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# CLASSIFICATION OF ROCKS AND SOILS FOR ENGINEERING GEOLOGICAL MAPPING PART I: ROCK AND SOIL MATERIALS

# CLASSIFICATION DES SOLS ET DES ROCHES EN VUE DE LA CARTOGRAPHIE GÉOTECHNIQUE PREMIERE PARTIE: LES MATÉRIAUX DES ROCHES ET DES SOLS

**Report of the Commission of Engineering Geological Mapping of the International Association of Engineering Geology**

Rapport de la Commission de cartographie géotechnique de l'Association internationale de géologie de l'ingénieur

## Preface

In 1976 UNESCO published a guide to the preparation of engineering geological maps prepared by the Commission on Engineering Geological Maps of the International Association of Engineering Geology. That guidebook gave a brief outline of the principles of classification of rocks and soils for engineering geological mapping. The present report presents the first part of a more detailed treatment of this topic, and deals with the classification and description of rock and soil material for mapping purposes.

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## Préface

En 1976 l'UNESCO publia un Guide pour la préparation des cartes géotechniques, préparé par la Commission de cartographie géotechnique de l'Association internationale de géologie de l'ingénieur. Ce guide donnait une brève esquisse des principes d'une classification des roches et des sols en vue de la cartographie géotechnique. Le présent rapport constitue la première partie d'une étude plus détaillée de cette question; il traite de la classification et de la description des matériaux des roches et des sols en vue de la cartographie.

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nom de roche ou de sol homogène, constituant un type

Texture
Couleur
Etat d'altération (degré d'altération)
Degré de fissuration
Densité relative des sols non cohérents
Consistance des sols cohérents
Résistance des roches dures et tendres
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## 1. Principles of engineering geological classification of rocks

The physical properties of rocks, including hard and soft rocks as well as engineering soils, are dependent on their lithogenesis, that is their origin and mode of formation. Thus a classification system of rocks for engineering geological purposes must of necessity be based on lithogenetic criteria. At present not enough is known of the relations between engineering properties and lithogenetic characters to establish a unified classification system in which individual classes would represent a natural rock unit characterized by a narrow range of engineering properties. Consequently, a three-part engineering geological classification is proposed (Tab. 1), comprising:

(i) a lithogenetic classification;
(ii) engineering geological characteristics of rock material and the rock mass; and
(iii) geotechnical classifications.

I LITHOGENETIC CLASSIFICATION

a) Major taxonomic unit (LS, LC, LT, ET)
b) Basic map unit and its lithogenetic characteristics
c) Number of map unit
d) Map symbol (pattern, colour, etc.)
e) Thickness
f) Age
g) Stratigraphical symbol
h) Genetic group

II ENGINEERING GEOLOGICAL CHARACTERISTICS

a) For the principal lithological types or engineering geological types, their classification characteristics (composite descriptive name) (2.1 and 2.3).

b) For rock material of the principal lithological or engineering geological types, the semiquantitative and quantitative values of indirect (3.5.1) and direct (5.2) characteristics of the rock material.

c) For lithological complexes in situ, characteristic rock mass properties and the structure of individual complexes (3.6).

III GEOTECHNICAL CLASSIFICATIONS

Tab. 1: Unified system of classification and characterization of rocks for use on the legend of engineering geological maps (arranged in vertical columns)

There is an obvious need to make the classification simple so that it may be readily understood and used by geotechnicians and other engineers for planning, design and construction purposes. Two other comments are necessary. The first concerns geotechnical classifications which are usually embodied in Codes of Practice drawn up by various countries. For the foreseeable future there appears to be little prospect of international agreement on such matters, and the very general suggestions in this report are only an indication of what might be achieved in the future.

A second comment concerns the use of the terms **rock** and **engineering soil**. Although both soil and rock are covered by the single geological term "rock", there is a clear distinction to be made between the engineering behaviour of the two. Another Working Party (Anon. 1972) has used as a guide to the distinction between soil and rock the following quotation: "Soil is an aggregate of mineral grains that can be separated by such gentle means as agitation in water. Rock, on the other hand, is a natural aggregate of minerals connected by strong and permanent cohesive forces. Since the terms "strong" and "permanent" are subject to different interpretations, the boundary between soil and rock is necessarily an arbitrary one" (Terzaghi & Peck 1967, p. 4), leading to the recognition of soft rocks or hard soils at the transition from rock to engineering soil.

## 2. Lithogenetic classification

### 2.1 Introduction

Internationally acknowledged taxonomic units (UNESCO-IAEG 1976) in the lithological classification of rocks for engineering geological maps are:

| | |
|---|---|
| Engineering geological type | ET |
| Lithological type | LT |
| Lithological complex | LC |
| Lithological suite | LS |

These units have been defined and for ease of reference the definitions (UNESCO-IAEG 1976, p. 12 and Section 7.2) are given here:

**Engineering geological type:**

The engineering geological type has the highest degree of physical homogeneity. It should be uniform in lithological character and physical state. These units can be characterized by statistically determined values derived from individual determinations of physical and mechanical properties.

