Chapter 5 - Soil and Rock Classification and Logging

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5.1 Introduction

5.1.1 Purpose

This Chapter provides practices and procedures used by the Oregon Department of Transportation for the classification of soil and rock. Updating this chapter is a continuing process and revisions are issued as required to enhance content clarity and reflect changes in the regulatory landscape. Technical bulletins may be issued between official chapter updates that address content clarity or errors, and changes in regulations. Future chapter updates would supersede outstanding technical bulletins. Users should continually consult the Section / Unit website to ensure the most current guidance is being used. This is not a legal document.

Detailed descriptions and classifications of soil and rock are an essential part of the geologic interpretation process and the geotechnical information developed to support design and construction. This manual contains standardized procedures and guidelines for describing and evaluating soils and rock materials and for preparing exploration logs.

The Unified Soil Classification System (USCS) provides a conventional system for categorizing soils by gradation and plasticity characteristics. However, it alone does not provide adequate descriptive terminology for identifying soils. The enclosed descriptive terminology used by ODOT is not intended to replace the USCS, but to expand it in order to make the classification more precise and better understood.

Various rock description systems exist, however, no one system is universally used. This manual contains a composite procedure that incorporates significant descriptive terminology relevant to geotechnical design and construction.

5.1.2 Roles And Responsibilities

Future updates of this section will outline the key roles and define the responsibilities of personnel involved with Engineering Geologic Investigations.

5.1.3 Points Of Contact

This section identifies the individuals who may assist the Chapters user. If a help desk facility or telephone assistance organization is established, it will be described it in this section.

5.1.4 Chapter Revision Process

Chapter revisions take place biannually. Submit requested changes to ODOTGeoAdminWorkOrders

5.2 Soil And Rock Logging Process

The process used by ODOT to classify and log soils and rock encountered during an exploration program is broken into three steps, field classification, office classification, and preparation of final exploration logs.

Planning and execution of the exploration program is described in Chapters 2 and 3 of the ODOT GDM. Consistent with that planning, the field geologist should be very familiar with the exploration plan as well as possess a general knowledge of the geologic conditions present in the project vicinity.

Final exploration logs are one of the products of a site characterization for project design. They represent the culmination of a lengthy process that starts with the siting of exploration points and ends with an evaluation of materials in context to the engineering geologic characteristics of the project area. Final log production is an iterative process that draws upon increasing data as the work proceeds from field collection and field testing through office evaluation, laboratory analysis, determination of engineering and geologic properties, and comparison of the individual explorations with one another to derive engineering geologic units. In general ODOT practice, the final logs are comprised of a description of the engineering geologic units encountered with or without the individual sample descriptions and classifications.

The process of final log production takes place in three general phases. Field logging includes the collection and description of samples at the exploration site. Office evaluation, check classification, and laboratory testing is the second phase. The final phase is the incorporation of laboratory testing and correction of sample classification and description based on these results, and the subsequent modification of the unit descriptions. The unit descriptions may be further modified during creation of the subsurface model.

5.3 Classification Format

The description and classification of soils and rock includes consideration of the physical characteristics and engineering properties of the material. Always describe the soil/rock as completely as possible. The soil and rock descriptions on boring logs should be based on field observations with further modification or confirmation from office and laboratory testing. Unit/Formation names and material origin should be based on literature research. The general descriptive sequence for soil and rock materials is provided in Table 5-1.

Table 5-1 Descriptive Sequence for Soil and Rock

SOIL	ROCK
Soil Name	Rock Name
USCS Designation	Color
Color	Degree of Weathering
Plasticity	Relative Strength
Moisture	Structure (joints, stratification, faults attitude, separation, filling, continuity, voids)
Consistency/Relative Density	Geologic Strength Index (GSI)

SOIL	ROCK
Texture	Core Recovery and RQD
Cementation	Other Characteristics as applicable (mineralization, slaking, field unit weight, discontinuity surface conditions, voids)
Structure	Unit/Formation
Fill Materials	
Other Constituents/Characteristics as applicable (unit weight, sensitivity, quality of coarse-grained constituents)	
Origin/Unit/Formation	

5.3.1 Decomposed Rock Vs Soil

An important facet of classification is the determination of what constitutes rock, as opposed to extremely weathered, partially cemented, or altered material which approaches soil in its character and engineering characteristics.

Material that may retain identifiable rock texture,is friable, and can be reduced to gravel size or smaller by normal hand pressure should be classified as soil. The soil classification would be preceded by the parent rock name. The following format is suggested:

Decomposed *rock-type*, **remolds to** *complete soil description*

The Origin/Unit/Formation may be noted as **Regolith or Saprolite** followed by the rock unit/formation, if known (Regolith/Boring Lava).

5.4 Field Classification Of Soil

This section presents the recommended procedures for field classification of soil. Preliminary descriptions contained on field exploration logs should be broadly consistent with ASTM D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure). The visual-manual method employs visual observations and simple manual tests (index tests) to estimate the size and distribution of the coarse-grained soil fractions and to indicate the plasticity characteristics of fine-grained fractions. These index tests should be performed on all samples collected.

The definitions for various soil constituents are presented in Table 5-2. For purposes of classification in this system, boulders larger than 5 feet in diameter are given the term “block” to distinguish their greater size.

Table 5-2 Soil Constituents - Definitions

CONSTITUENT	DEFINITIONS
Blocks	Particles of rock larger than 5-feet in diameter
Boulders	Particles of rock that will not pass a 12-inch square opening.
Cobbles	Particles of rock that will pass a 12-inch square opening and be retained on a 3-inch square opening.
Gravel	Particles of rock that will pass a 3-inch square opening and be retained on a # 4 sieve.
Sand	Particles of rock that will pass a # 4 sieve and be retained on a # 200 sieve.
Silt	Soil passing a # 200 sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry.
Clay	Soil passing a # 200 sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air dry.
Organic Soil	A soil with sufficient organic content to influence the soil properties
Peat	A soil composed primarily of vegetable matter in various stages of decomposition usually with an organic odor, or dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.
Muck	A soil composed primarily of fully decomposed vegetable matter usually with an organic odor, or dark brown to black color, and a slick, oily texture.

5.4.1 Soil Name

The first step in describing a soil is to determine whether it is predominately fine-grained, coarse-grained, or organic. A mixed-grain soil (containing both fine-and coarse-grained constituents) is categorized by determining its predominant engineering behavior and by visually estimating the percentages of fine- and coarse-grained constituents. There are three techniques available for estimating the percentage of gravel, sand, and fines in a sample: the jar method, the visual method, and the wash test, as described in Appendix X4 of ASTM D2488. Soils containing more than 50 percent visible particles are coarse-grained soils. After the sample is determined to be predominantly fine- or coarse-grained, the next step is to determine the primary, secondary, and additional constituents. For rapid and easy identification, the primary constituent should be written in upper case letters, i.e., GRAVEL, SAND, SILT, CLAY. The procedures for describing and classifying fine- and coarse-grained soils are described in the following subsections.

5.4.1.1 Fine-Grained Soils

Fine-grained soils are described by their engineering behavior considering such physical characteristics as dilatancy, dry strength, toughness, dispersion, and plasticity, as summarized on Table5-4. Examples of soil descriptions based on field index tests are shown on Table5-5. Table 5-6 summarizes the sub classification order for fine-grained soils. For instance, a soil which contains 80% fine-grained constituents (medium dry strength, slow dilatancy, medium toughness, low plasticity) and 20 % sand would be classified as "Clayey SILT with some sand." It is possible to have two secondary constituents. For instance, a soil with 40% sand and 60% fine-grained constituents (medium plasticity, no dilatancy, medium toughness, and medium dry strength) would be described as "sandy, silty CLAY."

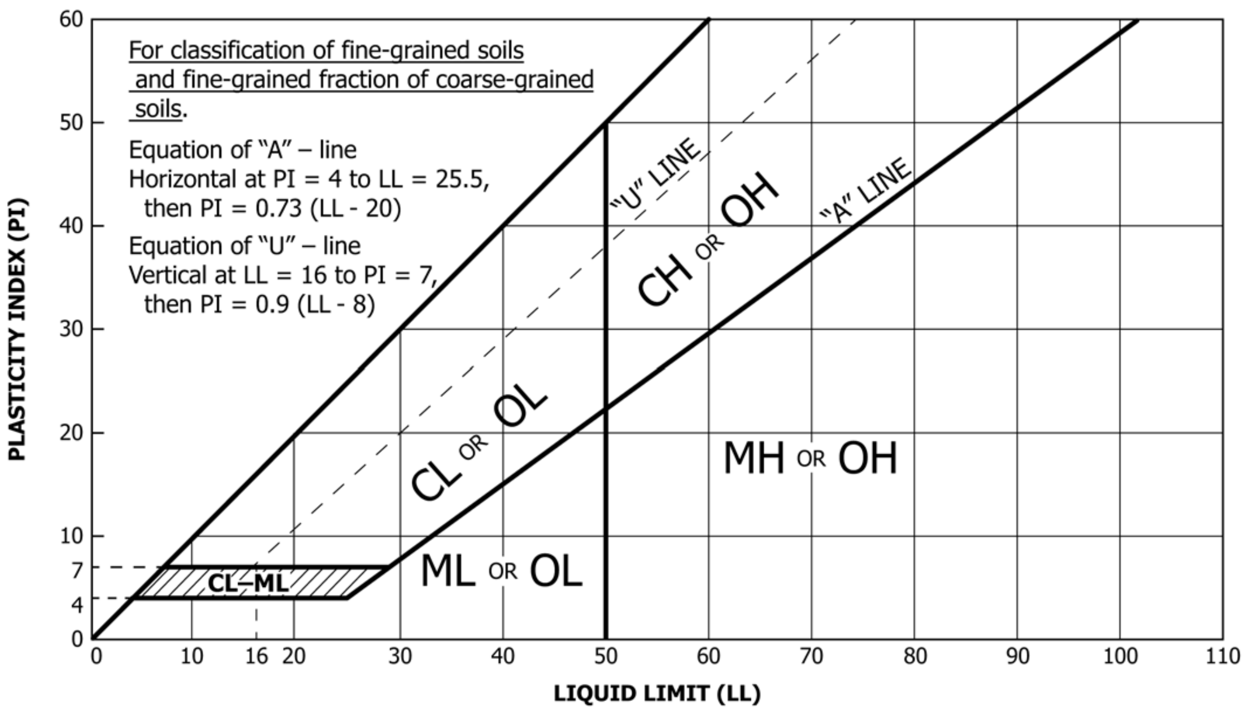


Figure 5-1 Plasticity Chart

Table 5-3 Silt and Clay Characteristics

CHARACTERISTIC	SILTS	CLAYS
DILATANCY Reaction to shaking, movement of water in voids. • None • Slow	Rapid Reaction. Water appears on the surface to give a livery appearance when shaken. Squeezing	Sluggish to no reaction. Surface of the sample remain lustrous. Little to no water appears when hand is shaken. Sample remains lustrous during squeezing.

