UNITED STATES DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

Bedrock and Surficial Engineering Geologic Maps of the Littleton Quadrangle, Jefferson, Douglas, and Arapahoe Counties, Colorado

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Open-File Report 80-321

1980

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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INTRODUCTION

The text and two maps is one of a series of engineering geologic studies of quadrangles along the margin of the Front Range between Boulder and Kassler, Colo. The investigation of the Littleton quadrangle began as part of an engineering geologic mapping program supported in part by the Denver Regional Council of Governments (DRCOG). Under the same program, a report on the engineering geology of the Indian Hills quadrangle has been published (Miller and Bryant, 1976) and preliminary reports published for the Boulder and Eldorado quadrangles (Gardner, 1968, 1969) and the Golden quadrangle (Gardner, Simpson, and Hart, 1971).

This report is intended to provide technical information for geologists, engineers, consultants, and others trained in the use of geologic maps and reports. The Littleton engineering geologic map is designed for the user who is primarily interested in the physical properties of materials which are at, or a few feet below, the earth's surface. Detailed soil or geologic site investigations should be the basis for decisions involving engineering geologic problems.

HOW THE MAPS AND MAP SYMBOLS WERE DERIVED

The maps, which show the distribution of bedrock and surficial deposits exposed at the surface, are derived from the geologic map of the Littleton quadrangle (Scott, 1962) and are modeled after the engineering geologic map of the Indian Hills quadrangle (Miller and Bryant, 1976). The map units are devised to group earth materials of similar properties, many of which were determined from laboratory tests. Engineering geologic map units, therefore, may not coincide with those on the published geologic map (Scott, 1962).

The symbols used on the engineering geologic maps identify lithologic characteristics of the materials rather than the geologic name and (or) age of a particular rock formation or surficial deposit. For the surficial units, the capital letter denotes the dominant grain size; the lowercase letters indicate subordinate grain size in decreasing order of abundance. "Sc" would be read as "clayey sand," and "Sp" would be read as "pebbly sand." Symbols for bedrock units are not capitalized. Thus, conglomerate and siltstone rock is symbolized on the map as "cgl-ms."

The Pierre Shale has been subdivided on the basis of fossiliferous zones as differentiated by Scott and Cobban (1965) into zones having restricted ranges of swelling pressures. These pressures were determined in the laboratory using the technique of Lambe (1960). Rock-type symbols having three underscoring lines indicate the map units that generally are believed to have the highest swelling pressures, two underscoring lines indicate moderate swelling pressures, and one underscoring line indicates non-swelling or slightly swelling characteristics. Rock-type symbols having an overscoring line indicates the map units generally are hard and resistant. These characteristics are described below and herein in the Physical Properties and Performance Characteristics of Map Units.

TERMINOLOGY

English units of measurement are used in this report and on the map. Table 1 is intended as a guide for those who wish to convert to the metric system, The International System of Units (SI) (American Society for Testing and Materials, 1973).

DESCRIPTION OF MAP UNITS

Each engineering geologic unit contains a brief lithology description of the thickness and technical terms which are used as relative terms to describe the map units.. These terms are summarized in the Explanation of technical terms section.

Rocks and rock fragments larger than 3 in. were excluded from laboratory tests but included in the descriptions of the engineering units based on field evaluation. Laboratory tests followed the standard testing procedures described in the Earth Manual--A water resources technical publication (U.S. Bureau of Reclamation, 1974).

Table 1.--Conversion factors for converting foot-pound units to metric (SI) units

To convert	Multiply by	To find
Length:		
Inches (in.)	2.54	Centimeters (cm)
Feet (ft)	0.3048	Meters (m)
Miles (mi)	1.6093	Kilometers (km)
Pressures:		
Pounds per square foot (lb/ft^2)	0.4788	Newtons per square meter (N/m^2)
Pounds per square foot (lb/ft^2)	0.00479	Kilonewtons per square meter (kN/m^2)
Angles:		
Degrees (°)	[1°÷180]	Radians (rad)
Liquid volumes:		
Gallons per minute (gpm)	0.063	Liters per second (l/s)

Potential volume change (PVC) was determined in the laboratory on samples believed to be representative of the engineering unit. The classification of this test is from Lambe (1960), and is listed in table 2. The PVC swell index is an indicator of relative swelling potential from dry to wet state and is not necessarily the design swelling pressure. A common troublesome swelling material found in soils and certain rocks in the area is the expansive clay material commonly called "bentonite," which is composed principally of the mineral montmorillonite. Bentonite occurs in soils derived from rocks containing montmorillonite; bentonite occurs as discrete particles in certain rocks and as thin layers in several of the sedimentary bedrock map units. One such layer on the east flank of the hogback was tested and had a swell index of 9,100 lb/ft^2. Colors were determined on air-dried materials matched to color chips on the Munsell-system "Rock-color chart" (Goddard, 1948).