**Lithological type:**

A lithological type is homogeneous throughout in composition, texture and structure, but usually is not uniform in physical state. Reliable values of average mechanical properties cannot be given for the entire unit; usually only a general idea of engineering properties, with a range of values, can be presented.

**Lithological complex:**

A lithological complex comprises a set of genetically related lithological types developed under specific palaeogeographical and geotectonic conditions. Within a lithological complex the spatial arrangement of lithological types is uniform and distinctive for that complex, but a lithological complex is not necessarily uniform in either lithological character or physical state. In consequence, it is not possible to define the physical and mechanical properties of the whole lithological complex, but only to give data on the individual lithological types comprising the complex and to indicate the general behaviour of the whole lithological complex. The lithological complex is used as a mapping unit on medium-scale and some small-scale maps.

**Lithological suite:**

The lithological suite comprises many lithological complexes that have developed under generally similar paleogeographical and tectonic conditions. It has certain common lithological characteristics throughout which impart a general unity to the suite and serve to distinguish it from other suites. Only very general engineering geological properties of a lithological suite can be defined.

In general, the lithogenetic classification for engineering geology should be simple but at the same time retain a scientific basis (Dearman 1974a). Such requirements are met only by a **typological classification** based on a limited number of distinctive, **named rock types** to which the mapping rock units can be referred. The same principles are applied for lithological complexes, where general lithological and genetical characteristics should not be replaced by various regional or local names for formations and other stratigraphical rock units (these, however, can provide **additional** information).

There are two aspects of the **classification of lithological types.** The first is expressed in the **fundamental name of the rock,** which in comparison with petrographic terminology is: simpler, technically more useful, and unified for all genetic rock groups. The second is the use of a unified descriptive system using a **composite descriptive name** for a particular lithological type.

### 2.2 Fundamental name

A simple, technically useful and unified classification of fundamental lithological types is proposed in Tab. 2. The classification comprises all genetic rock groups: **magmatic** (major intrusive, minor intrusive, effusive); **metamorphic** (regional, contact, dynamic, hydrothermal) and **sedimentary** (unconsolidated and consolidated, clastic, carbonaceous, chemical, biogenic). An important criterion for division is grain-size classified semiquantitatively (very coarse-grained, coarse-grained, medium-grained, fine-grained, very fine-grained to amorphous). The classification also considers other attributes: namely fundamental types of rock fabric and fundamental mineral compositions. In Tab. 2, the names of the most common rocks are indicated in capital letters; unlithified (unconsolidated) sediments are indicated in italics.

### 2.3 Descriptive name

A **composite descriptive name** involves a comprehensive description of engineering geological properties as an adjunct to the **fundamental rock name** fore each lithologically homogeneous rock type (LT, ET). It includes the semiquantitatively expressed characteristics of: **descriptive and physical properties** (colour and texture), **physical state** (jointing, relative density, consistency, weathered state), **mechanical properties** (strength, deformability), **permeability** and **durability.**

First in order of importance is the **fundamental rock or soil name** which provides basic information on mineral composition and grain size. In the description of the rock unit within the map legend (or explanation) it is recommended that the importance of the **rock name** is stressed by placing it first for instance, and by the use of capital letters or by underlining. Supplementary **petrographic properties** may be used where necessary to qualify the rock name, signifying, for example, a distinctive mineralogical feature or indicating minor admixtures of other lithological types. Lithological character is also defined by **physical properties**: 1. texture; 2. colour, which are placed next. Properties characterizing the **rock state** are placed after the lithological characteristics in the following order: 3. weathered state (or degree of weathering); 4. degree of jointing (and/or relative density in cohesionless soils, and/or consistency in cohesive soils). After that are placed the main **engineering geological properties**: 5. strength; 6. deformability; 7. permeability; 8. rock durability (resistance to external agents).

