Chapter 4

CLASSIFICATION OF ROCKS
AND DESCRIPTION OF PHYSICAL
PROPERTIES OF ROCK

Introduction

Uniformity of definitions, descriptors, and identification of rock units is important to maintain continuity in geologic logs, drawings, and reports from a project with multiple drilling sessions, different loggers and mappers. Also important is the recording of all significant observable parameters when logging or mapping. This chapter presents a system for the identification and classification of rocks and includes standard terminology and descriptive criteria for physical properties of engineering significance. The standards presented in this chapter may be expanded or modified to fit project requirements.

Rock Classification

Numerous systems are in use for field and petrographic classification of rocks. Many classifications require detailed petrographic laboratory tests and thin sections, while others require limited petrographic examination and field tests. The Bureau of Reclamation (Reclamation) has adopted a classification system which is modified from R.B. Travis [1]. While not based entirely on field tests or field identification of minerals, many of the classification categories are sufficiently broad that field identification is possible. Even where differences in the mineral constituents cannot be determined precisely in the field, differences usually are not significant enough to affect the engineering properties of the rock if classified somewhat incorrectly by lithologic name. Detailed mineralogical identification and petrographic classification can be performed on hand samples or core samples submitted to a petrographic laboratory.
FIELD MANUAL

If samples are submitted to a petrographic laboratory, the petrographic classification generally will coincide with the classification according to Travis. The petrographic igneous rock classifications are somewhat more precise and include specialty rock types based upon mineral composition, texture, and occurrence. For example, a lamprophyric dike composed of green hornblende phenocrysts or clinopyroxene in the groundmass could be classified as spessartite, whereas a lamprophyre containing biotite with or without clinopyroxene could be classified as a kersantite. Sedimentary rock classifications generally include grain size, type of cement or matrix, mineral composition in order of increasing amounts greater than 15 percent, and the rock type, such as medium-grained, calcite-cemented, feldspathic-quartzose sandstone, and coarse- to fine-grained, lithic-feldspathic-quartzose gray-wacke with an argillaceous-ferruginous-calcareous matrix. Metamorphic rock classifications include specific rock types based upon crystal size, diagnostic accessory minerals, mineralogical composition in increasing amounts greater than 15 percent, and structure. Two examples of metamorphic rock descriptions are medium-grained, hornblende-biotite schist, or fine- to medium-grained, garnetiferous, muscovite-chlorite-feldspar-quartz gneiss. The above classification can be abbreviated by the deletion of mineral names from the left to right as desired. The mineral type immediately preceding the rock name is the most diagnostic.

The term “quartzite” is restricted to a metamorphic rock only. The sedimentary sandstone equivalent is termed a “quartz cemented quartzose sandstone.”

Samples submitted to a petrographic laboratory should be representative of the in-place rock unit. For example, if a granitic gneiss is sampled but only the granite portion submitted, the rock will be petrographically classified as
ROCKS

a granite since the gneissic portion cannot be observed or substantiated by the thin section and hand specimen. Petrographic classifications can be related to the engineering properties of rock units and are important.

Geologic rock unit names should be simple, and general rock names should be based on either field identification, existing literature, or detailed petrographic examination, as well as engineering properties. Overclassification is distracting and unnecessary. For example, use “hornblende schist” or “amphibolite” instead of “sericite-chlorite-calcite-hornblende schist.” The term “granite” may be used as the rock name and conveys more to the designer than the petrographically correct term “nepheline-syenite porphyry.” Detailed mineralogical descriptions may be provided in reports when describing the various rock units and may be required to correlate between observations, but mineralogical classifications are not desirable as a rock unit name unless the mineral constituents or fabric are significant to engineering properties.

The classification for igneous, sedimentary, metamorphic, and pyroclastic rocks is shown on figures 4-1, 4-2, 4-3, and 4-4, respectively. These figures are condensed and modified slightly from Travis’ classifications, but the more detailed original classifications of Travis are acceptable. Figure 4-5 or appropriate American Geological Institute (AGI) data sheets are suggested for use when estimating composition percentages in classification.

Description of Rock

Adequate descriptors, a uniform format, and standard terminology must be used for all geologic investigations to properly describe rock foundation conditions. These
Figure 4.1.—Field classification of igneous rocks (modified after R.B. Travis [1955]).
<table>
<thead>
<tr>
<th>Texture</th>
<th>Grain Size</th>
<th>Clayey or Detrital Silica Clay</th>
<th>Detrital Silica Clay + Feldspar</th>
<th>Detrital Silica Clay + Feldspar + Calcite</th>
<th>Detrital Silica Clay + Feldspar + Calcite + Cements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;0.002 mm</td>
<td>Limestone, Dolomite, etc.</td>
<td>Quartzite Sandstone</td>
<td>Quartzite Sandstone</td>
<td>Quartzite Sandstone</td>
</tr>
<tr>
<td></td>
<td>0.002 - 2 mm</td>
<td>Quartz with &gt;25% Feldspar</td>
<td>Calcic Limestone Sandstone</td>
<td>Calcic Limestone Sandstone</td>
<td>Calcic Limestone Sandstone</td>
</tr>
<tr>
<td></td>
<td>&gt;2 mm</td>
<td>Quartz with &gt;25% Feldspar</td>
<td>Calcic Limestone Sandstone</td>
<td>Calcic Limestone Sandstone</td>
<td>Calcic Limestone Sandstone</td>
</tr>
</tbody>
</table>

