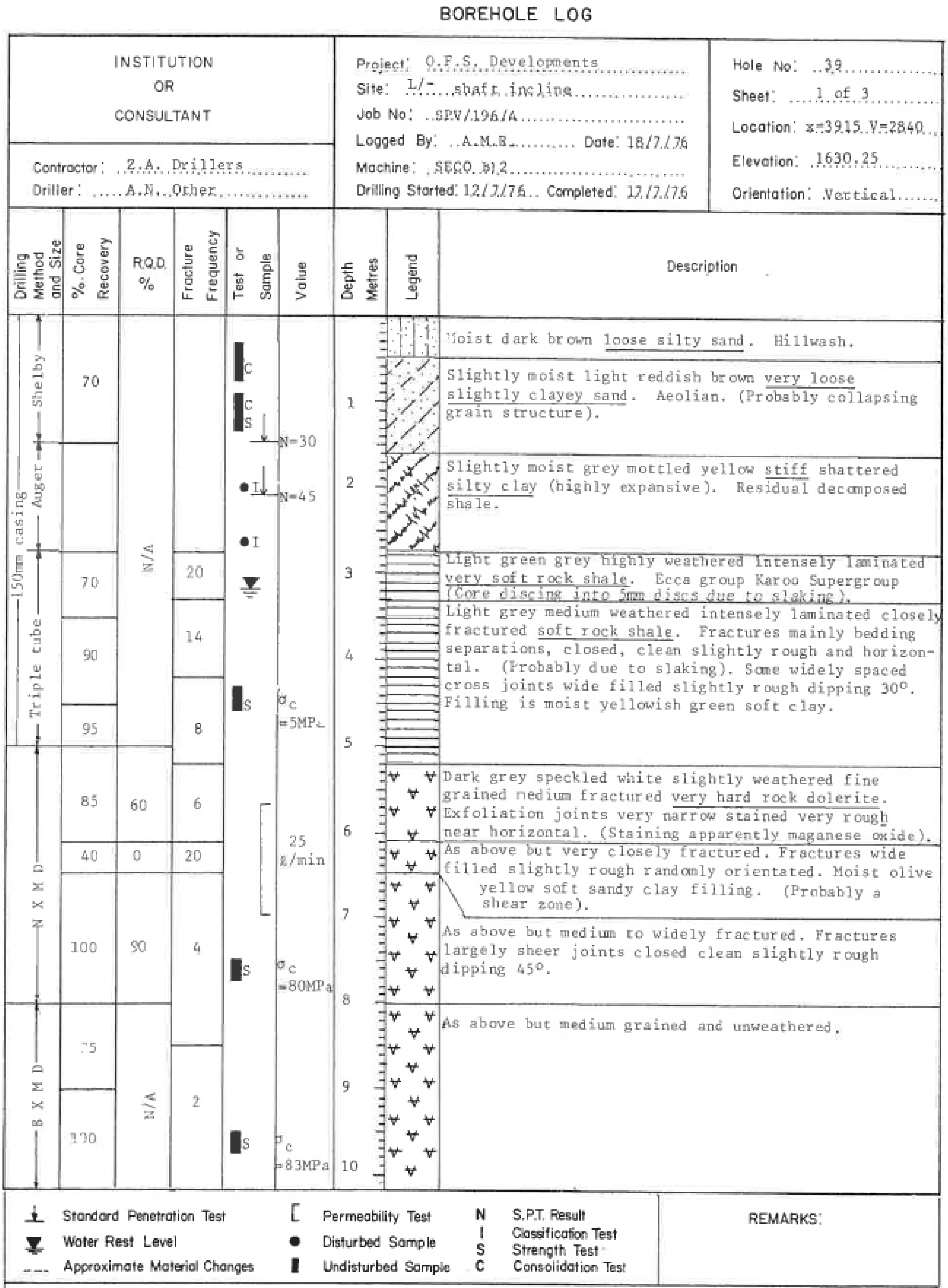

FIGURE 2 STANDARD BOREHOLE LOG

The suggested log sheet has been compiled so that the name of the Institute or Consultant, the borehole number, location and contract details are given at the top of the sheet. Conventionally, the sheet is divided into vertical columns to permit the sequential logging of the various borehole details against a single depth scale. At the base of the sheet a space is allowed for a key to the various symbols used on the log and for relevant remarks.

The sequence of vertical columns have been selected with due consideration to the sequence in which information is recorded on the sheet, ease of completion, cross referencing of information and ease of use of the completed log. Reading from the left the columns occur in the following order.