It is evident that such a comprehensive description deals not only with

| GENETIC GROUP | | | DETRITAL SEDIMENTARY | | | | | PYROCLASTIC | | CHEMICAL/ ORGANIC |
|---|---|---|---|---|---|---|---|---|---|---|
| Usual Structure | | | BEDDED | | | | | | | |
| Composition | | | Grains of rock, quartz, feldspar and clay minerals | | At least 50% of grains are of carbonate | | | At least 50% of grains are of fine-grained igneous rock | | |
| GRAIN SIZE (mm) > 60 | Very coarse-grained | RUDACEOUS | *BOULDERS* *COBBLES* | Grains are of rock fragments. Rounded grains: CONGLOMERATE | *CARBONATE GRAVEL* | CALCI-RUDITE | LIMESTONE and DOLOMITE (undifferentiated) | Rounded grains AGGLOMERATE | VOLCANIC ASH | |
| 60 – 2 | Coarse-grained | RUDACEOUS | *GRAVEL* | Angular grains: BRECCIA | | | | Angular grains VOLCANIC BRECCIA LAPILLI TUFF | | SALINE ROCKS Halite Anhydrite |
| 2 – 0.06 | Medium-grained | ARENACEOUS | *SAND* | Grains are mainly mineral fragments. SANDSTONE Grains are mainly mineral fragments QUARTZ SANDSTONE: 95% quartz, voids empty or cemented ARKOSE: 75% quartz, up to 25% feldspar: voids empty or cemented GREYWACKE: 75% quartz, 15% fine detrital material; rock and feldspar fragments | *CARBONATE SAND* | CALC-ARENITE | | TUFF | | Gypsum LIMESTONE DOLOMITE |
| 0.06 – 0.002 | Fine-grained | ARGILLACEOUS or LUTACEOUS | *SILT* | SILTSTONE 50% fine-grained particles. MUDSTONE SHALE: fissile mudstone MARLSTONE | *CARBONATE SILT* | CALCI-SILTITE CHALK | | Fine-grained TUFF | | CHERT |
| < 0.002 | Very fine-grained | ARGILLACEOUS or LUTACEOUS | *CLAY* | CLAYSTONE 50% very fine grained particles | *CARBONATE MUD* | CALCI-LUTITE | | Very fine-grained TUFF | | FLINT *PEAT* |
| | GLASSY AMORPHOUS | | | | | | | | | LIGNITE COAL |

Tab. 2: Classification of rocks and soils for engineering geological purposes (a) sedimentary rocks

| METAMORPHIC | | IGNEOUS | | | | GENETIC GROUP | GRAIN SIZE (mm) |
|---|---|---|---|---|---|---|---|
| FOLIATED | MASSIVE | | | | | Usual Structure | |
| Quartz, feldspars, micas, acicular dark minerals | | Light coloured minerals are quartz, feldspar, mica* | | Dark and light minerals | Dark minerals | Composition | |
| | | Acid rocks | Intermediate | Basic rocks | Ultrabasic | | |
| GNEISS (ortho-, para-) Alternate layers of granular and flakey minerals | MARBLE | PEGMATITE | | | PYROXENITE and PERIDOTITE | Very coarse-grained | |
| MIGMATITE | GRANULITE | GRANITE | DIORITE | GABBRO | SERPENTINITE | Coarse-grained | 60 |
| SCHIST | QUARTZITE HORNFELS AMPHIBOLITE | MICROGRANITE | MICRODIORITE | DOLERITE | | Medium-grained | 2 |
| PHYLLITE SLATE MYLONITE | | RHYOLITE | ANDESITE | BASALT | | Fine-grained | 0.06 |
| | | | | | | Very fine-grained | 0.002 |
| | | OBSIDIAN and PITCHSTONE | | TACHYLYTE | | GLASSY AMORPHOUS | |
| | | VOLCANIC GLASSES | | | | | |

Tab. 2: Classification of rocks and soils for engineering geological purposes (b) metamorphic and igneous rocks

**rock material**, but also to a certain degree with the **rock mass**, mainly when characterizing the physical state or permeability of rocks in natural conditions.

Methods for classifying the individual characteristics semiquantitatively are given in detail in Section 3.

## 3. Engineering geology rock and soil characteristics

### 3.1 Introduction

Both qualitative and quantitative characteristics of rocks and soils are currently used in engineering geological mapping. While **qualitative** description based on observation and simple measurements prevail in the first mapping phases and in the preparation of maps at the smaller scales, quantitative evaluations are inevitably made for more detailed maps.

**Quantitative** rock parameters include physical characteristics (unit weight, porosity, degree of saturation, plasticity), strength properties (tensile, compressive, uniaxial and triaxial, shear strength), deformation properties (deformation and elastic moduli, Poisson's ratio), permeability, rock durability and other properties, all of which are based on the laboratory testing of specimens or field tests, or both. Laboratory testing may also be undertaken in field laboratories which are a very valuable aid to mapping.

Also included are field tests for the determination of the index and physical-mechanical properties of individual homogeneous rock types. Here belong, for instance, vane tests, penetration-logging, pressuremetric tests, as well as various **in situ** tests to determine permeability.

**Semiquantitative** classifications represent an assessment of phenomena by ranking into classes which, however, are limited by quantitative values. When suitably set up, they provide information on a rock property which it is neither possible, necessary, nor appropriate to express by an exact numerical value. Though not exact, for the stated reasons, the information actually has a much higher value than a qualitative description of a phenomenon.

