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Preliminary report on the engineering geology of the Boulder quadrangle, Boulder County, Colorado

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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

This preliminary report is the first of a series of engineering-geology studies of eight adjacent quadrangles along the Rocky Mountain front from Boulder to Littleton, Colorado. The studies were undertaken by the U.S. Geological Survey at the request of, and in cooperation with, the Inter-County Regional Planning Commission (now the Denver Regional Council of Governments).

The purpose of these studies is to characterize the geology of the mountain front, foothills, and adjacent plains in such a manner that the geology will be of maximum value to planners, engineers, developers, and others concerned with land use.

The report is intended to serve as a guide to engineering soil and rock conditions that may be expected throughout the map area. Although the map and accompanying table and cross sections provide information of considerable detail at this map scale, they should not and do not take the place of thorough site exploration prior to construction. Both field and laboratory investigations are necessary for final site or subdivision evaluation and engineering design.

The map and cross sections, together with descriptions and interpretations summarized in the accompanying table, are based on data obtained from several sources. Most of the map data are from the geologic map of Boulder quadrangle by C. T. Wrucke and R. F. Wilson (1967). Some mapping of landslide deposits and certain surficial deposits, field evaluation of engineering characteristics of each map unit, auger drilling, sampling, and laboratory testing were done in connection with the present study to provide necessary technical information. Much of this information is included in the table. Descriptive information is included under headings on the left side of the table; interpretive information is included under headings on the right. Other data were compiled from unpublished maps and reports obtained from local private and governmental sources, and from records of the U.S. Geological Survey. R. V. Lord and Associates and William B. McDowell and Associates, both of Boulder, permitted access to their files which consisted of reports containing boring logs, test data, and engineering recommendations. The city of Boulder made available blueprints and maps containing similar data. One hundred samples of clay and clay shale were analyzed for clay-mineral content using X-ray diffraction techniques and engineering soil tests were conducted in the Geological Survey laboratory in Denver.

The following material explains some of the methods and usage in the report, gives definitions of some terms that may differ somewhat from ordinary meanings, and provides a list of useful references, some of which are cited in these notes.

Explanatory notes

This section consists of brief explanations concerning the engineering-geology map units, equivalent geologic map units, indices of bearing strength and swelling potential, criteria for septic-tank soil-absorption systems, excavation regulations of the State of Colorado, and landslide deposits.

Map units are differentiated in this engineering-geology report on the basis of texture and composition (lithology), rather than chiefly on the basis of stratigraphic succession and age as on the geologic map (Wrucke and Wilson, 1967). The name of each engineering-geology map unit is followed, in the second column of the table, by the names of equivalent geologic units and parts of geologic units. Many of the geologic units shown on the geologic map are here subdivided, subdivisions of similar lithology are regrouped into engineering-geology map units. For example, the silty part of the Slocum Alluvium plus the silty part of the Verdos Alluvium constitute the engineering-geology map unit "Silty bouldery sand and gravel (Smb)"; the clayey part of the Slocum Alluvium plus the clayey part of the Verdos Alluvium constitute the engineering-geology map unit "Bouldery gravel and clay (GCb)." Similarly, the Fort Hays Limestone Member has been differentiated from other parts of the Niobrara Formation, and the Glennon Limestone Member has been separated from other parts of the Lykins Formation. Both members are mapped on the engineering geologic map as a single map unit called "Limestone (ls)."

Some of the equivalent geologic units are biostratigraphic zones of the Pierre Shale differentiated on the basis of the contained fossil shellfish called ammonites (Scott and Cobban, 1965). These zones are continuous throughout the Pierre Shale and crop out in bands roughly parallel to the mountain front. Their composition, particularly clay minerals, and their engineering properties are also continuous laterally within the Boulder-Denver region. Gross changes in composition and engineering properties, however, take place across these zones and are commonly gradational. The gradational changes, which generally take place over a few hundred feet, make lithologic boundaries arbitrary in their location. Therefore, for reasons of convenience boundaries between many of the engineering-geology map units differentiated from the Pierre Shale were chosen to correspond to the centerline of the biostratigraphic zone nearest a gradational lithologic change.

The composition of some strata, such as the Pierre Shale and most other deposits laid in a marine sea, is persistent laterally over long distances. On the other hand, the Greenhorn Limestone is a marine deposit whose composition in the Boulder area is significantly different from that at the place where it was first studied. Near Pueblo it is dominantly a limestone as its name suggests. However, near Boulder the formation is dominantly a limy siltstone and is properly included in the engineering-geology map unit "Slightly swelling siltstone and shale (ms-sh)." The composition of deposits laid down by water flowing over the land, such as the Verdos Alluvium, is discontinuous laterally and may change within very short distances.

The engineering-geology map unit symbols are made up of rock name abbreviations for bedrock map units and textural symbols for surficial deposit map units. The symbols used are as follows:

Bedrock		Surficial deposits	
bg	- biotitic gneiss	B	- boulders
cgl	- conglomerate	b	- bouldery
cs	- claystone	C	- clay
db	- diabase or dark heavy igneous and metamorphic rocks	e	- earthwork
		f	- fill (manmade)
fr	- thoroughly fractured rock	G	- gravel
gt	- granite	LS	- landslide deposit
ls	- limestone	m	- silty
ms	- siltstone or mudstone	S	- sand
pa	- pegmatite and aplite	w	- waste implying sanitary fill
sh	- shale		
ss	- sandstone		

In addition, certain symbols are underscored, others overscored, to emphasize particular engineering characteristics. In the map-unit "Highly swelling claystone and siltstone (cs-ms)" the symbol is underscored three times because rocks of this unit generally have a high potential for swelling when wetted. Similarly, in the map unit "Moderately swelling claystone and shale (cs-sh)" the symbol is underscored twice because rocks of this unit have a moderate potential for swelling when wetted, and in "Slightly swelling siltstone and shale (ms-sh)" the symbol is underscored only once because these rocks have only a slight potential for swelling when wetted. The sandstone symbols ss and ss-ms-cs are overscored because the sandstones of those particular map units are harder than the sandstones of other map units.