CHARACTERISTIC	SILTS	CLAYS
• Rapid	the soil causes water to disappear rapidly.	
DRY STRENGTH Cohesiveness in dry state. • None • Low • Medium • High • Very High	None to low. Even oven-dry strength is low. Powder easily rubs off surface of the sample. Little or no cohesive strength, will crumble and slake readily.	High to very high. Exceptionally high if oven-dry. Powder will not rub off the surface. Crumbles with difficulty. Slakes slowly.
TOUGHNESS Plasticity in moist state. • Low • Medium • High	Plastic thread has little strength. Dries quickly. Crumbles easily as it dries below plastic range. Seldom can be rolled to 1/8″ thread without cracking.	Plastic thread has high strength. Dries slowly. Usually stiff and tough as it dries below plastic range. Can easily be rolled to 1/8″ thread without cracking.
DISPERSION Settlement in Water	Settles out of suspension in 15 to 60 minutes (sands settle in 30 to 60 seconds).	Settles in several hours or days, unless it flocculates (rapidly precipitates out in small clumps).
VISUAL INSPECTION AND FEEL	Only coarsest individual soil grains are visible to the naked eye. Feels slightly gritty when rubbed in fingers. Dries quickly and dusts off easily.	Individual grains cannot be observed by the naked eye. Feels smooth and greasy when rubbed in fingers. Dries slowly and does not dust off, must be scraped off.

Table 5-4 Examples of Fine-Grained Soil Field Identification

Typical Name	Dry Strength	Dilatancy Reaction	Toughness of Plastic Thread	Plasticity
SILT	none to low	rapid	low	nonplastic
SILT with some clay	low to medium	rapid, slow	low, medium	low
clayey SILT	medium	Slow	Medium	Low, medium
silty CLAY	medium to high	slow, none	medium, high	
CLAY with some silt	high	none	high	high

Typical Name	Dry Strength	Dilatancy Reaction	Toughness of Plastic Thread	Plasticity
CLAY	very high	none	high	high
Organic SILT	low	slow	low, medium	nonplastic, low
Organic CLAY	medium to very high	none	Medium, high	medium, high

Table 5-5 Fine-Grained Soil Sub classification

Terms	Percent (by Weight) of Total Sample Reaction	Primary Constituent
SILT, CLAY	*	PRIMARY CONSTITUENT*
Clayey, Silty	*	Secondary Fine-Grained Constituents
w/some (silt, clay)	*	Additional Fine-Grained Constituents
Sandy, Gravelly	30 – 50	Secondary Coarse-Grained Constituents
w/ some (sand, gravel)	15 – 30	Additional Coarse-Grained Constituents
w/trace (sand, gravel)	5 - 15	Additional Coarse-Grained Constituents
*** The relationship of clay and silt constituents is based on plasticity and normally determined by performing index tests. Refined classifications are based on Atterberg Limits tests and the Plasticity Chart (Figure 4.1)**		

5.4.1.2 Coarse-Grained Soils

Coarse-grained soils are described on the basis of particle-size distribution, as shown on Table 5-7. In the absence of grain-size test results, the percent distribution of the various constituents should be visually estimated. Where no constituent exceeds 50 percent of the total sample, then the coarse-grained constituent having the largest percentage becomes the primary constituent. If the soil does not include any discernable fines, then describe soil as “clean.” Where the secondary or additional constituent is fine-grained the term “clay” or “silt” is selected based on the predominant plasticity characteristics from index tests (Tables 5-5 and 5-6). For instance, a soil with 48% sand, 42% gravel, and 10 % fine-grained constituents (non-plastic, low dry strength) would be described as Gravelly SAND with some silt.

Table 5-6 Coarse-Grained Soil Sub classification

Terms	Percent (by Weight) of Total Sample Reaction	Primary Constituent
GRAVEL, SAND	Predominant Constituent	PRIMARY CONSTITUENT
Gravelly, sandy	30 – 50	Secondary Coarse-Grained Constituents
w/some (gravel, sand)	15 – 30	Additional Coarse-Grained Constituents
w/trace (gravel, sand)	5 – 15	Additional Coarse-Grained Constituents
Silty, Clayey	12 – 50	Secondary Fine-Grained Constituents
w/some (silt, clay)	5 – 12	Additional Fine-Grained Constituents
w/trace (silt, clay)	< 5	

* **Index tests and/or plasticity tests are performed to determine whether the term "silt" or "clay" is used.**

The standard format for soil descriptions requires the secondary constituent to be capitalized, the primary constituent to be written in all capital letters, and the additional constituents to be written without capitals. For example: Clayey SILT with some sand, ML or Sandy GRAVEL with some silt, trace clay.

Where stratified soils are encountered, each layer should be classified. The significant dimensions of the lenses/layers should be noted. For instance, a soil that is predominantly fine-grained (low dry strength, medium plasticity) with thin (1-inch) layers of clean sand would be described as "clayey SILT with 1- inch layers of clean sand."

5.4.1.3 Cobbles And Boulders

The sub classifications described above are not generally applied to cobbles and boulders. Rather, cobbles and boulders are described by their frequency within the formation.

Since cobbles and boulders are particles more than three inches in diameter, they will not generally be sampled through conventional driven or pushed samplers. However, an estimate of their distribution and frequency is a crucial element in adequately characterizing subsurface conditions encountered during field explorations.

Estimation of the volume of cobbles and/or boulders is based upon recovered intersected or observed lengths and/or drill rig behavior.

The logging of individual cobbles and boulders recovered during sampling should be logged with information consistent with logging rock samples, notably by reference to rock type, rock strength, and the encountered dimension.

For example, it is estimated that 30% by volume of the material is cobbles, describe the sample as:

SAND with Gravel and Cobbles; SW; Dark yellowish brown (10YR 4/2); Nonplastic; Wet; Medium dense; Coarse to fine rounded sand, coarse subrounded to rounded gravel, 30% by volume basalt cobbles, very strong, R5, 4-6 inches, subrounded; Not cemented; Stratified. Alluvium.

If the predominant constituent of the layer is estimated to be cobbles and/or boulders, the soil name must be “COBBLES” or “BOULDERS” or “COBBLES and BOULDERS” with the interstitial or matrix soil description following. For example, it is estimated that 60% by volume of the material is cobbles, describe the layer as:

Basalt COBBLES; 60% by volume; Very strong, R5; 8-10 inches, subrounded; with interstitial SAND with trace Gravel (SW); Dark yellowish brown (10YR 4/2); Nonplastic; Wet; Medium dense; Coarse to fine rounded sand; coarse, subrounded to rounded, gravel; uncemented; Stratified. Alluvium.

Or if there are 45% boulders in a SW matrix:

Basalt BOULDERS; 45% by volume; Very strong, R5; 18-24 inches; in a matrix of SAND with trace Gravel (SW); Dark yellowish brown (10YR 4/2); Nonplastic; Wet; Medium dense; Coarse to fine rounded sand; coarse, subrounded to rounded, gravel; Not cemented; Stratified. Alluvium.

Description of Cobbles and Boulders

The description of cobbles and boulders must include, at a minimum, the following information:

- Rock Type or Rock Name
- Rock strength
- Shape
- The intersected length(s)

An intersected length is the measured or observed length of cobble or boulder during drilling. This is not necessarily the maximum size of the cobble or boulder, e.g., a 10-inch intersected length may be identified as a boulder.

Rock Fragments

The terms “Gravel”, “Cobble”, and “Boulder” imply an alluvial origin of those materials. Coarse-grained soils of non-alluvial origins such as talus, landslide debris, or fill materials should be described as Rock Fragments. The size of rock fragments should be described with the same terminology as their alluvial equivalent, i.e. Gravel-sized ROCK FRAGMENTS, GP. Textural description should follow the same format; i.e. “gravel to cobble-sized rock fragments”, “coarse sand to gravel-sized rock fragments”.

5.4.1.4 Organics

Organics can generally be identified by their distinctive dark color and by their spongy feel. Fresh, wet organic soils usually have a distinctive odor of decomposed organic matter. This odor can be made more noticeable by heating the wet sample. The estimated percent and type of organic material present should be included in the sample description. An estimation of percent organics is based on a percent by volume of the total sample and may be obtained through visual comparison of the sample to a standardized comparison chart, Figure 5-2. The organic material sub classification is shown on Table 5-7.

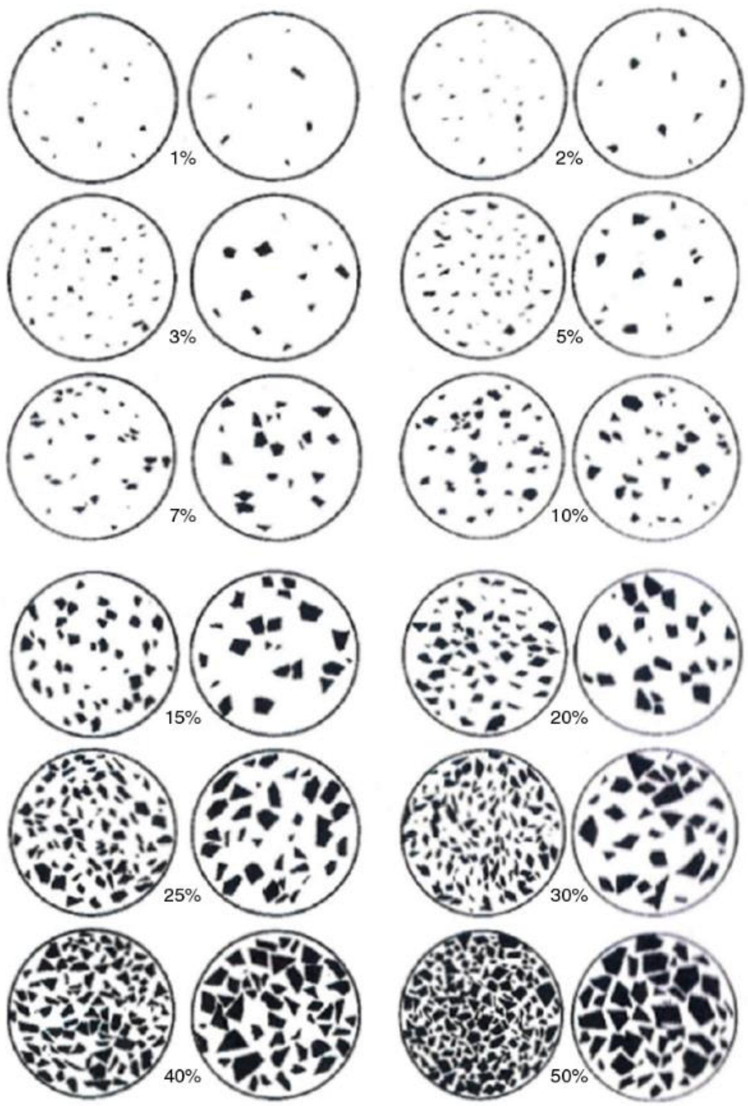


Figure 5-2 Visual Estimation of Volume-Based Distributions

After Rothwell (1989)

The definitions for various soil constituents are presented in Table 5-2.

Table 5-7 Organic Material Sub classification

TERM	ORGANIC PERCENT (BY VOLUME) OF TOTAL SAMPLE	
PEAT	50-100	PRIMARY CONSTITUENT
organic (SOIL NAME)	15-50	Secondary Organic Constituent
(SOIL NAME) w/ some organics	5-15	Additional Organic Constituents
(SOIL NAME) w/trace organics	<5	Additional Organic Constituents

Secondary soil constituents should be described for peats. For example, if a soil contains greater than 50% organics by volume and more than 12% silt by weight, the material would be described as a "silty PEAT." The term "Silty PEAT" would also apply to a material having greater than 50% organics by volume and a significant percentage of silt (i.e. 80%) by weight.

The type of organic material (i.e. peat, wood fibers, carbonized wood, grass, leaves, and roots) should be identified if possible, or referred to as organics. An example would be: "silty SAND with trace clay; some carbonized wood."