*Figure 4-2.—Field classification of sedimentary rocks (modified after R.B. Travis [1955]).*
Figure 4-3.—Field classification of metamorphic rocks (modified after R.B. Travis [1955]).
Figure 4-4.—Field classification of pyroclastic rocks. Blocks are angular to subangular clasts > 64 millimeters (mm); bombs are rounded to subrounded clasts > 64 mm. Determine percent of each size present (ash, lapilli, blocks, and bombs) and list in decreasing order after rock name. Proceed rock name with the term "welded" for pyroclastic rocks which retained enough heat to fuse after deposition. Rock names for such deposits are usually selected from the lower right portion of the classification diagram above. (Modified from Fisher, 1966 [2] and Williams and Mc Birney, 1979 [3]).

Paragraphs provide descriptors for those physical characteristics of rock that are used in logs of exploration, in narratives of reports, and on preconstruction geologic maps and cross sections, as well as construction or "as-built" drawings. The alphanumeric descriptors provided may be used in data-field entries of computer generated
Figure 4-5.—Charts for estimating percentage of composition of rocks and sediments.[4]
ROCKS

logs. Chapter 5 establishes descriptors for the physical characteristics of discontinuities in rock required for engineering geologic studies.

All descriptors should be defined and included in a legend when submitting data for design and/or records of construction. An example of a legend and explanation is figure 4-6, Reclamation standard drawing 40-D-6493, may be used for geologic reports and specifications where the standard descriptors and terminology established for rock are used during data collection.

Format for Descriptions of Rock

Engineering geology rock descriptions should include generalized lithologic and physical characteristics using qualitative and quantitative descriptors. A general format for describing rock in exploration logs and legends on general note drawings is:

• Rock unit (member or formation) name
• Lithology with lithologic descriptors
  composition (mineralogy)
  grain/particle size
  texture
  color
• Bedding/foliation/flow texture
• Weathering
• Hardness/strength
• Contacts
• Discontinuities (includes fracture indexes)
• Permeability data (as available from testing)
• Moisture conditions

Example descriptions are presented in a later section.
Rock Unit Names and Identification

Rock unit names not only are required for identification purposes but may also provide indicators of depositional environment and geologic history, geotechnical characteristics, and correlations with other areas. A simple descriptive name and map symbol should be assigned to provide other users with possible engineering characteristics of the rock type. The rock unit names may be stratigraphic, lithologic, genetic, or a combination of these, such as Navajo Sandstone (Jn), Tertiary shale (Tsh), Jurassic chlorite schist (Jcs), Precambrian granite (Pcgr), or metasediments (ms). Bedrock units of similar physical properties should be delineated and identified as to their engineering significance as early as possible during each geologic study. Planning study maps and other large-scale drawings may require geologic formations or groups of engineering geologic units with descriptions of their engineering significance in accompanying discussions.

Units should be differentiated by engineering properties and not necessarily formal stratigraphic units where differences are significant. Although stratigraphic names are not required, units should be correlated to stratigraphic names in the data report or by an illustration, such as a stratigraphic column. Stratigraphic names and ages (formation, member) may be used as the rock unit name.

For engineering studies, each particular stratigraphic unit may require further subdivisions to identify engineering parameters. Examples of important engineering properties are:

- Susceptibility to weathering or presence of alteration
Figure 4-6.—Descriptor legend and explanation example.
ROCKS

- Dominant discontinuity characteristics
- Hardness and/or strength
- Deformability
- Deleterious minerals or beds (such as swelling susceptibility, sulfates, or clays)

For example, a Tertiary shale unit, Tsh, may be differentiated as Tsh₁ or Tsh₂ if unit 2 contains bentonite interbeds and unit 1 does not, and Tsh₃ could be used as a unit name for the bentonite beds. A chlorite schist unit, Cs, may be differentiated as Csₐ or Csₙ where unit A contains higher percentages of chlorite or talc and is significantly softer (different deformation properties) than unit B. A metasediment unit, ms, may be further differentiated on more detailed maps and logs as msₘₙ (shale) or msₘₜ (limestone). All differentiated units should be assigned distinctive map symbols and should be described on the General Geologic Legend, Explanation, and Notes drawings.