### 3.2 Characteristics of rock and soil properties

Characteristic properties should always be given separately for hard and soft rocks, for cohesionless gravelly and sandy soils, and for cohesive soils. There are three kinds of characteristic: (a) classification, (b) indirect and (c) direct.

**Classification characteristics** serve for a systematic description and grouping of rocks into various classes, as well as for the mutual comparison of different rock types. They are currently evaluated in mapping, and in the preliminary stages of site investigation, by simple and inexpensive methods.

**Indirect characteristics** are those physical properties which are not used for direct engineering calculations. They are, however, closely correlatable with strength, deformation or permeability properties and therefore provide "index properties" for the indirect estimation of the physical state of rocks and their engineering behaviour.

**Direct characteristics**, the evaluation of the main physical properties of rocks (strength, deformation, permeability), serve directly for engineering calculations.

In Tables 3 and 15 the symbols Q, S and N respectively indicate the qualitative, semiquantitative and numerical (i.e. quantitative) ways for representing, (a) classification, (b) indirect, and (c) direct characteristics of rock properties in legends on maps of varied scale (I — small, II — medium, and III — large-scale).

### 3.3. Methods of representation of quantitative rock and soil characteristics

On the map and its legend, semiquantitatively and quantitatively assessed rock properties are delimited in different ways.

For semiquantitative evaluations on maps, boundaries are drawn around units which are homogenous in terms of, for example, a defined degree of plasticity, consistency, or relative density, or of such characteristics as degree of jointing or weathering grade. Quantitative assessments can also be expressed by lines of equal values (isolines)

| Characteristics of homogeneous rock types (ET, LT) | | Hard and soft rocks | | | Cohesionless soils | | | Cohesive soils | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Name of characteristic | I | II | III | I | II | III | I | II | III |
| Classification characteristics | Mineral composition | (Q) | Q | Q | (Q) | Q | Q | (Q) | Q | Q |
| | Texture (grain size) | S | S | S | S | S | S | S | S | S |
| | Colour | Q | Q | Q | Q | Q | Q | Q | Q | Q |
| | Weathered state | Q | Q | S | | Q | S | | Q | S |
| | Degree of jointing | Q(S) | S | S | | | | | | |
| | Relative density | | | | S | S | S | | | |
| | Consistency | | | | | | | S | S | S |
| | Strength | S | S | S | | | | | | |
| | Deformability | S | S | S | | | | S | S | S |
| | Permeability | Q | S | S | S | S | S | Q | S | S |
| | Durability | | | | | | | | | |

Footnotes:

1. The maps in the table are distinguished according to scale as: I - small, II - medium, III - large scale maps.
2. The rock characteristic is indicated by: S - Semiquantitative data, N - Numerical (quantitative data).
3. Data in brackets are not obligatory for that map-scale.

Tab. 3: Selected classification characteristics for a descriptive name of the rock and soil types

over the area mapped, although each mapped unit bounded by adjacent isolines is in essence a semiquantitatively classified map unit because intermediate values are not represented. Both types of map are, of course, examples of analytical maps.

The quantitative characteristics of rock and soil materials can be tabulated in so-called **enlarged legends** which are mainly produced to accompany maps of engineering geological conditions. In such maps all the fundamental components of the geological environment are represented by superposition. Apart from groundwater, relief and processes, particular attention is paid to the delineation, representation and general characterization of the spatial distribution, properties and physical state of rock units (ET, LT, LC or LS, depending on map scales). That is why, even within the enlarged legend and apart from the explanations of other mapped phenomena, most of the space is given to rocks and soils.

The engineering geological characteristics of rocks are represented as in Section II of Tab. 1 where:

(a) in **IIa** the semiquantitative assessments of all classification characteristics are indicated by using the composite descriptive name (2.3 and 3.4);

(b) in **IIb** the semiquantitative or quantitative values of direct and indirect characteristics of the rock material of individual lithological and engineering geological types are given (3.5.1 and 3.5.2);

(c) in **IIc** the classification, indirect and direct characteristics of rock masses **in situ** are presented for individual lithological complexes (3.6.1 and 3.6.2).

The quantitative characteristics of rock material can be given most fully in the **explanatory** text, memoir or report accompanying the map. As a rule such information is dealt with in chapters dealing with individual rock units and their properties. Usually arranged in stratigraphical sequence, the rock complexes thus receive a comprehensive, technical evaluation which, apart from detailed discussion of individual characteristics, also summarizes their properties in annotated tables, graphs and diagrams.

For sufficiently homogeneous rock and soil types, usually lithological (LT) and engineering geological types (ET), properties can be quantified in terms of:

(a) individual values,

(b) classes from a semiquantitative classification,

(c) general statistical values ($\bar{x}$, $x_{min}$, $x_{max}$, coefficient of variation, etc).

(d) statistically weighted values.