Organics may be fibrous and/or amorphous. Organic material may be very finely divided and hard to identify if a strong organic odor is not present. Consider the location when describing samples (i.e., former stream channel, flood plain). If you cannot identify organic material, but suspect its presence (due to color, odor, etc.) then indicate "organics may be present" or "organic odor." A natural moisture content determination or liquid limit test on samples before and after oven drying may verify your observation (Atterberg limits tests are not applicable for peat).

5.4.2 USCS Designation

The USCS designation should be determined by following the procedures specified in ASTM D2487. The USCS designation as reported on field exploration logs will be an approximation based on the visual-manual soil description (ASTM D2488). Figure 5-3 presents a summary of the USCS, simplified for field use. The ODOT hierarchy of terms (Sandy, Silty….Some, Trace) is used to convey a vernacularly comprehensible description of soil to all users of geologic information. Since a full USCS classification requires laboratory testing it is not reasonable to use the entire USCS description on a field log. Figure 5-3 represents the level of USCS classification that can plausibly be achieved in the field.

5.4.3 Color

Soil color is not in itself a specific engineering property, but may be an indicator of other significant properties such as soil chemistry, ground water (e.g., mottling indicating wet/dry cycles), alteration/weathering, or relative natural moisture content. Color may also be an aid in subsurface correlation.

Soil coloring may change quite quickly under exposure to air or through changes in moisture content or degree of oxidation. As such, the color should be field-determined from fresh soil samples at their natural moisture content. Use the Rock Color Chart (or Soil Color Chart) (Munsell Color System) to determine the color(s) of the soil. Record the color name and the alpha-numeric notation: i.e. Dark yellowish brown (10YR 4/2). Describe the "net" color, that is, for a sand with white and dark gray grains, the net color would be Medium gray (N5), not White (N9) and dark gray (N3). Generally, avoid listing more than two colors. When color variations are observed and considered significant, additional adjectives such as "mottled" or "streaked" may be used. For instance, "SAND, SW, Moderate brown (5YR 3/4) and medium gray (N5) mottled, etc."

Where Munsell Charts are unavailable, color should be described in terms of primary colors or combinations of primary colors and modified by shades when necessary i.e. Yellow-Brown, Light Orange, Yellow-Green, etc. Do not use popular color names such as "Peach", "Tan", "Lemon Yellow", or similar terms for color combinations of a specific definition. "Pink" is not a primary color.

UNIFIED SOIL CLASSIFICATION				
MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES
CLEAN COARSE GRAINED SOILS (LESS THAN 5% PASSING THE #200 SIEVE)	GRAVELS More than 50% of coarse fraction is retained on the # 4 sieve		GW	Well graded GRAVEL
			GP	Poorly graded GRAVEL
	SANDS More than 50% of coarse fraction passes the # 4 sieve		SW	Well graded SAND
			SP	Poorly graded SAND
COARSE GRAINED SOILS WITH FINES (BETWEEN 5% AND 12% PASSING THE #200 SIEVE)	GRAVELS More than 50% of coarse fraction is retained on the # 4 sieve		GW-GM or GW-GC	Well graded GRAVEL with silt or well graded GRAVEL with clay
			GP-GM or GP-GC	Poorly graded GRAVEL with silt or poorly graded GRAVEL with clay
	SANDS More than 50% of coarse fraction passes the # 4 sieve		SW-SM or SW-SC	Well graded SAND with silt or well graded SAND with clay
			SP-SM or SP-SC	Poorly graded SAND with silt or poorly graded SAND with clay
COARSE GRAINED SOILS WITH SIGNIFICANT FINES (MORE THAN 12% PASSING THE #200 SIEVE)	GRAVELS More than 50% of coarse fraction is retained on the # 4 sieve		GM or GC	Silty GRAVEL or clayey GRAVEL
	SANDS More than 50% of coarse fraction passes the # 4 sieve		SM or SC	Silty SAND or clayey SAND
FINE GRAINED SOILS More than 50% of the material passes the #200 sieve	SILT AND CLAY Liquid Limit less than 50		ML	Inorganic silt, rock flour, nonplastic to low plasticity
			CL	Inorganic clay, low to medium plasticity. Lean clay
			OL	Organic silt and clay, low plasticity
	SILT AND CLAY Liquid Limit greater than 50		MH	Inorganic silt, medium plasticity. Elastic silt
			CH	Inorganic clay, high plasticity. Fat clay
			OH	Organic silt and clay, medium to high plasticity
HIGHLY ORGANIC SOILS			PT	Peat and other highly organic soils
Boundary classifications			Soil possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder	

Figure 5-3 USCS Soil Classification Summary

5.4.4 Plasticity

Plasticity is a significant indicator property for cohesive soils. Field estimates of plasticity should be based on dry strength and toughness tests (ASTM D2488). The relationships between these index tests and the plasticity are shown on Table 5-8.

Table 5-8 Field Estimated Degree of Plasticity

TERM	PLASTICITY INDEX PI %	DRY STRENGTH	FIELD TEST (APPROXIMATION)
Nonplastic	0-3	Very Low	Dry specimen ball falls apart easily. Cannot be rolled at any moisture content.
Low Plasticity	3-15	Low	Dry specimen ball easily crushed with fingers. 1/8″ thread can barely be rolled within its plastic range.
Medium Plasticity	15-30	Medium	Difficult to crush dry specimen ball when dry. 1/8″ thread is easy to roll.
High Plasticity	30 or More	High	Impossible to crush dry specimen ball with fingers. 1/8″ thread takes considerable time to roll/knead to reach plastic limit. Can be rerolled several times without breaking after reaching plastic limit.

5.4.5 Moisture

A visual estimation of relative moisture content should be made during field classification (ASTMD 2488). Natural moisture contents should be determined in the laboratory for all soils containing more than 5 percent fine-grained material. The typical classifications are presented in Table 5-9.

Table 5-9 Field Moisture Designations

TERM	FIELD IDENTIFICATION
Dry	Absence of moisture. Dusty, dry to the touch.
Damp	Soil has moisture. Cohesive soils are below plastic limit (BPL) and usually moldable.
Moist	Grains appear darkened, but no visible water. Silt/clay will clump, sand will bulk. Soils are often at or near plastic limit.

TERM	FIELD IDENTIFICATION
Wet	Visible water on larger grain surfaces. Sand and cohesionless silt exhibit dilatancy. Cohesive silt/clay can be readily remolded. Soil leaves wetness on the hand when squeezed. Wet indicates that the soil is much wetter than the optimum moisture content and above plastic limit (APL).

5.4.6 Consistency/Relative Density Of Soils

An important index property of cohesive (plastic) soil is its consistency. The consistency of cohesive soil is expressed qualitatively by terms such as very soft, soft, medium stiff, stiff, hard, and very hard. Similarly, a significant index property of a cohesionless (non-plastic) soil is its relative density. Relative density terms include very loose, loose, medium dense, dense, and very dense.

Consistency.

Consistency is an indicator of the shear strength (s_u) of a cohesive soil. The shear strength can be estimated from manual and mechanical field tests (i.e., Standard Penetration Test [SPT], torvane, and pocket penetrometer), or determined by laboratory testing (i.e., unconfined compressive or triaxial shear strength). Normally, the above tests are performed on undisturbed materials. Pocket penetrometer tests on cohesive samples from SPT tests will generally underestimate the undisturbed shear strength. These results, although conservative, may still be useful in preliminary design. Correlation of consistency terms with various parameters determined from both field and laboratory tests are summarized in Table 5-10.

Table 5-10 Consistency of Cohesive Soils

CONSISTENCY	SPT N VALUE BLOWS/FOOT	APPROXIMATE UNDRAINED SHEAR STRENGTH S_U TSF	FIELD APPROXIMATION
Very Soft	<2	<0.125	Squeezes between fingers when fist is closed. Easily penetrated several inches by fist.
Soft	2-4	0.125-0.25	Easily molded by fingers. Easily penetrated several inches by thumb.
Medium Stiff	4-8	0.25-0.50	Molded by strong pressure of fingers. Can be penetrated several

CONSISTENCY	SPT N VALUE BLOWS/FOOT	APPROXIMATE UNDRAINED SHEAR STRENGTH S_U TSF	FIELD APPROXIMATION
			inches by thumb with moderate effort.
Stiff	8-15	0.50-1.0	Dented by strong pressure of fingers. Readily indented by thumb but can be penetrated only with great effort.
Very Stiff	15-30	1.0-2.0	Readily indented by thumb nail
Hard	30-60	>2	Indented with difficulty by thumb nail.
Very Hard	>60		

Pocket penetrometer and unconfined compression tests yield q_u. Torvane yields S_u. $S_u = q_u/2$

Relative Density.

Relative density of uncemented granular or cohesionless soils is a measure of the compactness of the soil. Nonplastic SILT soils which exhibit general properties of granular soil are given a relatively density description. Relative density can be estimated from a simple manual field test, or evaluated with the Standard Penetration Test (ASTMD 1586, AASHTO T206). Relative density terms are related to SPT N-values and rudimentary field tests, as shown in Table 5-11.

Table 5-11 Relative Density for Granular (Cohesionless) Soils

CONSISTENCY	SPT N VALUE BLOWS/FOOT	FIELD APPROXIMATION
Very Loose	0-4	Easily penetrated many inches (>12) WITH ½ inch rebar, pushed by hand.
Loose	4-10	Easily penetrated several inches with ½” rebar pushed by hand.
Medium Dense	10-30	Easily to moderately penetrated with ½” rebar driven by 5 lb. hammer.
Dense	30-50	Penetrated 1 foot with difficulty using ½“ rebar driven by 5 lb. hammer.
Very Dense	>50	Penetrated only a few inches with ½” rebar driven by 5 lb. hammer.

5.4.7 Texture

Texture refers to the actual size, shape, and gradation of the constituent grains. Table 5-12 defines the most common grain size terms. The maximum coarse-grained size recovered in soils should be noted. Figure 5-4 shows various shapes of bulky (granular) grains and their corresponding classification. The gradation definitions are presented in Table 5-13. Coarse-grained soils having less than 12 percent passing the # 200 sieve require gradation descriptions, i.e., well-graded, poorly-graded (uniform or gap-graded).

Table 5-12 Grain size terms and definitions

Term		Grain Size (inches or sieve #)
Blocks		> 5 feet
Boulders		>12 inches and < 5 feet
Cobbles		3 – 12 inches
Gravel	Coarse	¾ - 3 inches
	Fine	#4 – ¾ inches
Sand	Coarse	#10 - #4
	Medium	#40 - #10
	Fine	#200 - #40

Table 5-13 Gradation definitions

Gradation Term (USCS)	Definition	Example
Well-graded (GW, SW)	The full range of grain sizes, evenly distributed	Coarse to fine grained sand Coarse to fine gravel
Poorly-graded (GP, SP)	A limited range of contiguous grain sizes	Medium to fine grained sand
Uniformly-graded (GP, SP)	Predominantly one grain size	Fine grained sand Coarse gravel
Gap-graded (GP, SP)	Gaps within the range of grain sizes present	Medium to fine grained sand with coarse gravel Fine gravel with fine grained sand

Particle shape

When the particle shape of coarse grained soils can be observed directly (coarse sand grains, gravel, cobbles, and boulders) the angularity of the particles should be described, consistent with Figure 5-4.