Descriptors and Descriptive Criteria for Physical Characteristics of Rock

Lithologic Descriptors (Composition, Grain Size, and Texture).—Provide a brief lithologic description of the rock unit. This includes a general description of mineralogy, induration, cementation, crystal and grain sizes and shapes, textural adjectives, and color. Lithologic descriptors are especially important for the description of engineering geology subunits when rock unit names are not specific. Examples of rock unit names that are not specific are metasediments, Tertiary intrusives, or Quaternary volcanics.
1. **Composition.**—Use standard adjectives such as sandy, silty, calcareous, etc. Detailed mineral composition generally is not necessary or desirable unless useful in correlating units or indicating pertinent engineering physical properties. Note unique features such as fossils, large crystals, inclusions, concretions, and nodules which may be used as markers for correlations and interpretations.

2. **Crystal or particle sizes and shapes.**—Describe the typical crystal or grain shapes and provide a description of sizes present in the rock unit based on the following standards:

   • **Igneous and metamorphic rocks.**—Table 4-1 is recommended for descriptions of crystal sizes in igneous and metamorphic rocks. Crystal sizes given in millimeters (mm) are preferred rather than fractional inch (in) equivalents.

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Average crystal diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very coarse-grained or pegmatitic</td>
<td>&gt; 10 mm (3/8 in)</td>
</tr>
<tr>
<td>Coarse-grained</td>
<td>5-10 mm (3/16 - 3/8 in)</td>
</tr>
<tr>
<td>Medium-grained</td>
<td>1-5 mm (1/32 - 3/16 in)</td>
</tr>
<tr>
<td>Fine-grained</td>
<td>0.1-1 mm (0.04 - 1/32 in)</td>
</tr>
<tr>
<td>Aphanitic (cannot be seen with the unaided eye)</td>
<td>&lt;0.1 mm (&lt;0.04 in)</td>
</tr>
</tbody>
</table>

   • **Sedimentary and pyroclastic rocks.**—Terminology for particle sizes and their lithified products which form sedimentary and pyroclastic rocks is provided in table 4-2. The size
### Table 4-2.—Sedimentary and pyroclastic rock particle-size descriptors (AGI Glossary)

<table>
<thead>
<tr>
<th>USGS (soils only) Particle size</th>
<th>Size in mm (inches)</th>
<th>Sedimentary (epiclastic) Rounded, subrounded, subangular</th>
<th>Volcanic (pyroclastic) Lithified fragment</th>
<th>Lithified product*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulder</td>
<td>300 (12)</td>
<td>Boulder</td>
<td>Block+</td>
<td>Volcanic breccia+</td>
</tr>
<tr>
<td></td>
<td>256 (10)</td>
<td>Cobble</td>
<td>Cobble conglomerate</td>
<td></td>
</tr>
<tr>
<td>Cobble</td>
<td>75 (3)</td>
<td>Cobble</td>
<td>Bomb</td>
<td>Agglomerate</td>
</tr>
<tr>
<td></td>
<td>64 (2.5)</td>
<td>Cobble</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse gravel</td>
<td>20 (0.8)</td>
<td>Pebble</td>
<td>Lapilli</td>
<td>Lapilli tuff</td>
</tr>
<tr>
<td></td>
<td>8.75 (0.33)</td>
<td>Pebble</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine gravel</td>
<td>4.75 (0.19)</td>
<td>Pebble</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 (0.16)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse sand</td>
<td>2 (0.08)</td>
<td>Granule</td>
<td>Granule conglomerate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.1 (0.04)</td>
<td>Very coarse sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium sand</td>
<td>0.5 (0.02)</td>
<td>Coarse sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.42</td>
<td>Medium sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>Fine sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.125</td>
<td>Fine sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.074</td>
<td>Very fine sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine ash</td>
<td>0.0625</td>
<td>Fine ash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-plastic Silt</td>
<td>0.00391</td>
<td>Silt</td>
<td>Stalatine Shale</td>
<td></td>
</tr>
<tr>
<td>Plastic Clay</td>
<td></td>
<td>Clay</td>
<td>Claystone Shale</td>
<td></td>
</tr>
</tbody>
</table>

+ Broken from previous igneous rock block shaped (angular to subangular).
Solidified from plastic material while in flight, rounded clasts.
* Refer to figure 4-4.
FIELD MANUAL

limits do not correspond to the Unified Soil Classification System for soil particle size but are used for the field description and petrographic classification of rocks. These limits are the accepted sizes in geologic literature and are used by petrographic laboratories.

3. Textural adjectives.—Texture describes the arrangements of minerals, grains, or voids. These microstructural features can affect the engineering properties of the rock mass. Use simple, standard, textural adjectives or phrases such as porphyritic, vesicular, scoriaceous, pegmatitic, granular, well developed grains, dense, fissile, slaty, or amorphous. Use of terms such as holohyaline, hypidiomorphic granular, and crystaloblastic is inappropriate.