Table 2.--Potential volume change classification

PVC number	Category	Swell index (lb/ft^2)
Less than 2	Non-critical	Less than 1,700
2 to 4	Marginal	1,700 to 3,200
4 to 6	Critical	3,200 to 4,700
Over 6	Very critical	Greater than 4,700

FLOOD RISK AND GROUND WATER AVAILABILITY

Intense rainstorms and destructive flooding in this quadrangle and the surrounding areas extends back into pioneer days and even into Indian Legend (Follansbee and Sawyer, 1948). The floods of June 1965 (Matthai, 1969), and the rainstorm of May 1973 (Hansen, 1973), document the widespread geologic and hydrologic effects of erosion, sediment transport and deposition, and slope failure. Although the size of the area affected by local cloudbursts cannot be specifically outlined, valleys draining small and large watersheds and their downstream water courses are likely to be affected by such storms. Manmade structures or land modification on sites that are less than about 10 ft above an adjacent stream-channel floor should be carefully evaluated for likelihood of damage by seasonal flooding.

Characterization of ground-water availability in the Littleton quadrangle is from information published by the Colorado Water Conservation Board (McConaghy and others, 1964), and from this author's observations. Wells tapping permeable sedimentary bedrock units, especially sandstone and conglomerate, generally range in depth from a few hundred to a few thousand feet. Yields range from 1 to several gallons per minute (gpm) with most yields around 5 gpm.

Metamorphic and igneous bedrock units generally contain water only in fracture zones. Yields reported are generally small, usually about 1-3 gpm. The fractures are generally open to depths of about 300 ft, with very little or no water obtainable at depths greater than 400 ft.

The alluvium in the stream courses of the South Platte River and Plum Creek, yields quantities of water measured in several hundred gallons per minute. Most of the wells are shallow, generally less than 100 ft deep, and furnish good water; such water has commonly been developed for local municipality, power company, industrial, and commercial uses.

SLOPE STABILITY AND EARTHQUAKES

Rockslides and rockfalls are most common near or along the hogback in the southwestern part of the quadrangle. A few earth slides or slumps occur in roadcuts and oversteepened slopes in other parts of the quadrangle; these could be controlled with careful engineering of the cut faces (that is, engineered slopes, retaining walls to prevent or slow the infiltration of surface water). Study of specific potential slide areas is beyond the scope of this study.

Earthquakes may cause failure in areas of unstable slopes, causing rockfalls and rockslides. Earthquakes have been felt in the Littleton quadrangle area in the past, but intensities higher that VII on the Modified Mercalli scale have not been recorded, according to Hadsell (1958).

EXPLANATION OF TECHNICAL AND DESCRIPTIVE TERMS

This explanation includes items referred to in the text, references to standard test procedures followed in the laboratory, and a standard source of definitions of geologic and engineering geologic terms (Gary and others, 1974).

Lateral extent of units:

Persistent--probably extends for a few thousands of feet; may extend for miles.

Discontinuous--extends for several tens of feet; may extend for hundreds of feet.

Contacts between beds are described as:

Abrupt--in less than 1 in.

Distinct--more than 1 in. but less than 6 in.

Gradational--more than 6 in.

The surfaces of beds or layers in a unit are described as:

Even--planar to nearly planar.

Uneven--somewhat undulatory.

Very uneven--very undulatory or irregular.

The distance between bedding or foliation surfaces is described as:

Massive--partings more than 4 ft apart.

Slabby--partings from 2 in. to 4 ft apart.

Flaggy--partings from 0.5 to 2 in. apart.

Shaly--partings less than 0.5 in. apart.

Cohesiveness of materials in engineering units:

Noncohesive--nonadhering, loose.

Friable--adheres poorly, readily rubbed off by the fingers, breaks easily in the hand.

Firm--adheres well, rubbed off only with considerable difficulty.

Hard--adheres very well, does not rub off, breaks with great difficulty or may not break at all in the hands.

Other subjective modifying terminology are:

"Some," indicates an amount less than 50 percent.

"A small amount," indicates even less than 50 percent.

Particle-size terminology of Wentworth (1922) has been combined with particle-size distribution terminology of soils engineering usage as follows:

Well-graded--equal or nearly equal distribution of particle sizes from coarse to fine particles.