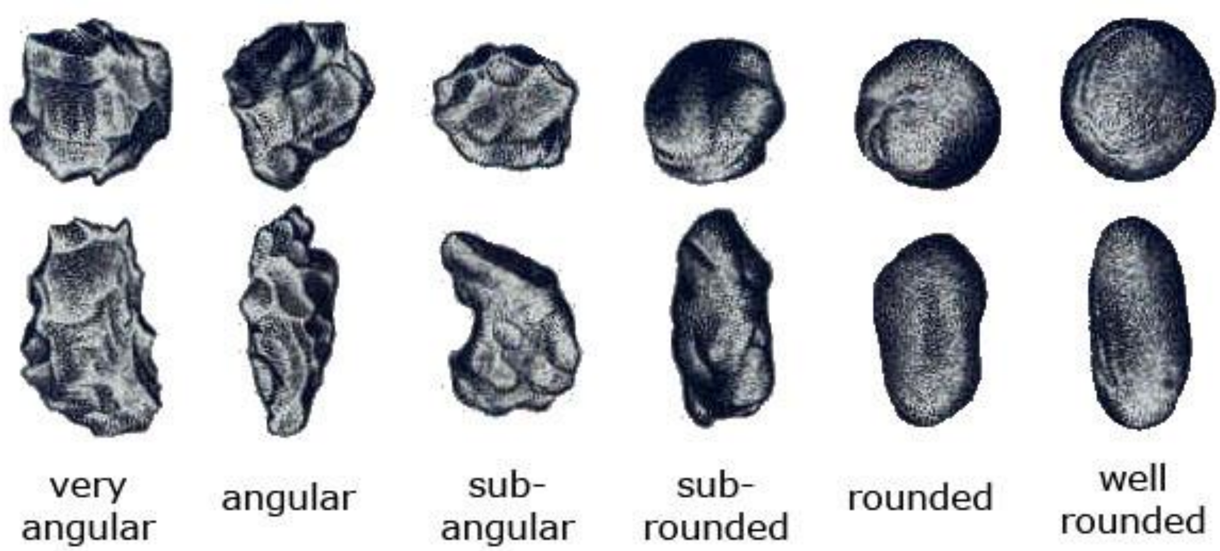


Figure 5-4 Particle Shape for Coarse-Grained Soil Particles

After Powers, 1953

Figure 5-5 Particle Shape for Coarse-Grained Soil Particles

After Field Studies Council, 2016.

5.4.8 Cementation

Cementation is the bonding of grains by secondary minerals (e.g., calcite) or degradation products (e.g., clay). Whenever possible, the cementing material should be noted i.e. "weak iron oxide cementaton, moderate calcium carbonate cementation, etc.". The presence of calcium carbonate cementation can be detected by its reaction to hydrochloric acid. The relative degree of cementation of undisturbed soil samples is defined in Table 5-14.

Table 5-14 Criteria for Describing Cementation

TERM	CRITERIA
Uncemented	No discernable cementation
Weak	Crumbles or breaks with handling or little finger pressure.
Moderate	Crumbles or breaks with considerable finger pressure.
Strong	Will not crumble or break with finger pressure.

5.4.9 Structure

Structural features include stratifications, varves, lenses, fissures, seams, slickensides, striations, blocky structure, relict rock structure, voids (root or worm holes, cavities). The thickness, frequency, and inclination of these features should be noted. Table 5-15 presents criteria for describing structure.

Table 5-15 Criteria for Describing Structure

TERM	CRITERIA
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick, note thickness.

TERM	CRITERIA
Laminated	Alternating layers of varying material or color with layers less than 6 mm thick, note thickness.
Fissured	Contains shears or separations along planes of weakness.
Slickensided	Shear planes appear polished or glossy, sometimes striated.
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown.
Lensed	Inclusion of small pockets of different soils, such as small lenses of clay, note thickness.
Homogeneous	Same color and appearance throughout.

5.4.10 Fill Materials

All soils should be examined to see if they contain foreign materials indicative of man-made fills. Nonstructural fills are often a problem in design. Man-made and other foreign fill items should be listed in each of the soil descriptions. Common man-made items include glass, brick, dimensioned lumber, concrete, metal, plastics, plaster, etc. Other items that could suggest fill include buried vegetation mats, tree limbs, stumps, etc. The soil description for a fill material should be followed by the term "(Fill)", i.e., for a clayey silt fill with some brick fragments the description would be "clayey SILT, ML, with gravel to cobble-sized brick fragments (Fill)." The size distribution of miscellaneous items should be noted. The limits (depth range) of fill material should be determined and identified at each exploration location.

5.4.11 Other Constituents/Characteristics

Additional constituents and/or pertinent characteristics not included in the previous categories should be described, depending on the scope and objectives of the project. Some of these other constituents/characteristics include the following:

Unit Weight. The total unit weight is generally laboratory determined on undisturbed soil samples, and may sometimes be determined in-situ. The field observation of significant variations in unit weight (soils obviously heavier or lighter than otherwise encountered within the borehole or project) should be noted on the field logs.

Quality of Coarse-Grained Constituents. Where the soil is predominantly coarse-grained, the nature and condition of the coarse grains should be described. For instance, the parent rock type(s), hardness (soft or hard), and weathering (fresh, weathered, or decomposed).

Identification or differentiation of formations can sometimes be discerned by noting the presence of mica, gypsum, quartzite, or other components.

Other characteristics that may be observed in the field should be noted. These include oxide staining, organic, chemical or petroleum odors, and oxide or carbonate concretions.

Note: Indications of contamination must be noted and safety precautions must be in place before proceeding if such evidence is detected. Health and Safety Plans must include procedures for encountering unanticipated site contaminantion.

5.4.12 Origin

The origin of the soil is generally interpreted based on a knowledge of geologic site conditions and soil description. A generic name for the soils origin may be provided at the end of the description, such as Alluvium, Colluvium, Decomposed [rock name], Fill, etc. Where known, the formation name should be included in parentheses at the end of the description.

DESCRIPTION

Sample descriptions will be written in the same order as they have been discussed previously: Seconday constituent, PRIMARY CONSTITUENT, secondary constituents, USCS designation; color, plasticity, moisture, consistency/relative density, texture, gradation, shape, cementation, structure, other constituents/characteristics, (Origin). A semicolon should follow the USCS designation with all descriptive terms in lower-case and separated by a comma. The Origin should be capitalized.

<u>Examples:</u>

Clayey SILT with some sand, ML; brown, low plasticity, moist, stiff, medium, subangular sand*, uncemented, homogeneous, micaceous, (Portland Hills Silt).

Sandy GRAVEL with trace silt, GW; brown and gray, nonplastic, damp, medium dense, fine to coarse gravel, fine to coarse sand, well-rounded gravel, subangular to subrounded sand, weak iron oxide cementation, homogeneous, basalt and quartzite gravel, (Alluvium).

GRAVEL with trace sand, GP; gray, nonplastic, dry, very dense, coarse, angular gravel, coarse, angular sand*, uncemented, homogeneous, andesite gravel, (Colluvium).

*The recorder has the option to combine size and shape descriptions for each coarse-grained constituent, i.e. describing the size and shape of the gravel and then the size and shape of the sand.

5.5 Field Classification Of Rock

Rock classification for engineering purposes consists of two basic assessments: that for intact character, such as a hand specimen or small fragment; and in-situ character, or engineering features of rock masses.

Intact Character. Classification of the intact rock, such as hand specimens or core, is in terms of its origin, mineralogical makeup, texture, and degree and nature of chemical and physical weathering or alteration.

In-Situ Character. Classification of in-place rock masses includes the nature and orientation of its constituent interlocking blocks, plates, or wedges formed by bounding discontinuities such as bedding, foliation planes, joints, shear zones, and faults.

Both assessments are essential for design. Both characteristics are the basis for rock slope design and excavation and many facets of rock anchorage and bearing capacity determinations.

5.5.1 Rock Name

Rocks are classically divided into three general categories: igneous, sedimentary, and metamorphic.

Igneous rocks are classified based on mineralogy and genetic occurrence (intrusive or extrusive). Texture is the most conspicuous feature of genetic occurrence.

Sedimentary rocks are classified on the basis of grain size, mineralogy, and on the relationship between grains.

The most conspicuous features of metamorphic rocks are generally their structural features, especially foliation.

The complete name of a rock specimen or rock unit should include texture and lithologic name. The rock name should be in simple geologic terms. The rock name should be completely written in capital letters. The following tables present common rock names and their characteristics.

5.5.1.1 Igneous Rocks

Table 5-16 Common Igneous Rocks

INTRUSIVE (COARSE-GRAINED)	ESSENTIAL MINERALS	COMON ACCESSORY MINERALS	EXTRUSIVE (FINE-GRAINED)
GRANITE	Quartz Orthoclase	Plagioclase Mica Amphibole Pyroxene	**RHYOLITE**
DIORITE	Plagioclase	Mica Amphibole Pyroxene	**ANDESITE**
GABBRO	Plagioclase	Amphibole	**BASALT**

INTRUSIVE (COARSE-GRAINED)	ESSENTIAL MINERALS	COMON ACCESSORY MINERALS	EXTRUSIVE (FINE-GRAINED)
	Pyroxene		

Table 5-17 Igneous Rock Textures

TEXTURE	GRAIN SIZE	ROCK TYPE
Pegmatitic	Very large crystals, diameters measured in inches or feet. Wide range of sizes.	Intrusive
Phaneritic	Crystals can be seen with the naked eye.	Intrusive or Extrusive
Aphanitic	Crystals cannot be seen with the naked eye.	Intrusive or Extrusive
Glassy	No crystals present.	Extrusive
Porphyritic	Larger crystals in a finer-grained groundmass.	Intrusive or Extrusive

Table 5-18 Pyroclastic Rocks

TERM	CRITERIA
Cinders	Uncemented glassy and vesicular ejecta 4-32 mm size.
Tuff Breccia (agglomerate)	Composed of ejecta >32 mm size, in ash/tuff matrix, indurated.
Lapilli Tuff	Composed of ejecta 4-32 mm size, in ash tuff matrix, indurated.
Tuff	Cemented volcanic ash particles <4 mm size, indurated.
Pumice	Excessively vesiculated glassy lava.

5.5.1.2 Vesicularity.

Vesicles in volcanic rocks are rounded cavities due to gas bubbles in molten lava. Cavities or openings in other rocks (e.g., intergranular space) should be described in other terms, such as porosity (e.g., porous sandstone).

The occurrence of vesicles are to be reported using the Comparison Chart (Figure 5-2) to estimate relative percent area occupied by vesicles and the designations in Table 5-21.

Table 5-19 Degree of Vesicularity

TERM	PERCENTAGE BY VOLUME OF TOTAL SAMPLE
Some Vesicles	5-25 Percent
Highly Vesicular	25-50 Percent
Scoriaceous	>50 Percent

5.5.1.3 Sedimentary Rocks

Table 5-20 Common Sedimentary Rocks

A. CLASTIC SEDIMENTARY ROCKS	
ROCK NAME	**ORIGINAL SEDIMENT**
CONGLOMERATE	Gravel, or sand and gravel.
SANDSTONE	Sand.
SILTSTONE	Silt.
CLAYSTONE	Clay.
MUDSTONE	Silt, clay, possibly with sand and/or gravel inclusions, massive.
SHALE (laminated claystone/siltstone)	Oriented, laminated, fissile, clay and silt.
B. CHEMICAL SEDIMENTARY ROCKS	
ROCK NAME	**MAIN MATERIAL**
LIMESTONE	Calcite.
DOLOMITE	Dolomite
CHERT	Quartz

A modifier may be necessary to describe a sedimentary rock formed from a combination of different soil types, i.e., a “silty SANDSTONE” would be predominantly composed of sand grains with a lesser amount of silt grains. This distinction is only necessary when the modifier has engineering significance. The term mudstone could be used when the composition of the sedimentary rock is uncertain or variable.