Textural terms which identify solutioning, leaching, or voids in bedrock are useful for describing primary texture, weathering, alteration, permeability, and density.

The terminology which follows defines sizes of voids, or holes in bedrock. However, when describing pits, vugs, cavities, or vesicles, a complete description which includes the typical diameter, or the "mostly" range, and the maximum size observed is required. For example:

"...randomly oriented, elliptically shaped vugs range mostly from 0.03 to 0.06 foot (ft) in diameter, maximum size 0.2 foot; decreases in size away from quartz-calcite vein; about 15 percent contain calcite crystals..."

or

"...cavity, 3.3 ft wide by 16.4 ft long by 2.3 ft high, striking N 45°W, dipping 85°SW was..."
ROCKS

• **Pit (pitted).**—Pinhole to 0.03 ft [\(d\) in] (<1 to 10 mm) openings.

• **Vug (vuggy).**—Small opening (usually lined with crystals) ranging in diameter from 0.03 ft [\(d\) in] to 0.33 ft [4 in] (10 to 100 mm).

• **Cavity.**—An opening larger than 0.33 ft [4 in] (100 mm), size descriptions are required, and adjectives such as small, or large, may be used, if defined.

• **Honeycombed.**—Individual pits or vugs are so numerous that they are separated only by thin walls; this term is used to describe a cell-like form.

• **Vesicle (vesicular).**—Small openings in volcanic rocks of variable shape formed by entrapped gas bubbles during solidification.

4. **Color.**—As a minimum, provide the color of wet altered and unaltered or fresh rock. Reporting color for both wet and dry material is recommended since the colors may differ significantly and cause confusion. The Munsell Color System, as used in the Geologic Society of America Rock Color Chart [5], is used to provide standard color names and assist in correlation. The chart also provides uniform and identifiable colors to others. Color designators are optional unless necessary for clarity, e.g., light brown (5YR 5/6). Terms such as banded, streaked, mottled, speckled, and stained may be used to further describe color. Also describe colors of bands, etc.

**Bedding, Foliation, and Flow Texture.**—These features give the rock anisotropic properties or represent potential failure surfaces. Continuity and thickness of these features influence rock mass properties and cannot
always be tested in the laboratory. Descriptors in table 4-3 are used to identify these thicknesses.

Table 4-3.—Bedding, foliation, or flow texture descriptors

<table>
<thead>
<tr>
<th>Descriptors</th>
<th>Thickness/spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive</td>
<td>Greater than 10 ft (3 meters [m])</td>
</tr>
<tr>
<td>Very thickly, bedded, foliated, or banded</td>
<td>3 to 10 ft (1 to 3 m)</td>
</tr>
<tr>
<td>Thickly</td>
<td>1 to 3 ft (300 mm to 1 m)</td>
</tr>
<tr>
<td>Moderately</td>
<td>0.3 to 1 ft (100 to 300 mm)</td>
</tr>
<tr>
<td>Thinly</td>
<td>0.1 to 0.3 ft (30 to 100 mm)</td>
</tr>
<tr>
<td>Very thinly</td>
<td>0.03 [3/8 in] to 0.1 ft (10 to 30 mm)</td>
</tr>
<tr>
<td>Laminated (intensely foliated or banded)</td>
<td>Less than 0.03 ft [3/8 in] (&lt;10 mm)</td>
</tr>
</tbody>
</table>

Weathering and Alteration.—

1. Weathering.—Weathering, the process of chemical or mechanical degradation of rock, can significantly affect the engineering properties of the rock and rock mass. For engineering geology descriptions, the term “weathering” includes both chemical disintegration (decomposition) and mechanical disaggregation as agents of alteration.

Weathering effects generally decrease with depth, although zones of differential weathering can occur and may modify a simple layered sequence of weathering.
ROCKS

Examples are: (1) differential weathering within a single rock unit, apparently due to relatively higher permeability along fractures; (2) differential weathering due to compositional or textural differences; (3) differential weathering of contact zones associated with thermal effects such as interflow zones within volcanics; (4) directional weathering along permeable joints, faults, shears, or contacts which act as conduits along which weathering agents penetrate more deeply into the rock mass; and (5) topographic effects.

Weathering does not correlate directly with specific geotechnical properties used for many rock mass classifications. However, weathering is important because it may be the primary criterion for determining depth of excavation, cut slope design, method and ease of excavation, and use of excavated materials. Porosity, absorption, compressibility, shear and compressive strengths, density, and resistance to erosion are the major engineering parameters influenced by weathering. Weathering generally is indicated by changes in the color and texture of the body of the rock, color, and condition of fracture fillings and surfaces, grain boundary conditions, and physical properties such as hardness.