Moderately graded--fairly equal distribution from coarse to fine particles.

Poorly graded--almost all the particles are of one size.

Evaluation of ground-water conditions; permeability, and percolation values for septic systems and sanitary landfills are based mainly on information published by the Colorado Water Conservation Board (McConaghy and others, 1964) supplemented by some personal observations.

Subjective descriptions are used where detailed information is unavailable for individual map units but still thought to be compatible with overall general engineering geologic conditions. Thus, ease of excavation compaction and drilling are described as: easy--material yields to hand shovels, picks, and rubber-tired rollers; moderate--heavy equipment needed such as backhoes, scrapers, sheepsfoot rollers; difficult--may require blasting and use of rippers. Foundation conditions: excellent--firm rock or well-drained dense materials; good--some swelling clays and (or) poorly drained materials; poor--swelling clays dominant, slopes too steep, or water table at or near surface. Slope stability: excellent--slopes stand without support; good--slopes may collapse or need support; poor--slopes unstable.

DESCRIPTION OF PHYSICAL PROPERTIES AND PERFORMANCE CHARACTERISTICS OF MAP UNITS

Bedrock units

cs-ms HIGHLY SWELLING CLAYSTONE AND SILTSTONE--Interbedded silty claystone and very clayey siltstone; mapped in three linear zones parallel to the mountains. Combined thickness exceeds 5,000 ft. Unit is laterally persistent; surfaces even; contacts between beds gradational. Material of unit is firm, becomes friable in near-surface weathered zone; contains discrete layers of bentonite 0.25 to more than 2 in. thick. Beds dip 30°-60° E; contain many short and irregular fractures; upper and lower contacts of unit gradational. PVC rating of the bentonite is in the very-critical range. PVC rating of nine samples ranged from noncritical to very critical. Swelling pressures of the unit increase with depth; maximum swell index of 5,300 lb/ft2 measured on a sample 12 ft below the surface. Permeability negligible

Performance characteristics and possible uses--Excavation is easy down to the base of the weathered and fractured material. Compaction and drilling are easy. Foundation conditions very poor to fair because material swells when wetted, shrinks when dried; such shrink-swell characteristics are greater within the lower near-surface horizon. Slope stability good where undisturbed, or on cuts less than 20 ft high. Easily eroded by wind and water where reworked. Percolation rate slow. Generally not suitable for septic systems, good to excellent for sanitary landfills. Possible source of expanding shale for manufacture of lightweight aggregate cs-ms MODERATELY SWELLING CLAYSTONE, SILTSTONE, SANDSTONE--

Interbedded claystone, siltstone, sandstone, and conglomerate; claystone and siltstone dominant; resistant sandstone beds occur in lower part of unit; conglomerate beds occur rarely throughout unit. Thickness of unit is over 1,500 ft. Beds are several inches to 10 ft or more thick, laterally persistent in lower part of unit, discontinuous in middle and upper part of unit; lower contact gradational, upper contact with surficial materials distinct. Beds along the hogback dip from nearly vertical at base of unit to nearly flat lying in middle and upper part of unit; trend of dip is eastward. Sandstone is indurated; cemented by silica and iron oxide; fine to medium grained; forms resistant ridges where exposed. Color is light gray to yellow brown. Siltstone is medium hard where unweathered; cemented by calcium carbonate. Color is olive gray to olive brown. Claystone is moderately hard where unweathered, moderately soft to soft where weathered; cemented by calcium carbonate. Color is olive gray to olive brown. Conglomerate is hard; contains pebbles of chert, quartz, and chalcedony up to 1 in. in diameter. Color is light yellowish brown to light gray. Overall permeability of unit low to negligible; locally high in sandstone and conglomerate. Coal in lower part of unit; four beds, 2-11 ft thick

Performance characteristics and possible uses--Excavation, compaction, and drilling easy to moderately difficult. Foundation conditions generally good on sandstone or conglomerate; however, poor if structure also rests on materials adjacent to sandstone and (or) conglomerate due to possible, differential shrink-swell effects of moderately swelling claystone and differential compaction of siltstone. Slope stability poor to fair on weathered material, good in unweathered part of unit; poor where ground water seepage saturates unit. Generally unsatisfactory for septic systems; good to excellent for sanitary landfills in claystone and siltstone, poor in sandstones and conglomerate because of high permeability. Possible source of embankment material cs-ms NONSWELLING TO SLIGHTLY SWELLING CLAYSTONE AND SILTSTONE--Interbedded silty claystone and clayey siltstone, clayey shale, and silty limestone interbedded with calcareous shale and thin hard limestone beds along the east flank of the hogback. Thickness about 1,650 ft. Beds persistent laterally; surfaces even; contacts between beds mostly gradational, but some are abrupt near the hogback. Contains layers of bentonite up to several inches in thickness; a 1-foot layer of bentonite at the base of the unit near the Hogback has a PVC rating of very critical. Physical properties are nearly the same as map units cs-ms and cs-ms except that this unit has lower swelling pressures, generally below 2,000 lb/ft^2. Permeability negligible