### 3.4 Classification characteristics for a full descriptive name of homogeneous rock and soil types

Properties include those that are purely descriptive, those that can be determined by classification tests requiring little or no test specimen preparation, and those that can be determined only by complex testing or requiring extensive specimen preparation, or both.

The most important classification characteristics (Tab. 3) are incorporated into the system of a **composite descriptive name** of the **lithological type** which is presented in Part IIa of the enlarged map legend (see Tab. 1). They are the following:

**Rock name**

Texture (grain size)
Colour
Weathered state
Degree of jointing
Relative density
Consistency
Strength
Deformability
Permeability
Durability

#### 3.4.1 Texture

Of the textural elements used for classification, the most important is **grain size** which can be classified semiquantitatively as in Tab. 4. It has been necessary to choose from classifications for different genetic groups one that expressed realistically the technical significance of grain size and could be adopted for all kinds of rocks and soil. The class boundaries have been fixed at the physically justified limits of grain size grades adopted for engineeering soils.

| CLASS | SIZE LIMITS (mm) | TERM |
|---|---|---|
| 1 | greater than 60 | Very coarse-grained |
| 2 | 60 - 2 | Coarse-grained |
| 3 | 2 - 0.06 | Medium-grained |
| 4 | 0.06 - 0.002 | Fine-grained |
| 5 | less than 0.002 | Very fine-grained and glassy |

Tab. 4: Grain size classification classes

Because grain size considerably affects the physical properties of a rock, it should be indicated directly in the rock name. Although not quantitatively classified many other aspects of rock texture may be used, such as:

(a) **relative grain size** (uniform, non-uniform, porphyritic);

(b) **grain shape** may be described by reference to the general **form** of the particles, their **angularity** which indicates the degree of rounding at edges and corners, and their **surface texture** (Tab. 5).

(c) the spatial arrangement of grains, referred to as the rock and soil fabric (for example, preferred orientation or lack of it; patterns produced by non-uniform arrangements of crystals, grains and groundmass, etc.).

| | |
|---|---|
| ANGULARITY | angular |
| | subangular |
| | subrounded |
| | rounded |
| FORM | equidimensional |
| | flat |
| | elongated |
| | flat and elongated |
| | irregular |
| SURFACE TEXTURE | rough |
| | smooth |

Tab. 5: Grain shape

#### 3.4.2 Colour

Rock colour can be quantitatively evaluated using, for example, the Rock Color Chart published by the Geological Society of America, 1963. As an alternative, it is recommended that the following simple system (Anon. 1972), which limits the subjectivity of an evaluation, should be used. One term is selected, as required, from each column (Tab 6, next page), and combined as a colour assessment.

Examples of use are: light yellowish brown, dark reddish yellow, dark brown etc. If necessary colour heterogeneity can be emphasised separately by the use of terms such as spotted, dappled, e.g. light yellowish brown spotted with dark brown.

#### 3.4.3 Weathered state (degree of weathering)

A qualitative classification based on the estimation and description of

| LIGHTNESS | CHROMA | HUE |
|---|---|---|
| light | pinkish | pink |
| dark | reddish | red |
| | yellowish | yellow |
| | brownish | brown |
| | greenish | green |
| | bluish | blue |
| | | white |
| | greyish | grey |
| | | black |

Tab. 6: Terms for lightness, chroma and hue which may be used for colour description.

physical disintegration and chemical decomposition of an originally sound rock is used for mapping purposes. Based on the analysis of various existing descriptive classifications, the following classification of the weathered state of the rock material is suggested (Tab. 7).

| CLASS | DEGREE OF WEATHERING % | TERM |
|---|---|---|
| 1 | 0- 25 | Slightly |
| 2 | 25- 50 | Moderately |
| 3 | 50- 75 | Highly |
| 4 | 75-100 | Completely |
| 5 | 100 | Residual soil |

Tab. 7: Classification of the degree of weathering of rock material

A classification suitable for such a purpose is one in which rock material is considered separately according to whether the weathered state is caused by **discoloration (D)**, by chemical **decomposition (CH)**, by physical **disintegration (M)**, or by hydrothermal or other **alteration (A)**. Five degrees are recognised; residual soil may be of type M (resulting from disintegration) or type CH (resulting from decomposition).

Examples of use are: fresh (rock); slightly decomposed; moderately disintegrated; highly altered; residual soil (CH). Usually combinations occur: highly disintegrated and moderately decomposed, etc.

### 3.4.4 Degree of jointing

For a semiquantitative classification of discontinuities in hard and soft rocks, the degree of jointing is the most important. The following classes are suggested (Tab. 8), based on a statistically representative evaluation of blocks determined by the smallest joint spacing:

| CLASS | SPACING (mm) | TERM |
|---|---|---|
| 1 | more than 2000 | Very widely spaced |
| 2 | 2000-600 | Widely spaced |
| 3 | 600-200 | Medium spaced |
| 4 | 200-60 | Closely spaced |
| 5 | less than 60 | Very closely spaced |

Tab. 8: Classification of spacing of discontinuities

### 3.4.5 Relative density of cohesionless soils

The following semiquantitative classification of the relative density of sandy soils is proposed in Tab. 9.