3.2 Drilling Method and Size

This column is to be used for recording the drilling technique, flush type, drilling or sampling tool and bit. Where casing is used, the type and size should be indicated. The use of conventional symbols such as NXM as defined by the Diamond Core Drill Manufacturers Association (DCDMA) or Swedish Method (Craelius)[12].

3.3 Percentage Core Recovery

This is the measured core recovery per drill run expressed as a percentage. This value may exceed 100% if core drilled during the previous run is recovered in the run described. As it is only possible to describe the core seen in the core box it is necessary to know on what proportion of the rock mass, intersected by the borehole, the description in the log is based. It may generally be anticipated that weak rock and fracture zones are most likely to be present in the sections of core not recovered. Poor core recovery is therefore indicative of poor rock mass strength. This parameter is considerably affected by the quality of drilling and drilling tools used. When recording the core recovery in any drill run, the core should be reassembled as far as is possible, as many drillers tend to spread the core out in the core box which gives a misleading impression of the recovery. Wherever possible the logger should indicate the probable reasons for core loss.

3.4 Rock Quality Designation

This column is used for recording Rock Quality Designation, RQD, as proposed by Deere[13]. Measurement of the RQD provides a method of assessing the quality of a rock mass, based on the size of individual core sticks obtained when drilling NX (54 mm diameter) size core. This method yields a numerical figure between 0 and 100. RQD is measured per drill run and is defined as the total length of the individual core sticks greater than 100 mm in length divided by the length of the drill run and expressed as a percentage.

3.5 Fracture Frequency

The fracture frequency is obtained by counting the number of natural fractures (complete separations) that occur per metre length of core recorded over the actual length of core over which that frequency occurs. Unlike RQD, this parameter is not based on a specific size of core. The fracture frequency is recorded as a number. It has been found that where the number of fractures is greater than 20 the specific number is not significant and therefore only numbers for 0 to 20 and >20 need be recorded. The fracture spacing can readily be recorded as a histogram in order to illustrate graphically, for example, where very closely or closely jointed zones are located within the core.

3.6 Test or Sample

The location and nature of any tests conducted in the borehole or on the core taken from the borehole should be indicated in this column. Tests commonly conducted in the borehole include standard penetration, shear vane, point load, permeability, pressure meter and geophysical tests. Tests on selected core samples may include index, shear strength, consolidation or permeability tests. Where symbols are used to indicate test types, these should be defined in the key.

3.7 Value

Where appropriate, the value obtained in the various tests conducted can be shown in this column. The nature of the value and the units in which it is quoted must be apparent from the manner in which it is recorded or the definitions given in the key. For example standard penetration test blow counts may be recorded in this column following the symbol N = with the appropriate definition in the key indicating that the number following N = indicates the number of blows per 300 mm advance in a Standard Penetration Test.

3.8 Depth

This column records depth to a definite scale. All other records on the borehole log should be referenced to this scale according to the depth in the borehole at which the data or description applies.

3.9 Water Rest Level

The level at which the water comes to rest in the borehole and the date at which this level is reached must be recorded on the log sheet in the test and value columns.

3.10 Legend

This column is used for the pictorial description of material type. The suggested symbols to be used for soils are those given by Jennings et al[1].

The suggested symbols for rock are those recommended by the International Standards Organisation[14]. An example of the symbols representing some rock type is included in Figure 3. The reference should be consulted for a complete description of this symbolic system. At the time of writing a standard had not been proposed for metamorphic rocks.

3.11 Description

This column is used for recording the core log in accordance with the proposals in this paper.

The proposed borehole log sheet can be used in the field as a field sheet or alternatively, specially constructed field sheets can be used from which the final log is completed in the office.

4 CORE HANDLING, LOGGING AND STORAGE TECHNIQUES

It is not the object of this section to prescribe standard methods for handling, logging and storage of core, but to provide a number of useful hints which make core logging easier, more accurate and consistent. It is assumed that the core has been obtained with due care and in accordance with current good practice.

Most of the points mentioned under 1 and 2 below are the responsibility of the drilling contractor but the core logger must be aware of these requirements in order to ensure that they are met.

4.1 Extraction and Protection of Borehole Bore

Core drilling is an expensive and highly specialised operation aimed at the recovery of a core which is as complete and undisturbed as possible. It is therefore of utmost importance that great care be taken not only when drilling but also when extracting the core from the barrel to avoid the further breaking up and loss of material. Extraction under steady, carefully applied pressure or the use of split inner tubes is to be preferred. Hammering or jetting of the core barrel should not be allowed

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under any circumstances. Weathered cores or cores susceptible to weathering should be wrapped in thin plastic tubing, tied at either end to retain moisture conditions.