Weathering is reported using descriptors presented in table 4-4, which divides weathering into categories that reflect definable physical changes due to chemical and mechanical processes. This table summarizes general descriptions which are intended to cover ranges in bedrock conditions. Weathering tables are generally applicable to all rock types; however, they are easier to apply to crystalline rocks and rocks that contain ferromagnesian minerals. Weathering in many sedimentary rocks will not always conform to the criteria established in
table 4-4, and weathering categories may have to be modified for particular site conditions. However, the basic horizontal categories and descriptors presented can be used. Site-specific conditions, such as fracture openness, filling, and degree and depth of penetration of oxidation from fracture surfaces, should be identified and described.

2. Alteration.—Chemical alteration effects are distinct from chemical and mechanical degradation (weathering), such as hydrothermal alteration, may not fit into the horizontal suite of weathering categories portrayed in table 4-4. Oxides may or may not be present. Alteration is site-specific, may be either deleterious or beneficial, and may affect some rock units and not others at a particular site. For those situations where the alteration does not relate well to the weathering categories, adjusting the description within the framework of table 4-4 may be necessary. Many of the general characteristics may not change, but the degree of discoloration and oxidation in the body of the rock and on fracture surfaces could be very different. Appropriate descriptors, such as moderately altered or intensely altered, may be assigned for each alteration category. Alteration products, depths of alteration, and minerals should be described.

3. Slaking.—Slaking is another type of disintegration which affects engineering properties of rock. Terminology and descriptive criteria to identify this deleterious property are difficult to standardize because some materials air slake, many water slake, and some only slake after one or more wet-dry cycles. The Durability Index (DI) is a simplified method for describing slaking. Criteria for the index are based
Table 4-4.—Weathering descriptors

<table>
<thead>
<tr>
<th>Descriptors</th>
<th>Diagnostic features</th>
<th>Mechanical weathering:—Grain boundary conditions (disaggregation) primarily for granitics and some coarse-grained sediments</th>
<th>General characteristics (strength, excavation, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha-numeric descriptor</td>
<td>Descriptive term</td>
<td>Body of rock</td>
<td>Fracture surfaces?</td>
</tr>
<tr>
<td>W1</td>
<td>Fresh.</td>
<td>No discoloration, not oxidized.</td>
<td>No discoloration or oxidation.</td>
</tr>
<tr>
<td>W2</td>
<td>Slightly weathered.</td>
<td>Discoloration or oxidation is limited to surface of, or short distance from, fractures; some feldspar crystals are dull.</td>
<td>Minor to complete discoloration or oxidation of most surfaces.</td>
</tr>
<tr>
<td>W3</td>
<td>Slightly weathered.</td>
<td>Discoloration or oxidation is limited to surface of, or short distance from, fractures; some feldspar crystals are dull.</td>
<td>Minor to complete discoloration or oxidation of most surfaces.</td>
</tr>
<tr>
<td>W4</td>
<td>Moderately to slightly weathered.</td>
<td>Discoloration or oxidation extends from fractures, usually throughout. Fe-Mg minerals are &quot;rusty,&quot; feldspar crystals are &quot;cloudy.&quot;</td>
<td>All fracture surfaces are discolored or oxidized.</td>
</tr>
<tr>
<td>W5</td>
<td>Moderately weathered.</td>
<td>Discoloration or oxidation extends from fractures, usually throughout. Fe-Mg minerals are &quot;rusty,&quot; feldspar crystals are &quot;cloudy.&quot;</td>
<td>All fracture surfaces are discolored or oxidized.</td>
</tr>
<tr>
<td>W6</td>
<td>Intensely to moderately weathered.</td>
<td>Discoloration or oxidation extends from fractures, usually throughout. Fe-Mg minerals are &quot;rusty,&quot; feldspar crystals are &quot;cloudy.&quot;</td>
<td>All fracture surfaces are discolored or oxidized.</td>
</tr>
<tr>
<td>W7</td>
<td>Intensely weathered.</td>
<td>Discoloration or oxidation extends from fractures, usually throughout. Fe-Mg minerals are &quot;rusty,&quot; feldspar crystals are &quot;cloudy.&quot;</td>
<td>All fracture surfaces are discolored or oxidized.</td>
</tr>
<tr>
<td>W8</td>
<td>Very intensely weathered.</td>
<td>Discoloration or oxidation extends from fractures, usually throughout. Fe-Mg minerals are &quot;rusty,&quot; feldspar crystals are &quot;cloudy.&quot;</td>
<td>All fracture surfaces are discolored or oxidized.</td>
</tr>
<tr>
<td>W9</td>
<td>Decomposed.</td>
<td>Discoloration or oxidation extends from fractures, usually throughout. Fe-Mg minerals are &quot;rusty,&quot; feldspar crystals are &quot;cloudy.&quot;</td>
<td>All fracture surfaces are discolored or oxidized.</td>
</tr>
</tbody>
</table>

Note: This chart and its horizontal categories are more readily applied to rocks with feldspars and mafic minerals. Weathering in various sedimentary rocks, particularly limestones and poorly indurated sediments, will not always fit the categories established. This chart and weathering categories may have to be modified for particular site conditions or alteration such as hydrothermal effects; however, the basic framework and similar descriptors are to be used.