Relative density is defined by the expression:

$$\frac{e_{max} - e_n}{e_{max} - e_{min}}, \quad \text{where } e_{max} \text{ and } e_{min}$$

are the void ratio corresponding to the loosest and densest laboratory states for a given soil, and $e_n$ is the void ratio of the soil in the field.

| CLASS | RELATIVE DENSITY (%) | TERM |
|---|---|---|
| 1 | less than 20 | Very loose |
| 2 | 20 - 33 | Loose |
| 3 | 33 - 66 | Medium loose |
| 4 | 66 - 90 | Dense |
| 5 | 90 - 100 | Very dense* |

*usually weakly cemented

Tab. 9: Relative density of sands and gravels

### 3.4.6 Consistency of cohesive soils

The physical state of cohesive soils is very closely expressed by the term consistency: the relative ease with which a soil can be deformed. Evaluation of consistency, based on simple manual tests, is very advantageous for mapping and may be used as an approximate indication of the strength of cohesive soils (Tab. 10).

| TERM | FIELD INDICATION | APPROXIMATE UNDRAINED (IMMEDIATE) SHEAR STRENGTH $kN/m^2$ |
|---|---|---|
| Very soft | Exudes between the fingers when squeezed in the fist | less than 20 |
| Soft | Easily moulded in the fingers | 20 to 40 |
| Firm | Can be moulded in the fingers by strong pressure | 40 to 75 |
| Stiff | Cannot be moulded in the fingers | 75 to 150 |
| Very stiff or hard | Brittle or very tough | greater than 150 |

Tab. 10: Classification of cohesive soils on the basis of consistency indicated by field tests

A consistency index may be determined from the numerical values of moisture content (m), liquid limit (LL) and plastic limit (PL):

$$\text{Consistency index CI} = \frac{LL - m}{LL - PL}$$

### 3.4.7 Strength of hard and soft rocks

A reliable indication of the strength of rock material is well expressed in terms of dry uniaxial unconfined compression strength, which may be used as the basis of a semiquantitative rock strength classification (Tab. 11).

| CLASS | STRENGTH (MPa) | TERM |
|---|---|---|
| 1 | 1.5* - 15 | Weak |
| 2 | 15 - 50+ | Moderately strong |
| 3 | 50 - 120 | Strong |
| 4 | 120 - 230 | Very strong |
| 5 | greater than 230 | Extremely strong |

*Rocks with a strength lower than 1.5 MPa are, as a rule, hard soils and should be tested accordingly

+Soft rocks are weaker than 50 MPa; strong rocks stronger than 50 MPa.

Tab. 11: Strength classification for rocks

### 3.4.8 Deformability

The deformability of rock material may be characterized in terms of type:

(a) The rock is **brittle** when the stress-strain diagram indicates that the yield point is close to the failure limit; the plastic reserve is small.

(b) The rock is **ductile** when the yield point is far from the failure limit; the plastic reserve is great.

(c) The rock shows a **plastic creep behaviour** when slow plastic creep deformation occurs.

Five degrees of rock material deformability may be distinguished on the basis of a standard statical deformation modulus obtained by laboratory testing (Tab. 12).

| CLASS | DEFORMABILITY (MPa $.10^3$) | TERM |
|---|---|---|
| 1 | less than 5 | Very high |
| 2 | 5 - 15 | High |
| 3 | [illegible] | Moderate |
| 4 | [illegible] | Low |
| 5 | more than 60 | Very low |

Tab. 12: Deformability of hard and soft rock in terms of deformation modulus D.

Both of these characteristics are given in the descriptive rock name as follows: brittle, very low deformability; ductile, moderate deformability; plastic creep, very high deformability.

**Soil deformability** can be expressed as a semiquantitative modulus of compression (Tab. 13).

| CLASS | COMPRESSIBILITY (MPa) | TERM |
|---|---|---|
| 1 | less than 5 | Very great |
| 2 | 5 - 15 | Great |
| 3 | 15 - 25 | Moderate |
| 4 | 25 - 50 | Small |
| 5 | more than 50 | Very small |

Tab. 13: Soil deformability in terms of modulus of compression

### 3.4.9 Permeability

The degree of permeability for rock and soil material is given by the permeability value, k, obtained either by testing specimens or from a qualitative estimation related to the physical state of the rock materials **in situ** (porosity, microfissures, weathering state). Permeability values for rock masses, determined by rising and falling head tests and packer tests, are generally higher than those for corresponding rock material samples due to the influence of discontinuities. In homogeneous soil types, however, soil material and soil mass permeabilities may be in good agreement, provided that the soil material is not too highly disturbed by the sampling process.