Performance characteristics and possible uses--Similar to map units cs-ms, cs-ms except that foundation conditions are better because of the lower swelling pressures; however, only a limited number of samples were tested for this unit and it is possible that some bentonitic sections of the unit may have higher swelling pressures; site investigation recommended before building foundations cs-ms-ss MODERATELY SWELLING CLAYSTONE AND SILTSTONE--Interbedded silty claystone and clayey siltstone, sandy siltstone and clayey to fissile shale; mapped in two zones parallel to the mountains. Thickness of zones ranges from 120 to more than 1,200 ft. Physical properties are about the same as those of map unit cs-ms, except that this unit has swelling pressures generally below 3,950 lb/ft^2

Performance characteristics and possible uses--Same as highly swelling claystone and siltstone cs-ms, except that foundation conditions are slightly better because of lower swelling pressures; limited number of samples tested requires assumption that some areas of unit may have higher swelling pressures

$\overline{ss}$-ms-cs HARD SANDSTONE, AND SILTSTONE AND CLAYSTONE--Predominantly sandstone, interbedded with some siltstone, silty and sandy claystone, and some conglomerate. Uppermost sandstone, which is about 85 ft thick, forms the east side of the hogback; other sandstone, siltstone, and claystone beds crop out in the steep west slope of the hogback; beds are a few inches to as much as 30 ft thick, laterally discontinuous, surfaces even to uneven, boundaries distinct to abrupt. Beds dip 30°-35° E; contain fractures 1-12 ft apart; lower contact gradational, upper contact distinct. Sandstone is firm, massive; cemented by silica and iron oxide. Color is light brown to light gray. Siltstone is similar to the sandstone, but finer grained. Claystone is hard where unweathered, soft where weathered; dark gray to greenish gray. PVC rating of 10 samples ranged from noncritical to marginal (1 sample); swelling pressure 1,750 lb/ft^2. Conglomerate is similar to sandstone, but contains fragments of quartz, chert, and granite up to 3 in. in diameter. Color is light brown to light gray

Performance characteristics and possible uses--Generally difficult for excavation, drilling, and compaction due to steep slopes, and possible rockfalls and rockslides. Possible use of this unit as open-space and recreation area ms-cs-ls-ss SILTSTONE, CLAYSTONE, LIMESTONE, AND SANDSTONE--Interbedded siltstone, claystone, limestone, sandstone, and gypsum in lower part. Siltstone and claystone dominant; limestone beds interspersed throughout most of unit; sandstone common in upper to middle part of map unit. Beds are several inches to 20 ft or more thick. Laterally persistent to discontinuous; surfaces even to uneven. Beds dip 30°-35° E; scattered short irregular fractures in sandstone. Upper contact of unit gradational, lower contact distinct. Sandstone is firm; fine to medium grained; locally cemented by calcium carbonate near limestone beds. Color is gray to reddish brown. Siltstone is hard where unweathered; cemented by calcium carbonate and silica. Color is yellowish brown to dark brown. Claystone is hard where unweathered; weathers to silty sandy clay; nonswelling to highly swelling clay minerals present. PVC rating of four samples ranged from marginal to very critical; swelling pressure greater than 7,000 lb/ft^2 locally. Color is light gray to green. Limestone is silty to crystalline, generally hard; flaggy to massive bedding; color light gray to pink. Gypsum is soft where weathered, firm where unweathered. Color is white in fresh excavations, black on weathered outcrops. Permeability low to negligible