Cores of slaking material must not be exposed to the sun but foil-wrapped and waxed as soon as possible after recovery (within an hour). Logging should be done before waxing, if possible, or otherwise as soon as possible thereafter. Wax should be removed without heat and after logging, cores must be re-waxed.

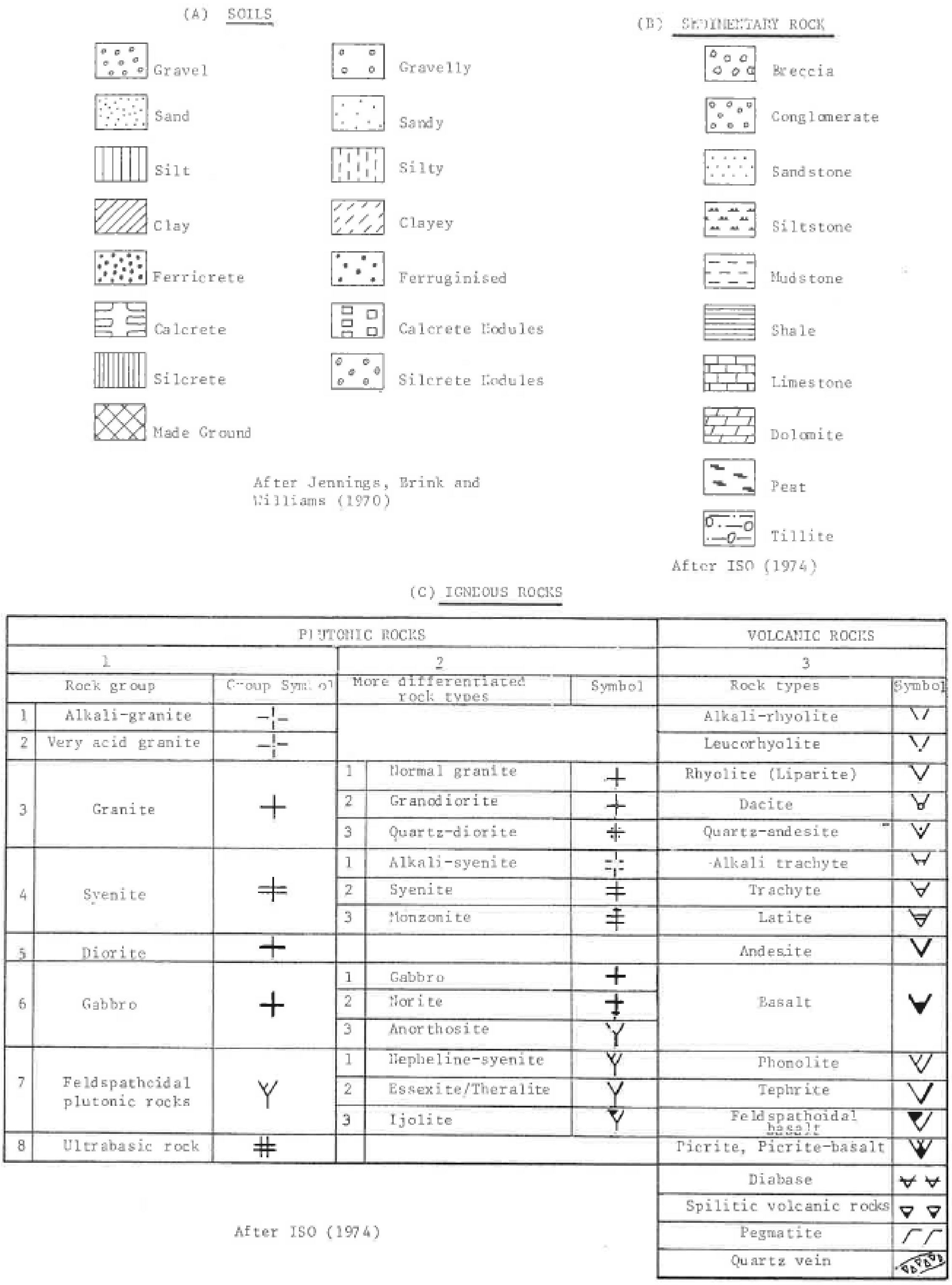

FIG. 3 PROPOSED GRAPHICAL SYMBOLS FOR USE ON PROFILE LEGENDS

4.2 Arrangement and Labelling of Core in Core Boxes

Core boxes should be of light but robust construction and of such a size that they can be handled with ease (maximum size recommended is 1,5 x 0,5 m). Wooden boxes are recommended. Boxes should be made to hold the particular size of core tightly, in rows separated by wooden slats. The lid of the core box may have a foam rubber lining to keep the core in position during transportation.