It is recommended that the following semiquantitative classification (Tab. 14) be used for describing the approximate order of permeability state in rocks and soils.

| CLASS | PERMEABILITY COEFFICIENT k ($m.s.^{-1}$) | TERM |
|---|---|---|
| 1 | less than $10^{-2}$ | Very highly |
| 2 | $10^{-2}$ - $10^{-4}$ | Highly |
| 3 | $10^{-4}$ - $10^{-5}$ | Moderately |
| 4 | $10^{-5}$ - $10^{-7}$ | Slightly |
| 5 | $10^{-7}$ - $10^{-9}$* | Very slightly |

*below $10^{-9}$ practically impermeable

Tab. 14: Permeability classes

### 3.4.10 Durability

There is as yet no general agreement on the methods to be used for determining a durability index for hard and soft rocks. Similarly a swelling or slaking index would be a useful means of characterizing cohesive soils and soft rocks, but the methods of determining these indices still have to be investigated.

### 3.5 Quantitative classification of rock and soil material

A review of selected indirect and direct characteristics most often used for the quantitative evaluation of rock material properties is given in Tab. 15. These characteristics are represented in semiquantitative or numerical (quantitative) form in Part IIb of an enlarged map legend (see Tab. 1). Properties are assessed or statistically computed, or both, only for sufficiently homogeneous rock and soil types. Hard and soft rocks, cohesionless sandy and gravelly soils, and cohesive soils are classified separately. Classification characteristics for rock materials are included in Tab. 3 (see 3.4).

| Characteristics of homogeneous rock types (HI, LT) | | Hard and soft rocks | | | Cohesionless soils | | | Cohesive soils | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Name of characteristic | I | II | III | I | II | III | I | II | III |
| a) Indirect characteristics | Grain size (Fractions) | | | | | (N) | N | (N) | N | N |
| | Specific gravity | (N) | (N) | N | | (N) | N | | N | N |
| | Unit weight | (SN) | N | N | (SN) | N | N | (SN) | N | N |
| | Porosity | (SN) | N | N | (SN) | N | N | (SN) | N | N |
| | Natural moisture content | | (N) | N | | | | | N | N |
| | Saturation degree | | | | S | N | N | | N | N |
| | Plastic limit | | | | | | | (N) | N | N |
| | Liquid limit | | | | | | | (N) | N | N |
| | Plasticity index | | | | | | | S N | N | N |
| | Consistency index | | | | | | | S | N | N |
| | Sonic velocity | (SN) | N | N | | | | | | |
| b) Direct | Compressive strength uniaxial | N | N | N | | | | | N | N |
| | Tensile strength | | (N) | N | | | | | | |
| | Angle of friction | | | (N) | | (N) | N | | N | N |
| | Cohesion | | | (N) | | | | | N | N |
| | Deformation modulus | N | N | N | | | | | | |
| | Dynamic modulus of elasticity | N | N | N | | | | | | |
| | Poisson's ratio | | (N) | N | | | | | | |
| | Permeability coefficient | | (N) | N | | N | N | | N | N |

Footnotes:

1. The maps in the table are distinguished according to scale as: I - small, II - medium, III - large scale maps.
2. The rock characteristic is indicated by: S - Semiquantitative data, N - Numerical (quantitative data).
3. Data in brackets are not obligatory for that map-scale

Tab. 15: Selected indirect and direct characteristics for rock and soil material.

### 3.5.1 Indirect characteristics

Indirect characteristics are those (Tab. 15a) not concerned directly with technical calculations (with the exception of unit weight), but are indispensible, or at least very useful, for detailed definition of the pyhsical properties, physical state and behaviour of rocks. Several of these indirect characteristics are closely correlated with the direct characteristics of strength, deformability and porosity of rocks: therefore, they are also called "index" characteristics and are advantageously used in rapid, large-scale and inexpensive investigations of rock environments.

Indirect characteristics are given mainly within the enlarged legend of medium and large-scale maps or in the text of memoirs, by means of tables, graphs and diagrams. In Section 3.5 only those characteristics recommended for use are presented, apart from direct numerical data, such as, for example, grain size fractions, specific gravity, natural moisture content, plastic and liquid limits, as well as all direct characteristics and some semiquantitative classifications (e.g. consistency, 3.4.6).