Performance characteristics and possible uses--Excavation and compaction easy to moderately difficult, drilling easy. Foundation conditions variable because of layers of swelling clays throughout upper part of unit--foundation investigation recommended. Slope stability good where beds dip into slope. Percolation rate slow; not recommended for septic systems; poorly suited for sanitary landfills because of steep slopes along the hogback. Source of poor-quality clay for brick and tile; some gypsum mined in the area cgl-ms CONGLOMERATE AND SILTSTONE--Conglomerate, conglomeratic sandstone, and siltstone, generally interbedded with conglomerate in western one-fourth of unit as mapped in the quadrangle. Thickness is about 2,000 ft. Beds range from a few inches to tens of feet in thickness. Beds discontinuous laterally; surfaces uneven; boundaries abrupt. Unit is hard where cemented by oxides and silica, generally friable elsewhere. Conglomerate slabby to massive; friable. Contains fragments as large as 4 in. in diameter, generally of quartz or feldspar, but also contains fragments of igneous and metamorphic rocks; sand grains are quartz and feldspar. Beds dip 60°-70° E. Lower contact abrupt, upper contact gradational vertically, and gradational where map units are intermixed. Locally, weathered zone may be silty, clayey, sandy gravel about 3 ft thick. Color is reddish brown where weathered, purplish red brown where unit consists of unweathered siltstone. Permeability low to moderate in massive rock, higher along fractures

Performance characteristics and possible uses--Excavation may require blasting. Compaction difficult, may require crushing. Drilling easy to moderately difficult. Foundation conditions excellent. Slope stability good. Generally satisfactory for septic systems and sanitary landfills in weathered zone. Possible source of fair to good quality fill ms SILTSTONE--Clayey siltstone, some siltstone and limestone. Thickness about 350 ft. Beds persistent laterally; surfaces uneven. Beds dip about 30° E; distinct upper and lower contact of unit. Color light gray to rusty red. Permeability low

Performance characteristics and possible uses--Excavation may require blasting below weathered zone. Compaction moderately difficult and drilling generally easy to moderately difficult. Generally good foundation conditions. Slope stability good; steep cuts may be hazardous (where dip of bedding and fracturing along joints may create unstable slopes). Not recommended for septic systems because of slow percolation rate, may be suitable for sanitary landfills. Possible source of fill material, depending on binder-size material in unit

$\overline{ls}$ HARD LIMESTONE--Limestone, clayey to silty; occurs as distinctive rock unit within other materials. Individual layers of about 35, 30, 15, and at least 3 ft thick comprise the mapped unit; total thickness of about 80-85 ft. Beds persistent laterally, surfaces even; contacts distinct. Hard; flaggy to massive bedding, thin shale and bentonite layers in parts of map unit east of hogback. Beds west of hogback range from 2 to about 8 in. in thickness. Beds are discontinuous to persistent laterally; contacts abrupt. Beds dip 30-60° E. Blocky to irregular fractures; upper and lower contacts distinct. Color is light gray to reddish brown. Permeability low in most places, moderate along fractures

Performance characteristics and possible uses--Excavation may require blasting. Compaction of broken rock moderately difficult; drilling moderately easy. Foundation conditions good. Slope stability good. Not recommended for septic systems and sanitary landfills because of percolation of fluids along fractures. Possible source of agricultural lime

$\overline{ss}$ HARD SANDSTONE--Sandstone and some conglomerate; conglomerate generally occurs in transition zone with underlying unit. Thickness about 190 ft. Beds a few inches to several feet thick, discontinuous laterally; surfaces uneven to even; contacts distinct to abrupt. Unit is resistant where cemented by silica; soft and friable where weathered. Massive. Sand grains mainly quartz; conglomeratic beds contain pebbles and fragments of chert, quartz, and sandstone. Beds dip 30° E; fractures several inches to several feet apart; lower contact gradational; upper contact abrupt. Color is light gray weathering to yellowish gray. Permeability low, high along fractures

Performance characteristics and possible uses--May require blasting to excavate. Large blocks make compaction difficult. Drilling moderately difficult. Foundation conditions excellent. Slope stability good; inspection of rock face in steep cuts is recommended where intersecting bedding and joint surfaces may contribute to rockfall conditions. Not recommended for septic systems because of close fractures. Poor for sanitary landfills mrx METAMORPHIC ROCK UNDIFFERENTIATED--Metamorphosed rocks rich in feldspar, quartz, biotite; includes amphibolite, quartzite and gneiss. Massive to shaly; layers persistent to discontinuous. Color ranges from pinkish white to greenish black. Weathering greatest on gentle upland slopes (less than 30°) where rock is decomposed into coarse to fine clayey sand. Permeability moderate to high in fractures and where weathered; negligible in dense rock