5.5.1.4 Metamorphic Rocks

Table 5-21 Common Metamorphic Rocks

	A. FOLIATED METAMORPHIC ROCKS		
ROCK NAME	TEXTURE	FORMED FROM	MAIN MATERIALS
SLATE	Platy, fine-grained	Shale, argillite	Clay, mica, quartz
PHYLLITE	Parting surfaces (foliation) defined by fine-grained platy minerals (mica, graphite, etc.) giving the surfaces a silky sheen.	Slate	Mica, clay, quartz
SCHIST	Irregular layers, medium grained	Slate/phyllite, igneous rocks	Mica, quartz, feldspar, amphibole
GNEISS	Layered, coarse-grained	Igneous rocks, schist, sandstone	Mica, quartz, feldspar, amphibole
	B. NONFOLIATED METAMORPHIC ROCKS		
ROCK NAME	**TEXTURE**	**FORMED FROM**	**MAIN MATERIALS**
MARBLE	Crystalline	Limestone, dolomite	Calcite, dolomite
QUARTZITE	Crystalline	Sandstone	Quartz
SERPENTINITE	Massive to layered, fine- to coarse-grained	Ultramafic rocks, i.e., peridotite, gabbro	Serpentine-group (antigorite, lizardite, and chrysotile [asbestos])

5.5.2 Color

Rock color is not in itself a specific engineering property, but may be an indicator of the influence of other significant conditions such as groundwater (e.g., mottling indicating wet/dry cycles), and alteration/weathering. Color may also be an aid in subsurface correlation.

Color should be determined from a freshly broken surface. Describe the "net" color of the rock mass. Wetting the rock sample may be necessary if drying has occurred or when determining the color from the cut surface of a core sample. Use the Rock Color Chart (Munsell Color System) to determine the color(s) of the rock. Record the color name and the alpha-numeric notation and whether the sample is dry or wet: i.e. Dark yellowish brown, 10YR 4/2 (D *or* W). Avoid listing more than two colors except when describing multi-colored mottling or large-scale color variations within a rock mass.

5.5.3 Degree Of Weathering

Weathering and alteration should be described as part of the rock classification. Weathering is the process of mechanical and/or chemical breakdown of rocks through exposure to the elements, which include rain, wind, plant action, groundwater, ice, and changes of temperature. In general, the strength of rock tends to decrease as the degree of weathering increases. In the earliest stages, weathering is manifested by discoloration of intact rock and only slight changes in rock texture. With time, significant changes in rock strength, compressibility, and permeability occur. And the rock mass is altered until the rock is decomposed to soil. For determining the stage of weathering for rock, use Table 5-22, Scale of Relative Rock Weathering. For example, a basalt that is more than 50 percent decomposed (but not completely) would be described as "BASALT, predominantly decomposed." The degree of weathering should be determined for each rock core sample. Multiple designations would be required for variable rock conditions.

In select cases, the term alteration may be used, which applies specifically to changes in the chemical or mineral composition of rock due to hydrothermal or metamorphic activity. Alteration may occur as zones and pockets and can be found at depths far below that of normal rock weathering. Separate the terms weathering and alteration, since alteration does not strictly infer a reduction in rock strength. For example, a gray basalt that is closely jointed with extensive hydrothermal alteration and secondary mineralization may exhibit only slight weathering along joint surfaces and would be described as "BASALT, gray, slightly weathered, close jointed, extensive hydrothermal alteration with secondary mineralization."

Table 5-22 Scale of Relative Rock Weathering

DESIGNATION	FIELD IDENTIFICATION
Fresh	Crystals are bright. Discontinuities may show some minor surface staining. No discoloration in rock fabric.
Slightly Weathered	Rock mass is generally fresh. Discontinuities are stained and may contain clay. Some discoloration in rock fabric. Decomposition extends up to 1 inch into rock.
Moderately Weathered	Rock mass is decomposed 50 percent or less. Significant portions of rock show discoloration and weathering effects. Crystals are dull and show visible chemical alteration.

DESIGNATION	FIELD IDENTIFICATION
	Discontinuities are stained and may contain secondary mineral deposits.
Predominantly Decomposed	Rock mass is more than 50 percent decomposed. Rock can be excavated with a rock hammer. All discontinuities exhibit secondary mineralization. Complete discoloration of rock fabric. Surface of core is friable and usually pitted due to washing out of highly altered minerals by drilling water.
Decomposed	Rock mass is completely decomposed. Original rock fabric" may be evident. May be reduced to soil with hand pressure.

5.5.4 Relative Strength Of Rock

Differentiating between rock and soil, for engineering purposes, is based primarily on values of unconfined compressive strength. Rock strength may be estimated through manual field tests yielding a "field classification," which can be refined through laboratory testing. The scale of rock strength to be used is presented on Table 5-23. The relative strength of rock should be determined for each rock core sample; multiple designations would be required for variable rock conditions, such as changes in weathering and joint filling.

Table 5-23 Scale of Relative Rock Strength

TERM	STRENGTH DESIGNATION	FIELD CLASSIFICATION	APPPROXIMATE UNCONFINED COMPRESSIVE STRENGTH (PSI)
Extremely weak	R0	Indented by thumbnail	35-150
Very weak	R1	Crumbles under firm blows with point of a rock hammer, can be peeled by a pocket knife	150-725
Weak	R2	Can be peeled with a pocket knife with difficulty, shallow indentation made by firm blow with point of a rock hammer	725-3,500
Medium strong	R3	Cannot be scraped or peeled with a pocket knife, specimen can be	3,500-7,250

TERM	STRENGTH DESIGNATION	FIELD CLASSIFICATION	APPPROXIMATE UNCONFINED COMPRESSIVE STRENGTH (PSI)
		fractured with a single blow from a rock hammer	
Strong	R4	Specimen requires more than one blow of a rock hammer to fracture it	7,250-14,500
Very strong	R5	Specimen requires many blows of a rock hammer to fracture it	14,500-36,250
Extremely Strong	R6	Specimen can only be chipped with a rock hammer	>36,250

5.5.5 Structure

Structure refers to large-scale (megascopic) planar or oriented features which are significant to the overall strength, permeability, and breakage characteristics of the rock unit. Planar structural features include joints, bedding, and faults. These terms are defined below. Other oriented structural features include mineral/grain orientation (i.e., foliation, flow banding, and folded originally planar features) or root holes.

5.5.5.1 Joints.

Planar breaks or fractures in rock along which no movement has occurred parallel to the fracture surface are defined as joints. They may range from perpendicular to parallel in orientation with respect to bedding. Repetitive patterns of more or less parallel joints is called a joint set. Two or more joint sets or a pattern of joints define a joint system. The number of joint sets is most reliably obtained from rock exposures.

5.5.5.2 Stratification.

Stratification of rock is evidenced by changes in texture, composition, age, or unique forms. Bedding applies primarily to sedimentary and pyroclastic rocks. Other terms related to stratification are defined in Table 5-24.

Table 5-24 Stratification Terms

TERM	CHARACTERISTICS
Laminations	Thin beds (<1 cm).

TERM	CHARACTERISTICS
Fissile	Tendency to break along laminations.
Parting	Tendency to break parallel to bedding, any scale.
Foliation	Non-depositional, e.g., segregation and layering of minerals in metamorphic rocks.

5.5.5.3 Joint Or Bedding Spacing.

In determining the range of distances between individual joints or beds, care must be taken to distinguish between joints and mechanical breaks that are caused by handling or drilling. These types of mechanical breaks are typically rough and irregular, showing a fresh rock surface and are disregarded for description. Some mechanical breaks, though, may be caused by handling or drilling, but occur along existing joints or fractures, and should be described accordingly. Joint/bedding spacing is based on Table 5-25.

Table 5-25 Joint and Bedding Spacing Terms

SPACING	JOINT SPACING TERMS	BEDDING/FOLIATION SPACING TERMS
Less than 2 in.	Very close	Very thin (laminated)
2 in. to 1 ft.	Close	Thin
1 ft. to 3 ft.	Moderately close	Medium
3 ft. to 10 ft.	Wide	Thick
More than 10 ft.	Very wide	Very thick (massive)

Planar breaks or fractures, along which displacement has occurred parallel to the fracture surface are termed faults. The presence of gouge (pulverized rock), bedding offset, and polished or slickensided surfaces (commonly with mineral or clay coating), may be indicators of fault movement. However, not all slickensides are caused by faulting: slickensides can be caused by deformation (i.e., folds, flows) or landsliding. When offset is apparent, indicate the relative sense of movement (normal, reverse, or strike-slip)

5.5.5.4 Attitude.

The orientation of joints, faults, bedding planes or other planar features must be determined and recorded. Figure 5-6 presents the orientation information that should be identified/measured. Strike and dip of joint and bedding planes are usually measured in test pits or on outcrops, since core obtained in most drilling operations will not be properly oriented.

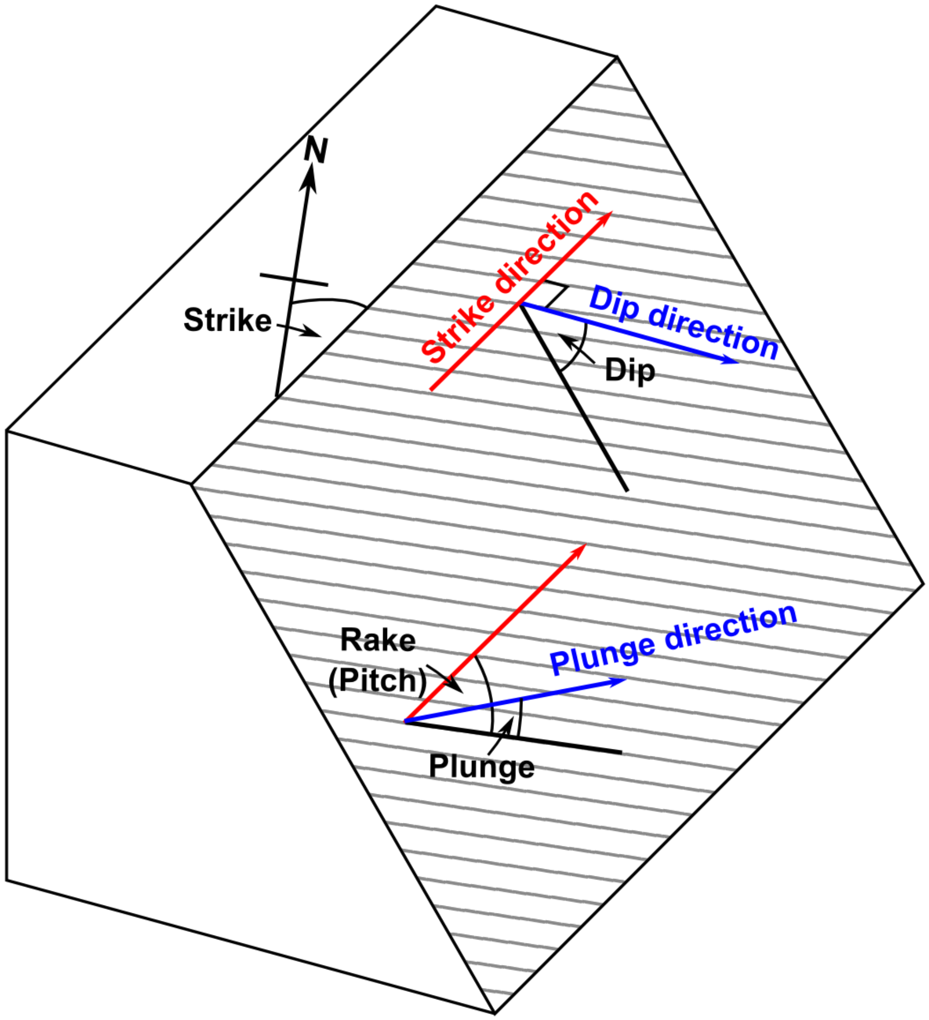


Figure 5-6 Orientation Measurements of Planar and Linear Features

(Norton, 2010)

5.5.5.5 Core

Unless oriented core is obtained, the true orientation (strike and dip) of discontinuities cannot be determined. The inclination (dip) of a joint or bedding plane is measured perpendicular to the strike trace of the feature and down from horizontal. Joint sets and bedding may be characterized by the average inclination observed in the sample. For unique discontinuities, such as faults and widely spaced or random joints, determine the inclination for each feature.