They are mainly:

(a) Unit weight
(b) Porosity
(c) Saturation degree
(d) Plasticity index
(e) Sonic velocity

#### 3.5.1.1 Unit weight

Unit weight is an important indicator of the physical properties of rock material, and correlates well with mineral composition, porosity and strength (Tab. 16).

| CLASS | UNIT WEIGHT ($g.cm^{-3}$) SOIL | ROCK | TERM |
|---|---|---|---|
| 1 | less than 1.40 | less than 1.80 | Very low |
| 2 | 1.40 - 1.70 | 1.80 - 2.20 | Low |
| 3 | 1.70 - 1.90 | 2.20 - 2.55 | Moderate |
| 4 | 1.90 - 2.20 | 2.55 - 2.75 | High |
| 5 | greater than 2.20 | greater than 2.75 | Very high |

Tab. 16: Dry unit weight classes for soil and hard and soft rocks

#### 3.5.1.2 Porosity

Porosity is as important for the estimation of pyhsical properties of rocks as unit weight, particularly so in relation to permeability. The following semiquantitative classifications are recommended, using values of either porosity or void ratio (Tab. 17).

#### 3.5.1.3 Saturation degree

Degree of saturation is an important index characteristic for the physical state of cohesionless soils, mainly sands. It may be classified semiquantitatively according to the degree of saturation (Tab. 18).

#### 3.5.1.4 Plasticity index

Classification according to the plasticity index is given in Tab. 19.

HARD AND SOFT ROCKS

| CLASS | VOID RATIO | POROSITY (%) | TERM |
|---|---|---|---|
| 1 | greater than 0.43 | greater than 30 | Very high |
| 2 | 0.43 - 0.18 | 30 - 15 | High |
| 3 | 0.18 - 0.05 | 15 - 5 | Medium |
| 4 | 0.05 - 0.01 | 5 - 1 | Low |
| 5 | less than 0.01 | less than 1 | Very low |

SOILS

| CLASS | VOID RATIO | POROSITY (%) | TERM |
|---|---|---|---|
| 1 | greater than 1.0 | greater than 50 | Very high |
| 2 | 1.0 - 0.80 | 50 - 45 | High |
| 3 | 0.80 - 0.55 | 45 - 35 | Medium |
| 4 | 0.55 - 0.43 | 35 - 30 | Low |
| 5 | less than 0.43 | less than 30 | Very low |

Tab. 17: Classification of porosity in hard and soft rocks and in soils

| CLASS | DEGREE OF SATURATION (%) | TERM |
|---|---|---|
| 1 | 0 - 0.25 | (naturally dry) |
| 2 | 0.25 - 0.50 | Wet |
| 3 | 0.50 - 0.80 | Very wet |
| 4 | 0.80 - 0.95 | Highly saturated |
| 5 | 0.95 - 1.00 | Saturated |

Tab. 18: Classification of degree of saturation

| CLASS | PLASTICITY INDEX (%) | TERM |
|---|---|---|
| 1 | less than 1 | Non-plastic |
| 2 | 1 - 7 | Slight plastic |
| 3 | 7 - 17 | Moderately plastic |
| 4 | 17 - 35 | Highly plastic |
| 5 | 35* | Extremely plastic |

*for very "fat" clays

Tab. 19: Plasticity index classes of soils

| CLASS | SONIC VELOCITY ($m.s.^{-1}$) | TERM |
|---|---|---|
| 1 | less than 2500 | Very low |
| 2 | 2500 - 3500 | Low |
| 3 | 3500 - 4000 | Moderate |
| 4 | 4000 - 5000 | High |
| 5 | more than 5000 | Very high |

Tab. 20: Sonic velocity classes for hard and soft rocks

#### 3.5.1.5 Sonic velocity

Sonic velocity is a good index characteristic of the mechanical properties of hard and soft rocks, and may be classified semiquantitatively as in Tab. 20.

### 3.5.2 Direct characteristics

Numerical values referring to strength, deformation and permeability properties of rock material are usually given (Tab. 15b) and they can also be used for some direct engineering calculations. Their semiquantitative classes (3.4) serve as the classification characteristics for preliminary purposes and for grouping and comparing various types of rock, mainly in mapping.

## 3.6 Quantitative classification of rock and soil masses

Characteristic quantitative properties of entire lithological complexes or lithological types (Tab. 1, Part IIa, c) under the natural conditions in which rock masses occur are much more important than characteristic rock material properties from selected specimens. In spite of this, methods for investigating and classifying rock masses are much less developed than those for rock and soil material, and the difficulties are substantially greater.

Details of a proposed classification are under discussion and will be published as Part II of this Report.

# 4. Geotechnical classifications

The use of rock (rock and soil) classifications based on various building standards and codes provides a useful additional engineering evaluation of the lithological units delineated on current engineering geological maps (see Part III, Tab. 1).

The most frequently applied classifications are related to:

1. Design and construction of foundations in industrial and residential construction;
2. Suitability of rocks and foundations and as building material for embankments in road construction;
3. Suitability for earth dams and levees;
4. Difficulty of disintegration in stripping operations and excavations (ease of excavation).

All these and many other engineering classifications are based on quantitative definition of specified limits between individual classes according to selected criteria. Thus, they are also semiquantitative classifications.

# 5. References

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