Performance characteristics and possible uses--Excavation, compaction, and drilling are difficult where unweathered; moderately easy to excavate where deeply weathered. Foundation conditions excellent in unweathered rock; good in weathered rock. Slope stability generally good. Resistant to erosion where unweathered; weathered material erodes easily. Percolation rate slow in unweathered and weathered rock and rapid along fractures; makes rock unit unsuitable for both septic systems and sanitary landfills. Possible source of good to high quality crushed aggregate and riprap

Surficial units

S SAND--Fine- to medium-grained sand; contains less than 10 percent silt- and clay-sized particles. Thickness less than 10 ft west of Plum Creek and as much as 30 ft east of Plum Creek and the South Platte River. Derived mainly from flood plain of nearby streams by wind. Deposit is discontinuous laterally; gradational contact at edge of pattern with map unit Csm; noncohesive. Poorly graded. Color light brown to tan. Permeability moderate to good

Performance characteristics and possible uses--Excavation, compaction, and drilling are easy. Foundation conditions generally good to excellent on flat to gentle slopes; poor on steep slopes because of lack of shear strength in unconfined state. Slope stability good where protected from storm water runoff; subject to caving and rapid erosion near stream courses during high runoff from rainstorms. Percolation rate moderate to high; suitable for septic systems, away from main water courses, poor for sanitary landfills. Possible limited source of plaster sand, and fair to good quality fill

So ORGANIC SAND--Sand mixed with organic material, and as humus and limbs and roots of trees. Layers of bouldery, cobbly material on stream floors where streams flow through coarse materials. Thickness from 4 to 15 ft. Derived from surficial and bedrock materials and generally deposited close to its source. Commonly composed of alternating beds of organic and nonorganic sand in layers from 3 to 12 in. thick. Discontinuous laterally, surfaces generally even. Contacts distinct to gradational. Materials noncohesive to slightly cohesive. Contains layers of magnetite. Color is grayish brown to red brown depending upon color of source material. Permeability high

Performance characteristics and possible uses--Excavation, compaction, and drilling easy. Foundation conditions poor because material generally covered by normal flood. Easily eroded. Generally unsatisfactory for septic systems in large stream areas; unsatisfactory for landfills because of high percolation rate. Source of soil-conditioning material where high in organic matter

Sp PEBBLY SAND--Sand containing pebble-sized fragments. Thickness as much as 25 ft, but more commonly about 5-10 ft. Derived mainly from igneous rocks (from the mountainous area to the west); reworked from colluvial and alluvial deposits and from sedimentary rocks. Well stratified in finer sandy fraction, crudely stratified in coarse pebbly fraction; discontinuous laterally; surfaces even; contacts distinct. Materials are friable to noncohesive. Moderately graded; fragments are subangular to subrounded. Surface of deposit covered by layer of humus 1-6 in. thick. Color yellowish brown to reddish brown. Permeability moderate to high

Performance characteristics and possible uses--Excavation, compaction, and drilling easy. Foundation conditions good. Slope stability good; cut slopes may stand for days without support for construction purposes. Not easily eroded except by gully wash on steep slopes. Locally satisfactory for septic systems, but high percolation rate probably makes unit poorly suited for sanitary landfills. Source of good quality sand and gravel, road metal, and fill

Scm SILTY-CLAYEY SAND--Sand mixed with clay and silt, locally some gravel. Thickness as much as 35 ft. Derived chiefly from sedimentary rocks; some material from metamorphic rocks west of the hogback. Massive; local layers of sand and gravel from 1 to 3 ft thick occur throughout, and layers of pebbles and cobbles occur in the lower part of unit; discontinuous to persistent laterally; surfaces even; contacts distinct to gradational. Friable to firm. Moderately graded. Rock fragments as large as 10 ft in diameter lie on the surface near mountains; cobbles and boulders as large as 2 ft in diameter are common. Color reddish brown to brown. Clay-enriched zone as much as 2 ft thick; calcium carbonate zone in upper part of the deposit as thick as 4 ft; some metamorphic and foliated rocks decomposed. Permeability moderate

Performance characteristics and possible uses--Excavation, drilling, and compaction generally easy except where large boulders occur. Foundation conditions good. Slope stability good. Susceptible to erosion on slopes where unprotected by ground cover. Satisfactory for septic systems. Unsuitable for sanitary landfill. Source of fair to good quality fill

Scmo ORGANIC SILTY CLAYEY SAND--Sand mixed with organic material, silt, and clay. Thickness ranges from 5 to 15 ft. Material derived from sheet erosion of soil-covered slopes deposited in layers 1-10 in. thick, discontinuous to persistent laterally; pebbles and cobbles common in lower part; surfaces even; contacts distinct to gradational. Materials noncohesive to firm. Well to moderately graded, pieces subangular to subrounded. Color gray to pale brown. Permeability moderate to high