The angle that striations (slickensides) make with a horizontal line is known as the ”rake”, as shown on Figure 5-6. Determine the rake for any linear features observed on discontinuity surfaces.

5.5.5.6 In Situ

Joint and bedding planes should be described in terms of orientation, i.e., strike and dip. Linear features (striations and slickensides) should be described in terms of rake or bearing and plunge. Primary and secondary joint sets should be defined where possible. Typically in rock, one joint set may yield slabs, two intersecting joint sets may yield wedges, and three or more intersecting joint sets may yield blocks or highly fragmented rock.

Additional information of rock structure can be found in Chapter 11 of the GDM.

5.5.5.7 Separation.

The separation or relative openness of joints may be described as:

a) Open. An existing planar surface that is separated or separates easily when handled and may have mineralization or staining/weathering on the joint surfaces. Where measureable, identify the opening width (aperture). Open joints are possible groundwater drainage paths.
b) Closed. An existing planar surface that separates with greater difficulty, seen as a "hairline" trace on the outside of the sample/core, and usually contains soil or minerals as a filling between joint surfaces.
c) Healed. Breaks open easily or with difficulty, seen either as a hairline trace or seam of some thickness on the outside of the sample/core, and usually contains soil or minerals as a filling between joint surfaces.

5.5.5.8 Filling.

This term refers to the material in the space between adjacent surfaces of a discontinuity. The filling material may consist of weathered or hydrothermally altered products, secondary mineral precipitates, or gouge. The material description and thickness of the filling material should be reported.

5.5.5.9 Continuity.

Continuity is an expression of the lateral extension of the discontinuity, as measured or projected along its strike and dip. Continuity is a very important property of the rock mass, as a single continuous joint may actually control the behavior of the entire mass. Whether or not joints are continuous may require test pit, outcrop, or additional borehole information for confirmation. The description of joint continuity, as defined in Table 5-26, should include an indication of certainty and the method of observation. Where continuity cannot be determined in core specimens, it should be noted as "Indeterminate".

Table 5-26 Degree of Continuity

TERM	LENGTH
Discontinuous	0 to 5 feet
Slightly Continuous	5 to 10 feet
Continuous	10 to 40 feet
Highly Continuous	>40 Feet

5.5.5.10 Geological Strength Index

The Geological Strength Index (GSI), when combined with the intact rock properties, can be used for estimating the reduction in rock mass strength for different geologic conditions. This system is presented in Table 5-27, for blocky rock masses, and Table 5-28 for heterogeneous rock masses such as flysch, molasse and mélange/ophiolite.

A GSI should be determined for each rock core sample; multiple values may be required for variable joint conditions, such as changes in spacing or surface conditions. Record the GSI in the Discontinuity Data column of the log as “GSI=XX”.

Table 5-27 GSI for blocky rock masses on the basis of interlocking and joint surface conditions

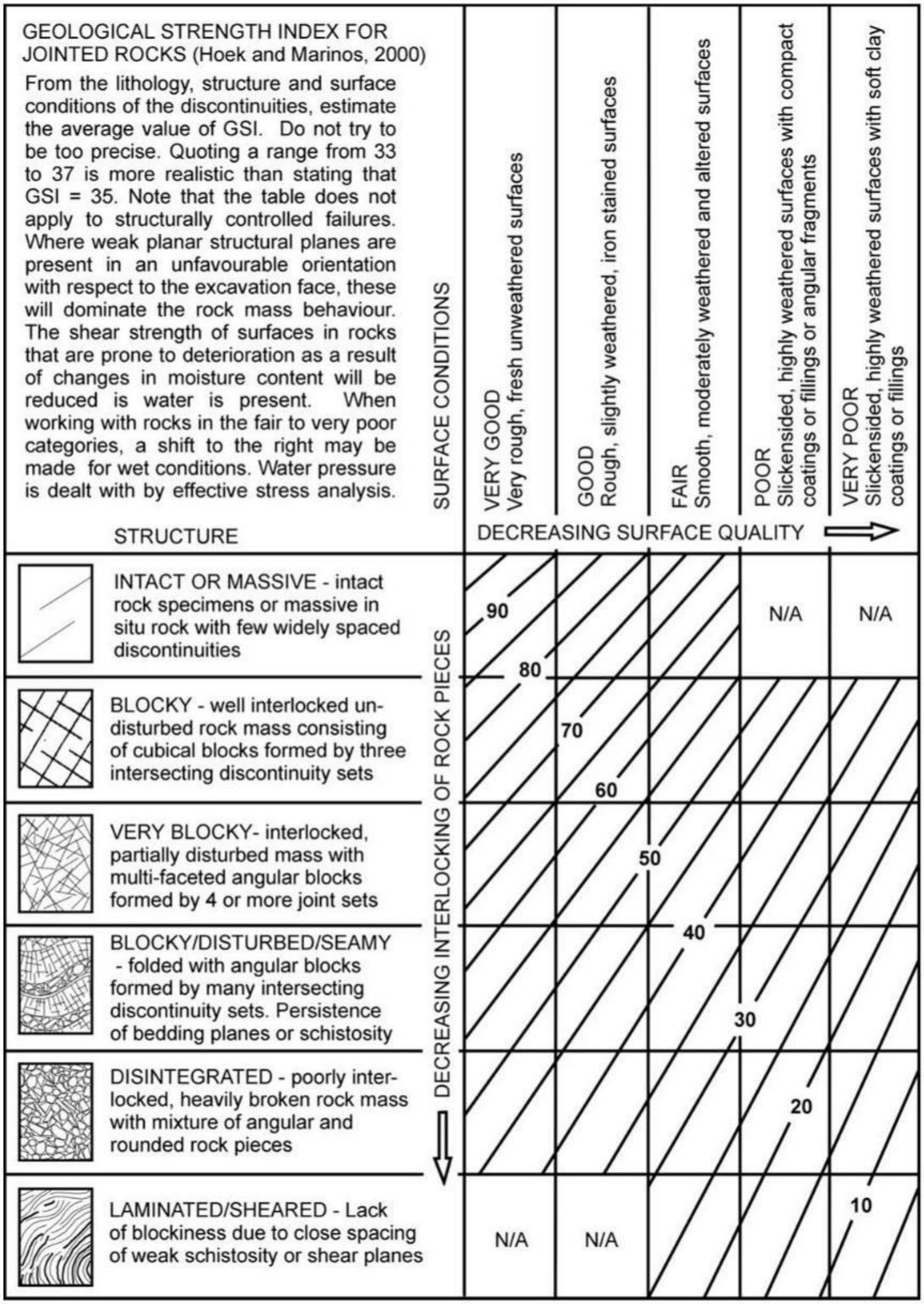
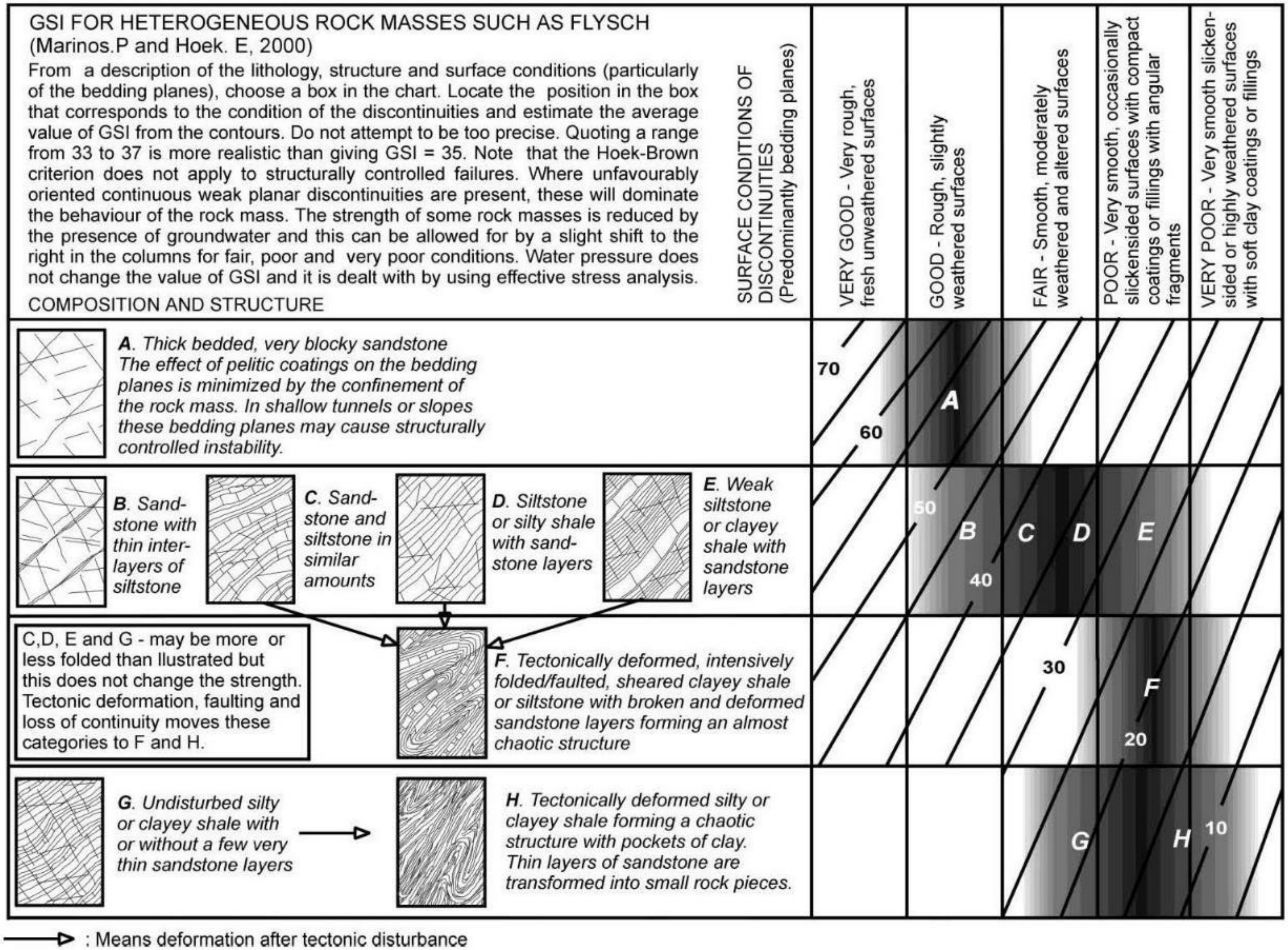


Table 5-28 GSI for heterogeneous rock masses such as flysch.