* Combination descriptors are permissible where equal distribution of both weathering characteristics are present over significant intervals or where characteristics present are "in between" the diagnostic feature. However, dual descriptors should not be used where significant, identifiable zones can be delineated. When given as a range, only two adjacent terms may be combined (i.e., decomposed to lightly weathered or moderately weathered to fresh) are not acceptable.

† Does not include directional weathering along shears or faults and their associated features. For example, a shear zone that carried weathering to great depth into a fresh rock mass would not require the rock mass to be classified as weathered.

§ These are generalizations and should not be used as diagnostic features for weathering or excavation classification. These characteristics vary to a large extent based on naturally weak materials or cementation and type of excavation.
ROCKS

on time exposed and effects noted in the field (see table 4-5). These simplified criteria do not specify whether the specimen or exposure is wetted, dried, or subjected to cyclic wetting and drying, and/or freeze-thaw. When reporting slaking or durability, a complete description includes the test exposure conditions. For example, the material could be classified as having “characteristics of DI 3 upon drying.” Slaking is not the same as the effects of bedding separation or disaggregation produced by stress relief.

Table 4-5.—Durability index descriptors

<table>
<thead>
<tr>
<th>Alphabetic descriptor</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>DI0</td>
<td>Rock specimen or exposure remains intact with no deleterious cracking after exposure longer than 1 year.</td>
</tr>
<tr>
<td>DI1</td>
<td>Rock specimen or exposure develops hairline cracking on surfaces within 1 month, but no disaggregation within 1 year of exposure.</td>
</tr>
<tr>
<td>DI2</td>
<td>Rock specimen or exposure develops hairline cracking on surfaces within 1 week and/or disaggregation within 1 month of exposure.</td>
</tr>
<tr>
<td>DI3</td>
<td>Specimen or exposure may develop hairline cracks in 1 day and displays pronounced separation of bedding and/or disaggregation within 1 week of exposure.</td>
</tr>
<tr>
<td>DI4</td>
<td>Specimen or exposure displays pronounced cracking and disaggregation within 1 day (24 hours) of exposure. Generally ravel and degrades to small fragments.</td>
</tr>
</tbody>
</table>
A field test suitable for evaluating the degree and rate of slaking for materials, primarily clayey materials and altered volcanics, is described below. The slaking test evaluates the disaggregation of an intact specimen in water and reflects the fabric of the material, internal stresses, and character of the interparticle bonds.

To evaluate slaking behavior, immerse two intact specimens (pieces of core or rock fragments consisting of a few cubic inches or centimeters) in water. One piece should be at natural water content (wrapped jar sample) and one piece from an air-dried sample. Test results should be photographed with labels to identify specimens and exposure times.

Results of the evaluation should be reported for each specimen. Describe the behavior of the specimens as follows:

a. Volume changes.—The volume of the material reduced to individual particles should be estimated and compared to the initial volume of material. The degree of disaggregation is described using the following descriptive criteria:

<table>
<thead>
<tr>
<th>Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>No discernable disaggregation</td>
</tr>
<tr>
<td>Slight</td>
<td>Less than 5 percent of the volume disaggregated</td>
</tr>
<tr>
<td>Moderate</td>
<td>Between 5 and 25 percent of the volume disaggregated</td>
</tr>
<tr>
<td>Intense</td>
<td>More than 25 percent but less than the total volume disaggregated</td>
</tr>
<tr>
<td>Complete</td>
<td>No intact piece of the material remains</td>
</tr>
</tbody>
</table>
b. Rate of slaking.—The following descriptors are used to identify the time to slake:

- **Slow slaking**
  Action continues for several hours

- **Moderate slaking**
  Action completed within 1 hour

- **Rapid slaking**
  Action completed within 2 minutes

- **Sudden slaking**
  Complete reaction, action completed instantaneously

[Generally, slaking applies to rock; disaggregation applies to soils.]

4. **Character of material.**—The character of the remaining pieces of material after the test is completed is described as follows:

- **No change**
  Material remains intact

- **Plates remain**
  Remaining material present as platy fragments of generally uniform thickness

- **Flakes remain**
  Remaining material present as flaky or wedge-shaped fragments

- **Blocks remain**
  Blocky fragments remain

- **Grains remain**
  Remaining material chiefly present as sand-size grains

- **No fragments**
  Remaining material entirely disaggregated to clay-size particles

**Hardness—Strength.**—Hardness can be related to intact rock strength as a qualitative indication of density and/or resistance to breaking or crushing. Strength is a necessary engineering parameter for design that
The hardness and strength of intact rock is a function of the individual rock type but may be modified by weathering or alteration. Hardness and strength are described for each geologic unit when they are functions of the rock type and also for zones of alteration or weathering when there are various degrees of hardness and/or strength due to different degrees of weathering or chemical alteration. When evaluating strengths, it is important to note whether the core or rock fragments break around, along, or through grains; or along or across incipient fractures, bedding, or foliation.