Performance characteristics and possible uses--Excavation, compaction, and drilling easy. Foundation conditions generally good, but organic material may allow deposit to compress under load when water added. Slope stability good. Easily eroded by stream scour. Generally satisfactory for septic systems; overall permeability likely to be unsuitable for sanitary landfills. Possible source of topsoil

Smpg COBBLY, PEBBLY SILTY SAND--Sand mixed with cobbles, pebbles, silt, and a few layers of clay. From 20 to over 100 ft thick. Consists chiefly of igneous and metamorphic rock material derived locally from small intermittent streams deposited in discrete layers from a few inches to 15 ft in thickness, discontinuous laterally; surfaces generally even; silty layer generally contorted and deformed; contacts distinct. Materials friable to firm. Poorly graded bedding in lower part of material; coarse material is subangular to subrounded. Silty layers well stratified. Color is yellowish brown to reddish brown; stained with iron oxide and manganese oxide in cobbly layer. Permeability high

Performance characteristics and possible uses--Excavation, compaction, and drilling easy. Foundation conditions excellent. Slope stability good; cut slopes stand steeply without support. Not easily eroded except by gully wash on steep slopes. Satisfactory for septic systems, but high percolation rate probably makes unit unsatisfactory for sanitary landfills. Source of good quality screened aggregate, sand, embankment fill, and road metal

Scp PEBBLY CLAYEY SAND--Sand mixed with clay and pebbles, and some gravel. Thickness as much as 20 ft, commonly 5-10 ft; lower 2-5 ft generally pebble and cobble layers. Derived chiefly from sedimentary rocks, but contains igneous and metamorphic rock fragments near the mountains. Consists of layers of sand and pebble gravel 1-3 ft thick, discontinuous laterally; surfaces even; contacts distinct. Deposit is firm to hard. Moderately graded. Color yellowish brown to red brown. Clayey zone as much as 2 ft thick, has noncritical swell rating of 500 lb/ft^2; calcium carbonate cements the deposit to a depth of about 6 ft; some metamorphic and foliated rock cobbles can be crushed in the hand. Permeability moderate below clayey zone

Performance characteristics and possible uses--Excavation, compaction, and drilling easy. Foundation conditions good. Slope stability good. Locally satisfactory for septic systems; unsuitable for sanitary landfills because of moderate percolation rate. Possible source of fill and road metal

Smb BOULDERY SILTY SAND--Sand containing boulders, cobbles, pebbles, silt, and clay. Thickness from 5 to 15 ft. Derived from igneous, metamorphic, and sedimentary rocks. Deposit is layered and cobbles and boulders are locally concentrated; sand beds along Massey Draw contain scattered boulders approximately 1-2 ft in diameter; discontinuous laterally; surfaces even; contacts abrupt. Deposit is noncohesive to firm. Well to moderately well graded; rock fragments subrounded to angular. Color reddish brown to brown. Clay zone 1-12 in. thick near surface of deposit; calcium carbonate zone extends down to about 3 ft below surface. Unit is highly permeable below clay zone

Performance characteristics and possible uses--Excavation, compaction, and drilling easy to moderately easy (cobbles and boulders may interfere with drilling). Foundation conditions good to excellent. Slope stability good. Generally not easily eroded except by heavy stream and gully wash. Percolation rate rapid; generally unsuitable for septic systems and sanitary landfills; local source of water for stock tanks and domestic use. Source of aggregate, screened road metal, and fill

Msc CLAYEY SANDY SILT--Silt containing clay and sand, locally pebbly. Thickness less than 15 ft. Derived from bedrock adjacent to stream valleys. Layers generally less than 2 ft thick, discontinuous laterally; surfaces even to very uneven; contacts distinct. Deposit is noncohesive to moderately firm. Well to moderately well graded. Color tan to reddish brown. Clay-enriched upper zone well developed. Permeability moderate

Performance characteristics and possible uses--Excavation, compaction, and drilling easy. Foundation conditions good. Slope stability good. Susceptible to erosion by heavy sheet wash. Easily eroded by stream scour. Satisfactory for septic systems; because of permeability, likely to be unsuitable for sanitary landfills. Possible source of topsoil