5.5.6 Core Recovery And Rock Quality Designation (RQD)

Core recovery and the Rock Quality Designation are measured indicators of the quality and structure of rock. Both the core recovery and the RQD should be determined and recorded on the field boring log for each core run. The core recovery is the measured length of core retained in the core barrel. The percent recovery is the measured recovery divided by the total run length expressed as a percent. Record the measured recovery in the appropriate column and the percent recovery at the end of the sample description.

The RQD provides a subjective estimate of rock mass quality/structure. The RQD is a modified core recovery percentage in which only pieces of intact rock core 4 inches or greater in length are measured (average length). The smaller pieces are considered to be the result of close jointing, fracturing, or weathering in the rock mass, and are therefore excluded from the RQD determination. RQD is defined as the cumulative total length of all pieces 4 inches long or longer divided by the total run length, expressed as a percentage. Mechanical breaks, such as caused by handling or drilling, should be noted as such and not included in the RQD calculations. Completely healed joints, veins, and mineralization zones should be treated in the same manner as mechanical breaks.

In some cases, where significant soil is encountered at one end of the core run, the RQD should be determined on the basis of rock core length recovered: where this is done it should be clearly defined. RQD is not applicable to fissile rocks such as shales. Difficulties such as distinguishing natural fractures in the rock core from mechanical breaks and the insensitivity of the RQD to the tightness of individual joints may limit the use of the RQD in evaluating in situ rock properties.

Record the RQD in the Discontinuity Data column of the log as “RQD=XX%”.

5.5.7 Other Rock Characteristics

Other physical characteristics should be described, depending on the scope and objectives of the project. These may include the following:

5.5.7.1 Mineralization.

Secondary mineralization is the introduction of new minerals to a rock mass from an outside source, or through alteration of existing materials. Mineralization may occur in voids, along joints, or within the ground mass.

Iron-oxide staining usually indicates the static groundwater level may fluctuate within the discolored zone. The iron-oxide may only be a discoloration of surfaces, or an accumulation of bright orange material several inches thick and varying in hardness. Sulfide or carbonate minerals, such as pyrite or calcite, may be present and could denote groundwater of high mineral or bicarbonate content. Alteration products may indicate an increase in hardness/brittleness (i.e., silicification, usually due to hydrothermal alteration), or reduction of rock strength if soft clay minerals have developed along joints or replaced major constituent minerals (e.g., the feldspar crystals in basalt altered to clay).

5.5.7.2 Slaking.

The tendency for rock to disintegrate under conditions of wetting and drying, or when exposed to air is called slaking. This behavior is related primarily to the chemical composition of the material. It may be identified in the field if samples shrink and crack, or otherwise degrade upon drying, or being exposed to the air for several hours. If degradation occurs, and slaking is suspected, an air dried sample may be placed in clean water to observe a reaction. The greater the tendency for slaking, the more rapidly degradation will occur. This tendency should be expressed on field logs as “potential for slaking”, and can be confirmed through laboratory testing.

5.5.7.3 Field Unit Weight.

The unit weight of rock can be important and useful in engineering design and practice. The unit weight can be determined by performing a field bulk specific gravity test and multiplying by the unit weight of water to get the rock unit weight. The procedure consists of weighing the sample in air (B) and then weighing it in water (C).

$$\gamma_{field} = \left[\frac{B}{(B-C)}\right] \times (62.4\ lbs/ft^3)$$

5.5.7.4 Discontinuity Surface Condition.

If applicable to the project, the joint/fault surfaces should be inspected and the surface condition described. Joint surface roughness can be defined in terms of a Joint Roughness Coefficient (JRC), which requires estimation or measurement of the surface unevenness, i.e., rough or smooth undulation, rough or smooth nearly planar. The JRC should be determined in the direction of anticipated block movement. Surface roughness is best determined on in-place discontinuities rather than core samples. For further detail see References 5, 6, and 13.

5.5.7.5 Voids.

Open spaces in sedimentary and metamorphic rocks are generally caused by chemical dissolution or the action of running water. Since most of these voids result from the action of groundwater, the openings are usually elongate in the horizontal plane. The size of voids, where significant, should be measured and recorded with the rock classification.

5.5.8 Formation Name

Rock units are generally known by group or formation names (i.e., Columbia River Basalt [Group], Astoria Formation, Otter Point Formation) and can be identified within project boundaries by examination of core samples, rock outcrops, and geologic literature. Where the formation name is known, it should be included at the end of the rock classification.

5.6 Field Exploration Logs

The primary roles of the field geologist or engineer are recording exploration activities on the standard form, collecting samples in accurately labeled containers, description of samples according to this manual, and transporting samples to the office or laboratory. Field exploration log data may be entered into the gINT® software at this point, although additional information including check classification and laboratory testing results make changes likely.

A field log must be produced for each exploratory boring, hand-auger hole, probe hole, and test pit. The log can also be used to describe soil and rock in cut slopes and outcrops. Soil and rock descriptions/classifications and terminology should be consistent with this manual. Abbreviations are to be avoided unless they are defined on the log form. Log forms are provided for use in the field and are printed on water-resistant media ("Rite-In-The-Rain®" or "DuraRite®"). Figures 6.1a and 6.1b display the front and back of the ODOT standard log form.

The field log must contain basic reference information at the top, including project name, purpose of the boring, location and elevation, exploration hole number, start and end dates, total depth, drilling equipment, personnel, etc. The location can be approximate coordinates (project coordinates or Lat./Long.), alignment station and offset, intersecting road names (include intersection quadrant or distance and direction), nearby roadway feature (manhole, sign support, utility/luminaire pole, etc.; include distance and direction).

The field log is a record which should contain all of the information obtained from an exploratory hole whether or not it may seem important at the time of the exploration.

On field logs. Linear measurements, depths, etc., should be measured and recorded to the nearest 0.1 foot. The total depth of drilling and date/time should be recorded in the remarks section of the log at the end of each day and at completion of the exploration.

A list/description of any instrumentation installed should be written at the end (bottom) of each exploration log.

5.6.1 Sample Logging

The log form includes columns for depth, test type and number, measured recovery, driving resistance/discontinuity data, graphic log, material description, drilling remarks, and backfill/instrumentation (Figures 5-7 & 5-8). Use of the graphic log and backfill/instrumentation columns is optional.

It is important to record all information in an accurate manner. Legibility is important. All soil and rock samples are to be fully described immediately on recovery. Referencing a previous sample is acceptable when performed thoughtfully.

The log form does not have a fixed scale, use as much space as needed for each description.

The following information is recorded for each sample.

5.6.1.1 Depth

Record the start depth of the sample.

5.6.1.2 Test Type And Number

Some common test-type abbreviations are provided on the log form. Tests are numbered sequentially by type (i.e. N-1, N-2; U-1, U-2; C-1, C-2; etc.). For drive samples, the standard 2-inch sampler is denoted "N" (N-1). A 3-inch sampler, used for recovering samples in gravel, is denoted "DM" (DM-2).

5.6.1.3 Measured Recovery

Record the length of the sample in the sampler. Generally, the length should be equal to or less than the interval sampled.

Soil

The length of the typical drive sampler is 2.0 feet. The sample interval of a standard penetration test (SPT) is 1.5 feet. Measure the sample from bottom to top, including any sample in the sampler drive shoe. If the measured recovery exceeds the sampled interval, there are several likely explanations:

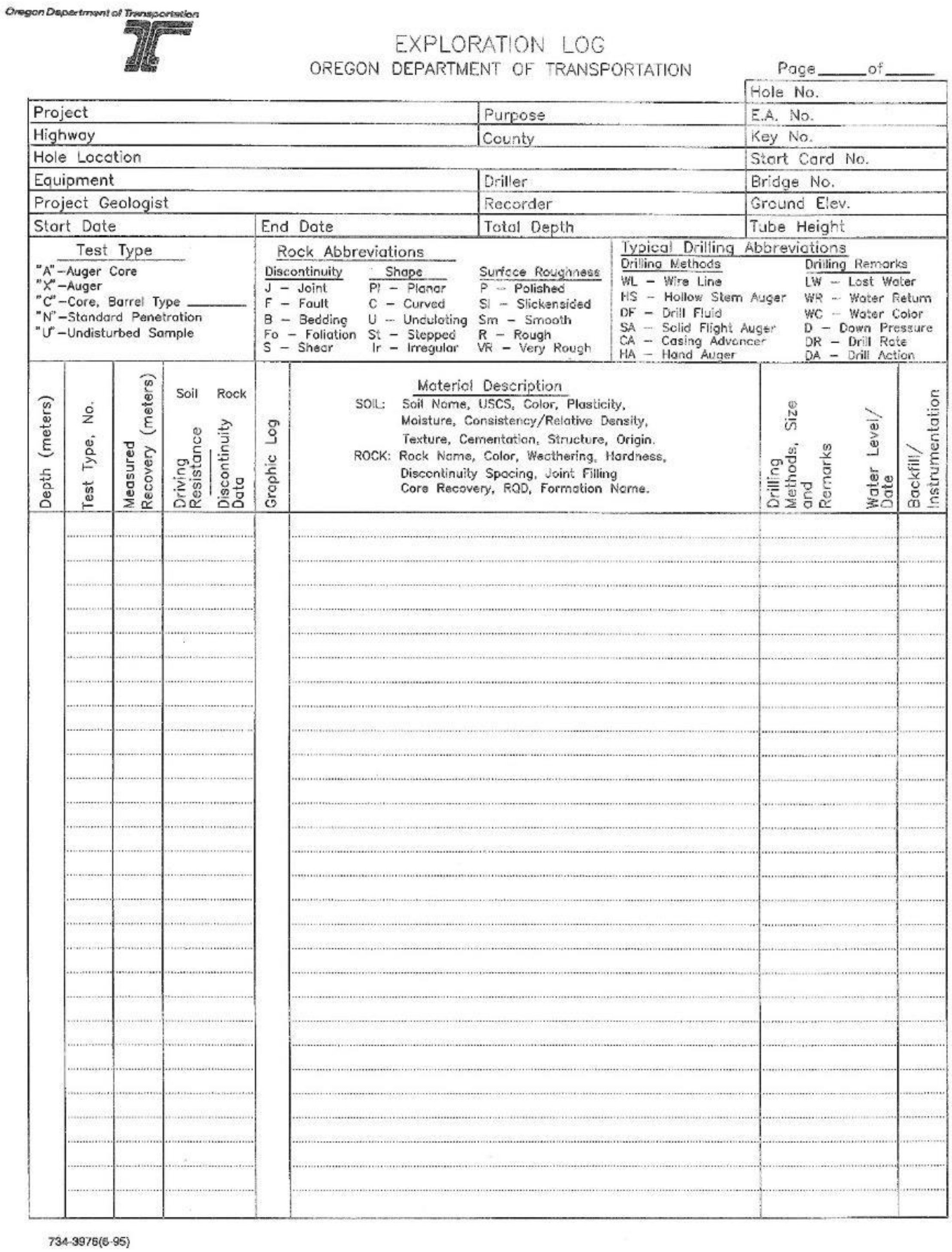
- The sampler penetrated some thickness of cuttings before reaching the test depth. This material is usually soft and/or fragmented and is easily differentiated from the actual sample. If the sampler is full, note the length of this material in the Drilling Remarks, as it can affect the observed driving resistance.
- The sampler was driven past the sample interval. This happens occasionally. If it happens frequently, the driller must take greater care during sampling.
- The soil is so soft that the sampler penetrates under its own weight and could not be stopped in time.
- The soil expanded in the sampler. This is rare and usually associated with peat or other highly organic soils. Some clays may also expand.