Hardness and especially strength are difficult characteristics to assess with field tests. Two field tests can be used; one is a measure of the ability to scratch the surface of a specimen with a knife, and the other is the resistance to fracturing by a hammer blow. Results from both tests should be reported. The diameter and length of core or the fragment size will influence the estimation of strength and should be kept in mind when correlating strengths. A 5- to 8-inch (130- to 200-mm) length of N-size core or rock fragment, if available, should be used for hardness determinations to preclude erroneously reporting point, rather than average hardness, and to evaluate the tendency to break along incipient fractures and textural or structural features when struck with a rock pick. Standards (heavy, moderate, and light hammer blow) should be calibrated with other geologists mapping or logging core for a particular project. Descriptors used for rock hardness/strength are shown on table 4-6.
### Table 4.6.—Rock hardness/strength descriptors

<table>
<thead>
<tr>
<th>Alpha-numeric descriptor</th>
<th>Descriptor</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>Extremely hard</td>
<td>Core, fragment, or exposure cannot be scratched with knife or sharp pick; can only be chipped with repeated heavy hammer blows.</td>
</tr>
<tr>
<td>H2</td>
<td>Very hard</td>
<td>Cannot be scratched with knife or sharp pick. Core or fragment breaks with repeated heavy hammer blows.</td>
</tr>
<tr>
<td>H3</td>
<td>Hard</td>
<td>Can be scratched with knife or sharp pick with difficulty (heavy pressure). Heavy hammer blow required to break specimen.</td>
</tr>
<tr>
<td>H4</td>
<td>Moderately hard</td>
<td>Can be scratched with knife or sharp pick with light or moderate pressure. Core or fragment breaks with moderate hammer blow</td>
</tr>
<tr>
<td>H5</td>
<td>Moderately soft</td>
<td>Can be grooved 1/16 inch (2 mm) deep by knife or sharp pick with moderate or heavy pressure. Core or fragment breaks with light hammer blow or heavy manual pressure.</td>
</tr>
<tr>
<td>H6</td>
<td>Soft</td>
<td>Can be grooved or gouged easily by knife or sharp pick with light pressure, can be scratched with fingernail. Breaks with light to moderate manual pressure.</td>
</tr>
<tr>
<td>H7</td>
<td>Very soft</td>
<td>Can be readily indented, grooved or gouged with fingernail, or carved with a knife. Breaks with light manual pressure.</td>
</tr>
</tbody>
</table>

Any bedrock unit softer than H7, very soft, is to be described using USBR 5000 consistency descriptors.

**Note:** Although "sharp pick" is included in these definitions, descriptions of ability to be scratched, grooved, or gouged by a knife is the preferred criteria.

A few empirical and quantitative field techniques which are quick, easy, and inexpensive are available to provide strength estimates. Quantitative strength estimates can
be obtained from the point load test. A lightweight and portable testing device is used to break a piece of core (with a minimum length at least 1.5 times the diameter) between two loading points. If a new fracture does not run from one loading point to the other upon completion of the test, or if the points sink into the rock surface causing excessive deformation or crushing, the test should not be recorded. Raw data are given with the reduced data (equations to empirically convert load data to compressive strengths are usually supplied with the equipment). The Schmidt \(L\) hammer may also be used for estimating rock strengths; refer to Field Index Tests in chapter 5. Each of these tests can be used to calibrate the manual index (empirical) properties described in table 4-6, and a range of compressive strengths can be assigned. Depending on the scope of the study and structure being considered, laboratory testing may be required and used to confirm the field test data.

Discontinuities.—Describe all discontinuities such as joints, fractures, shear/faults, and shear/fault zones, and significant contacts. These descriptions should include all observable characteristics such as orientation, spacing, continuity, openness, surface conditions, and fillings. Appropriate terminology, descriptive criteria and descriptors, and examples pertaining to discontinuities are presented in chapter 5.

Contacts.—Contacts between various rock units or rock/soil units must be described. In addition to providing a geologic classification, describe the engineering characteristics such as the planarity or irregularity and other descriptors used for discontinuities.

Descriptors applicable to the geologic classification of contacts are:
ROCKS

- Conformable
- Unconformable
- Welded—contact between two lithologic units, one of which is igneous, that has not been disrupted tectonically
- Concordant (intrusive rocks)
- Discordant (intrusive rocks)

Descriptors pertinent to engineering classification of contacts are:

- Jointed—contact not welded, cemented, or healed—a fracture
- Intact
- Healed (by secondary process)
- Sharp
- Gradational
- Sheared
- Altered (baked or mineralized)
- Solutioned

If jointed or sheared, additional discontinuity descriptors such as thickness of fillings, openness, moisture, and roughness, should be provided also (see discontinuity descriptors in chapter 5).