Mops SANDY PEBBLY ORGANIC SILT--Silt mixed with sand, pebbles, and humus; organic material throughout comprises about 10 percent of deposit by volume; contains localized layers of pebbles and cobbles generally at base of deposit (near hogback) and pebbles and sand farther east of the hogback. Thickness from 1-10 ft. Derived from igneous, metamorphic, and sedimentary rocks, and surficial materials. Beds 1-12 in. thick; coarse layers near the hogback as much as 12 in. thick; east of hogback and near stream courses from fraction of an inch to several inches, discontinuous laterally; surfaces even; contacts abrupt to distinct. Deposit is slightly cohesive to moderately firm. Well-graded. Color reddish brown to brownish gray. Permeability low to moderate

Performance characteristics and possible uses--Excavation, compaction, and drilling easy. Deposit may compact when wet; slightly to very sticky when wet. Slope stability good. Easily eroded by stream scour. Locally may be suitable for septic systems and sanitary landfills. Source of organic-rich topsoil where free from stones and pebbles

Csm SILTY SANDY CLAY--Clay mixed with sand and silt and a few pebbles from adjacent units brought in by streams and sheet wash. Thickness from 5-25 ft; thickest on windward side of source areas such as stream valleys. Derived from bedrock or surficial material, transported primarily by wind. Discontinuous laterally. Deposit is noncohesive to friable. Well graded. Color light tan to light brown. Humic layer 1-6 in. at surface; clayey zone has noncritical to marginal swelling rating of 2,400 lb/ft^2. Permeability low to moderate

Performance characteristics and possible uses--Excavation, compaction, and drilling easy. Foundation conditions good where adequate drainage is provided to prevent consolidation of unit. Slope stability good. Susceptible to erosion on steep slopes by slope wash and gullying. Generally good on slope protected by vegetation cover. Marginal for septic systems, and for sanitary landfill because of moderate permeability

Rfl ROCKFALLS AND RUBBLE--Accumulation of rocks, generally loose; spaces between fragments filled with sand and silt. Thickness between 5 and 25 ft. Derived from sedimentary rocks along the hogback and from igneous rocks in the mountains. Fragments range in size from a few inches to blocks measuring several feet on a side. On east flank of hogback, unit grades into rubbly, sandy, silty, material with scattered boulders and cobbles. Thickness 1-5 ft as a loose veneer overlying bedrock unit. Discontinuous laterally; surfaces very uneven. Contacts between beds gradational. Permeability high

Performance characteristics and possible uses--Excavation, compaction, and drilling difficult to moderately difficult depending on steepness of slopes, size, and number of fragments. Foundation conditions and slope stability generally poor. Suitable for use as open land (greenbelts, recreation). Possible source of aggregate, rip-rap, and embankment fill; location on steep slopes may preclude economic uses

Ls LANDSLIDE DEPOSIT--Material composed of igneous and metamorphic rock fragments in the mountainous area; claystone and siltstone east of the Hogback. Thickness ranges from a few feet to less than 20 ft. Forms jumbled mass of coarse to fine material at foot of steep slopes or elongated mass of slumped debris on more gentle slopes

Performance characteristics and possible uses--Excavation, compaction, and drilling easy in fine-grained debris moderate to difficult in rock debris. Foundation conditions generally poor. Slope stability generally poor; excavation of slide material at toe of slide or loading of head of slide could reactivate some slides. Not easily eroded except in fine-grained material. Percolation and infiltration rates locally high. Suitable for use as open land (parks, pastures), possible source of minor amounts of fill material fe EARTHWORKS--Mixture of sand, silt, clay, pebbles, cobbles, and boulders (east of mountains), and angular rocks and other materials removed from roadcuts and other excavations (mountainous areas). Thickness ranges from about 5 ft to more than 140 ft. Includes engineered earthworks such as Chatfield dam, major highway fills, and embankments consisting of compacted layers 4-12 in. thick, and a few nonengineered embankments and dumped materials

Performance characteristics and possible uses--Excavation, compaction, and drilling generally easy, except where large rock fragments occur. Foundation stability is variable, depending upon emplaced compaction and type of structure; site investigation recommended where fills are to be more than 20 ft high. Slope stability generally good where compacted or protected by rip-rap, generally poor where loose. Easily eroded by sheet and gully wash and stream erosion where not protected

Bx BEDROCK OUTCROP, UNDIFFERENTIATED--The bedrock units that are exposed or underlie the surficial units are described and shown on Plate 1. The engineering geologic information for the bedrock units and the surficial units are shown separately on the two plates because of the variety of engineering uses in a metropolitan area. Large structures and homes with foundations that penetrate the surficial units will require a foundation design much different than that of a structure founded solely on the surficial unit. Design of foundations for a particular map unit is beyond the scope of these maps and text

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