Rock

- The run length is the drilled/sampled interval. The length of a typical inner barrel is 5.0 feet and this defines the maximum run length. As with soil, the measured recovery is the length of the sample brought to the surface. For most rock, this is easily measured. In soft, highly fractured rock or rock-soil mixtures, reconstruct the sample to the approximate diameter of the core barrel and measure the reconstructed sample length.
- The measured recovery may occasionally be greater than the run length, especially if the run is shorter than the maximum length. This occurs when some core from the previous run remains in the barrel and is recovered during the next run and is usually due to a worn core lifter. Tool marks on the core sample may indicate where the "new" sample begins. Recovery should include only the "new" sample length. The length of the "old" sample should be recorded in the Drilling Comments and can be added to the recovery of the previous run.

5.6.1.4 Driving Resistance/Discontinuity Data

- Driving resistance refers to soil and consists of the blow-count data from the standard penetration test. The blows for each 6-inch interval are recorded in the form X-X-X, where X is the number of blows for the first, second, and last 6-inch interval. Also record the N-value, which is the sum of the blow-counts for the last two 6-inch intervals. Refusal occurs when the sampler cannot be advanced 6 inches with 50 blows. Measure the penetration and record as 50/X" or 50 for X". If the sampler bounces, the test can be stopped and the results may be recorded as above. If the sampler bounces at the start of the test, record 50/0" and the test can be stopped. Continuing the test when the sampler is bouncing will likely damage the drive shoe and will not provide any additional useful data.
- Discontinuity data refers to rock. There are two components: Rock Quality Determination (RQD) and Geological Strength Index (GSI). Determine the values of RQD and GSI as described in Chapter 5 and record them in this column.


Oregon Department of Transportation

EXPLORATION LOG

OREGON DEPARTMENT OF TRANSPORTATION

Page_____of_____

			Hole No.
Project		Purpose	E.A. No.
Highway		County	Key No.
Hole Location			Start Card No.
Equipment		Driller	Bridge No.
Project Geologist		Recorder	Ground Elev.
Start Date	End Date	Total Depth	Tube Height

Test Type
"A"–Auger Core
"X"–Auger
"C"–Core, Barrel Type ______
"N"–Standard Penetration
"U"–Undisturbed Sample

Rock Abbreviations

Discontinuity	Shape	Surface Roughness
J – Joint	Pl – Planar	P – Polished
F – Fault	C – Curved	Sl – Slickensided
B – Bedding	U – Undulating	Sm – Smooth
Fo – Foliation	St – Stepped	R – Rough
S – Shear	Ir – Irregular	VR – Very Rough

Typical Drilling Abbreviations

Drilling Methods	Drilling Remarks
WL – Wire Line	LW – Lost Water
HS – Hollow Stem Auger	WR – Water Return
DF – Drill Fluid	WC – Water Color
SA – Solid Flight Auger	D – Down Pressure
CA – Casing Advancer	DR – Drill Rate
HA – Hand Auger	DA – Drill Action

Depth (meters)	Test Type, No.	Measured Recovery (meters)	Soil: Driving Resistance	Rock: Discontinuity Data	Graphic Log	Material Description — SOIL: Soil Name, USCS, Color, Plasticity, Moisture, Consistency/Relative Density, Texture, Cementation, Structure, Origin. ROCK: Rock Name, Color, Weathering, Hardness, Discontinuity Spacing, Joint Filling, Core Recovery, RQD, Formation Name.	Drilling Methods, Size and Remarks	Water Level/Date	Backfill/Instrumentation

734-3976(6-95)

Figure 5-7 Standard log form-front

Project Name ____________ Hole No. ____________ Page ____ of ____

Depth (meters)	Test Type, No.	Measured Recovery (meters)	Soil: Driving Resistance / Rock: Discontinuity Data	Graphic Log	Material Description SOIL: Soil Name, USCS, Color, Plasticity, Moisture, Consistency/Relative Density, Texture, Cementation, Structure, Origin. ROCK: Rock Name, Color, Weathering, Hardness, Discontinuity Spacing, Joint Filling Core Recovery, RQD, Formation Name.	Drilling Methods, Size and Remarks	Water Level/ Date	Backfill/ Instrumentation

Figure 5-8 Standard log form-back

5.6.1.5 Material Description

The log form provides reminders for the components of soil and rock descriptions, in the order they should be recorded.

Soil

Soil Name, USCS, Color, Plasticity, Moisture, Consistency/Relative Density, Texture, Cementation, Structure, Origin/Formation.

Each sample description starts with the sample type and number, followed by the sampled interval:

N-3 (7.5-9.0)

Material Description/Classification as described in Chapter 5.

If more than one material type is present in the sample, use the following format:

N-3 (7.5-9.0)

N-3a (7.5-8.1)

Material Description/Classification as described in Chapter 5.

N-3b (8.1-9.0)

Material Description/Classification as described in Chapter 5.

Etc.

Each material must be placed in a separate container.

When referencing a previous sample, use the following format:

N-3 (7.5-9.0)

Silty SAND, as in N-2

Rock

Rock Name, Color, Weathering, Strength, Discontinuity Spacing, Joint Filling, Core Recovery, RQD, Formation Name.

The general formats are the same as those for soil.

Some notes on describing discontinuities/joints:

- "Discontinuity" and "Joint" are often used interchangeably. All joints are discontinuities, but not all discontinuities are joints. Fractures, partings, and faults are also discontinuities.
- Include the following for each joint set present in the core sample: spacing, attitude, separation, and filling.
- Individual, significant, discontinuities, especially faults, shall be described as above and include the depth to the center of the discontinuity, the rake of any slickensides, and a description of any gouge or filling.

- In the field, angles can be measured (preferred) or estimated. If estimated angles are recorded, those angles should be confirmed by measurement, prior to check-classification. An inexpensive plastic or metal goniometer (angle ruler, swing-arm protractor) will aid angle measurement.

5.6.1.6 Drilling Remarks

Drilling remarks are observations made during drilling in addition to sample descriptions. Subsurface conditions are not always fully characterized by depending solely on material descriptions. Therefore, any comments with regard to the character of drilling and difficulties encountered while advancing the boring should be included on the exploration log. These observations can provide valuable supplemental information for the design of foundations, excavations, performance of fills, and other geotechnical designs.

Drilling remarks may include:

- Drilling method(s)
- Obstructions
- Difficulties in drilling (caving, heaving sand, caverns, etc.)
- Loss of circulation and possible cause
- Estimated percent drill fluid return and applied pump pressure
- Color of drill fluid return
- Return drill fluid constituents
- Relative drilling down-pressure and depth of major pressure changes
- Drilling action, i.e. drill chatter, smooth, bouncy, etc.
- Length of time for each drill run
- Possible reason(s) for incomplete sample recovery (SPT, Shelby, core)
- Approximate depth to first encountered groundwater
- Artesian pressure or elevation head, and depth where encountered
- Reasons for using drilling muds, casing, or special drill bits.
- Equipment problems or breakdowns
- Hole abandonment information (materials used and depths/intervals)

5.7 Check Classification Of Soil And Rock

Check classification is a part of the overall QA/QC process (ODOT GDM, Ch. 2). Check classification is performed to provide verification of the soil and rock classifications derived in the field. Check classification also provides process improvement by detecting systematic errors in the field classifications. The check classification must be performed by an engineering geologist (preferred) or geotechnical engineer experienced in soil and rock classification and not a participant in the field logging. Typically, the check classifications are performed by the engineering geology reviewer or the project engineering geologist (if logging was performed by other staff).

Check classification compares the elements of the sample descriptions (classifications) with the samples. Notes and comments are recorded on a copy of the field log, along with the checker's name and the date of the check classification. These check classification logs should be retained as part of the project QC documentation. The results of the check classification effort should be discussed with the field personnel and the project engineering geologist.

5.7.1 Check Classification Of Soil

The checker reviews each sample description and compares it to the sample. This includes performing the appropriate field index tests. The following table outlines the general workflow for soil.

Table 5-29 General check classification workflow for soil.

Property	Comment
Color	Color may be different due to oxidation, especially in fine-grained soil. Compare to fresh material if available. Comment as appropriate.
Plasticity	Perform field test, correct as necessary.
Moisture	Compare and correct as appropriate.
Consistency/Relative Density	Check N-value and plasticity. Correct as necessary.
Texture	Compare and correct as necessary.
Cementation	Compare and correct as necessary.
Structure	Compare and correct as necessary.
Soil Name	Correct as necessary.
USCS	Correct as necessary.
Origin	Comment as appropriate.

The checker should include any observations omitted from the field description. For example, the presence of iron oxide, minor amounts of organics, mottling, odor, etc. The checker should recommend laboratory index tests in cases where the field and check classifications differ significantly. These recommendations should be noted on the check classification log.

5.7.2 Check Classification Of Rock

As with soil, the checker reviews each sample description and compares it to the sample. This includes performing the appropriate field tests. The following table outlines the general workflow for rock.

Table 5-30 General check classification workflow for rock.

Property	Comment
Recovery	Measure and correct as necessary.
Rock Name	Compare and correct as necessary.
Color	Compare and correct as necessary. May require wetting of sample.
Weathering	Compare and correct as necessary.
Strength	Compare and correct as necessary.
Discontinuity Angle, Spacing, Surface Condition/Filling	Compare and correct as necessary.
GSI	Compare and correct as necessary.
RQD	Calculate and correct as necessary.
Formation Name	Comment as appropriate.

The checker should include any observations omitted from the field description. For example, the presence of iron oxide, vesicles, mottling, odor, etc. The checker should recommend laboratory index tests in cases where the field and check classifications differ significantly. These recommendations should be noted on the check classification log.

5.8 Final Exploration Logs

Final logs incorporate the field log information, surveyed location data, check classification results, and laboratory test results. The final log may also include drilling remarks, results of specialized field tests and any instrumentation data available. The final log also includes geologic/geotechnical unit descriptions.

Final exploration logs are prepared using the gINT® software. The format of the log is standardized statewide. Each project will be recorded in a separate gINT® database. This process may have begun as part of the field exploration program, but some significant changes to this existing data should be anticipated.

Once complete, the laboratory test results are entered into the gINT program for inclusion on the exploration log where appropriate. The laboratory results are used to refine sample descriptions which then necessitate adjustments to the engineering geologic units. These changes may be simple changes to the descriptions and classifications. Adjustments to the units themselves may be needed if the lab test results require it. As the project geologist compiles the logs in this iteration, the engineering geologic units in the individual borings are complete enough to construct a preliminary or intermediate geologic model of the site. The project geologist should review the relationships between explorations in the model. Where necessary, adjustments to the units may take place based on stratigraphic position, material properties, or other engineering geologic considerations. Finally, the project engineer and geologist review the subsurface model together to consider any final adjustments to support engineering analysis.

5.9 References

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