Permeability Data.—Permeability (hydraulic conductivity) is an important physical characteristic that must be described. Suggested methods for testing, terminology, and descriptors are available in the Earth Manual and Ground Water Manual. Numerical values for hydraulic conductivity (K) can be determined using any of several methods. These values may be shown on drill hole logs. For narrative discussions or summary descriptions, the numerical value and descriptors may be used. Descriptors to be used—such as low,
moderate—are those shown on figure 4-7. Whether permeability is primary (through intact rock) or secondary (through fractures) should be indicated.

Example Descriptions

The examples which follow are in representative formats for describing bedrock in the physical conditions column of drill hole logs and on a legend, explanation, and notes drawing.

Core Log Narrative

Several examples of descriptions for core logs are presented. These examples illustrate format and the use of the lithologic descriptors but do not include a description of discontinuities.

Log with Alphanumeric Descriptors and English Units.—

... 12.6 to 103.6: Amphibolite Schist (JKam). Fine-grained (0.5 to 1 mm); subchistose to massive; greenish-black (5G 2/1) with numerous blebs and stringers of white calcite to 0.02 ft thick with solution pits and vugs to 0.03 ft, mostly 0.01 ft, aligned subparallel to foliation; very thinly foliated, foliation dips 65° to 85°, steepening with depth. Moderately to slightly weathered (W4), iron oxide staining on all discontinuities. Hard (H3), can be scratched with knife with heavy pressure, core breaks parallel to foliation with heavy hammer blow. Slightly fractured (FD3),...
Figure 4-7.—Permeability conversion chart.
Log with Alphanumeric Descriptors Using Metric Units.—

103.60 to 183.22: Sandstone (TU$_{sa}$). Ferruginous quartzose sandstone. Medium-grained (0.25 to 0.5 mm), well sorted, subrounded to rounded quartz grains are well cemented by silica; hematite occurs as minor cement agent and as thin coating on grains. Moderate reddish-brown (10R 6/6). Moderately bedded, beds 250 to 310 mm thick, bedding dips 15$^\circ$ to 29$^\circ$, averages 18$^\circ$. Slightly weathered. Hard, cannot be scratched with knife, core breaks with heavy hammer blow across bedding and through grains. Moderately fractured. Core recovered . . .

172.41-176.30: Claystone (TU$_{cl}$). Calcareous montmorillonitic clay with 20 percent subangular, fine sand-size quartz fragments. Strong reaction with hydrochloric acid (HCl), grayish pink (5R 8/2). Moderately to rapidly slaking when dropped in water. Very thinly bedded to laminated with bed thickness from 8 to 20 mm. Very intensely weathered. Very soft, can be gouged with fingernail, friable, core breaks with manual pressure, smaller fragments can be crushed with fingers. . . Upper contact is parallel to bedding, conformable, gradational, and intact; lower contact is unconformable, sharp and jointed but tight; dips 35$^\circ$. . . . .

Legend

The example which follows could be typical of a rock unit description on a general legend, explanation, and note drawing. The object is to describe as many physical properties as possible which apply to the entire rock unit at the site. If individual subunits can be differentiated, they could be assigned corresponding symbols and
ROCKS

described below the undifferentiated description. Those characteristics in the subunits which are similar or are included in the undifferentiated unit do not need to be repeated for each subunit.

**Amphibolite Schist - Undifferentiated.**—Mineralogy variable but generally consists of greater than 30 percent amphibole. Contains varying percentages of feldspar, quartz, and epidote in numerous, thin, white and light green (5G 7/4), discontinuous stringers and blebs. Texture ranges from fine grained and schistose to medium grained and subschistose. Overall, color ranges from greenish black (5G 2/1) to olive black (5Y 2/1). Thinly foliated; foliation dips steeply 75° to 85° NE. Weathering is variable but generally moderately weathered to depths of 75 ft, slightly weathered to 120 ft, and fresh below. Where oxidized, moderate reddish-brown (10R 4/6), frequently with dendritic patterns of oxides on discontinuities. Hard, fresh rock can be scratched slightly with heavy knife pressure; fresh N-size core breaks along foliation with moderate to heavy hammer blow. Foliation joints are variably spaced and discontinuous, spaced more closely where weathered. Joint sets are prominent but discontinuous. (Joint sets are identified in the specifications paragraphs). Commonly altered 0.1 to 6 ft along contacts of dikes and larger shears with epidote and quartz ("altered amphibolite" on logs of exploration). When altered, harder than amphibolite. Based on drill hole permeability testing, hydraulic conductivity is very low to low, with values ranging from 0.09 to 130 feet per year (ft/yr) averages 1.5 ft/yr in slightly weathered and fresh rock.
FIELD MANUAL

BIBLIOGRAPHY