Core boxes should be clearly identified by painting the project number, site name, borehole number, core box number, top and bottom depths of core contained and the drilling contractor's name on the outside and inside of the lid as well as on at least one side of the core box.

Core must be laid out in the core box to read in book fashion, that is with the shallowest cores in the left side of the top row next to the lid hinge and the next row of core starting again with its shallowest depth in the left side and deepening towards the right.

At the beginning and end of every core run, a wooden block of appropriate dimensions should be placed. On these blocks, and if possible also on the core, the direction of drilling and the depth must be written in well-spaced figures with a size of at least 20 mm. The marking of depths on the core box is not recommended.

Core loss should be indicated by placing a wooden block, with length equal to that of the loss, in the appropriate position and by writing the depths at both ends of the block. Blocks indicating core loss are often painted red. Where core samples are removed for laboratory testing, yellow blocks equal in length to the core removed, should be instituted in the box.

Before logging or photographing is undertaken, it is advisable to make sure that the core is properly packed and marked in a core box. It is usually necessary to turn cores around in order to orientate according to a known marker feature such as bedding, schistosity or a major joint set and to fit pieces of core together in order to measure core recovery etc. At this stage it may be necessary to rewrite depths on the core or to add further depth marks.

4.3 Core Photography

It is recommended that colour photographs of all borehole core be obtained as a permanent record and for comparison with the descriptive log. Core photography must be carried out before the core is removed for description and testing. The following procedures are recommended:

(i) One core box must be photographed at a time.
(ii) A label with the name of the site and borehole number must be attached to the core box.
(iii) All lettering must be well-spaced and have a minimum size of 20 mm.
(iv) A colour chart must be attached to the core box.
(v) A frame is useful to support the camera vertically above the core box or to support the core box in a tilted (60^{o}) position so that its surface is normal to the direction of photography.
(vi) The best results are achieved if photography is carried out under roof and with flood lights. Good results can however be obtained in the field with the use of natural light.
(vii) Machine printing of photo's is not recommended and it is useful to obtain prints on a scale of 1:10.

4.4 Core Logging

Only persons trained and experienced in engineering geology or geotechnical engineering should be allowed to log borehole core. It is recommended that the method of description as presented in this paper be adopted.

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Equipment that is considered essential for the logging of rock cores includes the drillers log, paper, pencil, metric tape, compass, clinorule, water, brush or cloth, knife, geological pick and magnifying glass. A labourer to assist in the moving of core boxes can be most helpful.

Useful additional equipment includes pre-printed logging forms, clip-board, geological compass, clinometer, annular protractor to fit core, orientator box, insecticide type garden spray for wetting cores, table or stand for core box, point load apparatus, camera and accessories, and colour chart.

The best place to log core is at the borehole position which avoids unnecessary handling and disturbance of the core. The best time to log is as shortly after the core is removed from the core barrel as is possible, due to the rapid deterioration of cores (especially sedimentary rocks) and core boxes.

It is preferable that the driller be present while logging, in order to draw on his intimate knowledge of drilling and rock conditions and to obtain drilling information required on the core log. The following comments apply to the filling in of the log sheet:

(i) Drilling method and size: This information is obtained from the driller's log.
(ii) Core recovery, RQD and fracture frequency: These measurements are normally carried out after the core has been properly arranged and before pieces are removed for laboratory testing. A 3 m retractable steel tape is a most useful tool and it is advisable to record information on a special sheet with space for calculations and the entering of percentages. Fracture frequency is measured by counting all fractures intersecting an imaginary line drawn along the top of the core.
(iii) Colour: Wetting of the core is best achieved by means of a garden insecticide type spray, filled with water. Otherwise a bucket with water and a soft brush or a cloth can be used.
(iv) Weathering and fabric: A magnifying glass is useful.
(v) Fracture spacing: The average spacing of all fractures intersecting an imaginary line drawn along the top of a core is determined.
(vi) Hardness can be determined by using a knife (1-3 MPa), geological pick (3-25 MPa) and a portable point load apparatus (> 25 MPa).

4.5 Long-term Storage of Core Boxes

Cores are normally stored for a period of several years (until construction has been completed). Core boxes must be stored in well ventilated, weatherproof rooms with concrete floors and should preferably be placed on racks rather than in stacks. Provision must be made for space around the racks or stacks in order to reach individual boxes for re-examination.

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