Information included in the descriptive columns of the table emphasizes these properties and other features that are most significant in interpreting the general engineering behavior of each engineering-geology map unit. The bearing strength, classification, and swelling potential of engineering soils are essential parts of such information.

Relative density of granular soils and consistency of clayey soils are indices commonly used with other criteria to interpret the bearing strengths of engineering soils. Relative density and consistency of engineering soils are determined by a resistance to penetration of the soil. Data on resistance to penetration were here compiled in terms of Standard Penetration Resistance (Terzaghi and Peck, 1948, p. 265), a field test generally made with standard soil-sampling tools. A hollow cylindrical sampling tool, 2 inches in outside diameter, is driven into the subsoil by a 140-pound hammer. The fall of the hammer is 30 inches. The Standard Penetration Resistance is measured by the number of blows of the hammer required to drive the sampling tool 1 foot into the subsoil. The following table shows the relation of bearing strength to standard penetration resistance, together with relative density and consistency (modified from Terzaghi and Peck, 1948, p. 294 and 300).

Bearing strength	Granular soils (sand and gravel)		Clayey soils (clay and silt)	
	Standard penetration resistance (blows per foot)	Relative density	Standard penetration resistance (blows per foot)	Consistency
Very low	Less than 4	Very loose	Less than 2	Very soft
			2 - 4	Soft
Low	4 - 10	Loose	4 - 8	Medium
Moderate	10 - 30	Medium	8 -15	Stiff
			15 -30	Very stiff
High	30 - 50	Dense	30 -100	Hard
Very high	Over 50	Very dense	Over 100	Very hard

Where practical, descriptions of surficial deposits and weathering products of bedrock units include capitalized letters in parentheses (e.g., GM, GW). The letter combinations are Unified Soil Classification symbols as adopted by the U.S. Army Corps of Engineers (1953). This classification is based on grain size, size gradation, plasticity, and compressibility of engineering soils. Few such data were available for classifying soils in the Boulder area, but the classifications given are believed to be generally representative of the engineering-geology map units.

The dominantly clay shale formations (Graneros Shale, Greenhorn Limestone, Carlile Shale, Smoky Hill Member of the Niobrara Formation, and Pierre Shale excluding the Hygiene Sandstone Member) are subdivided and regrouped into four engineering-geology map units. The four units are classified according to lithology and the potential of their rocks for swelling when wetted and, therefore, according to the potential for damaging light structures such as homes, concrete floors, and pavements. The potential for swelling was interpreted from laboratory tests including X-ray diffraction analysis of mineral content, Atterberg limits tests, and the PVC (potential volume change) test of Lambe (1960).

Results of PVC tests for some engineering-geology map units are included in the tables under the heading "Other features." PVC tests were made on air-dried remolded samples in the U.S. Geological Survey laboratory in Denver. The PVC rating category, and swell index as established by Lambe (1960, p. 30 and fig. 20) are as follows:

PVC rating	Category	Swell index (pounds per square foot)
Less than 2	Noncritical	Less than 1,700
2-4	Marginal	1,700-3,200
4-6	Critical	3,200-4,700
Greater than 6	Very critical	Greater than 4,700

PVC swell-index data are used as indicators of relative swelling potential and should not be interpreted as absolute swelling pressures for engineering-design purposes.

Suitability of an engineering-geology map unit for septic-tank soil-absorption systems is related chiefly to the capacity of that unit to absorb the effluent. Percolation tests (U.S. Department of Health, Education, and Welfare, 1967, p. 4) as interpreted by the State of Colorado and most local health authorities are summarized in the following table.

Percolation rate (minutes per inch)	Percolation test evaluation	Suitability for septic systems
Less than 30	Too fast	Unsatisfactory
30-60	Satisfactory	Satisfactory
60-90	Marginal	Generally unsatisfactory
Greater than 90	Too slow	Unsatisfactory

In addition, conditions are generally unsatisfactory where impervious rock or the water table is within 7 feet of the surface, where the conditions of slope and rock structure are such that effluent may emerge as seeps on the slope or where the introduction of water may cause problems related to slope stability. Interpretations of the engineering-geologic aspects are based chiefly on the texture and structure of the deposits and rocks, together with a small amount of percolation test data.

In the table, the heading "Slope stability" refers to stability in relation to slope failure and landsliding and not to resistance to erosion. A statement of requirement of "support or 45° repose in excavations" is included where appropriate because of the resolution concerning "Rules and Regulations Governing Excavation Work, section 1, paragraphs 1-8," adopted by the Industrial Commission of Colorado on August 23, 1966.

Landslide deposits are masses of different sizes composed of earth, rock, manmade fill, or some combination of these, that have moved downslope from a former position. In this quadrangle they include deposits resulting chiefly from ancient massive rock slides, slumps, debris slides, and debris flows.

Recognition of landslides is based chiefly on topographic and geologic evidence. Topographic evidence includes pressure ridges, head-scarp fissures, head scarps, undrained depressions, hummocky terrain, benches, and level places (commonly grass covered) at the base of scarps. Geologic evidence includes displaced strata (commonly with the surface of sliding subparallel to the dip of the strata), disturbed earth and rock, ground-water seeps and springs, exposed surfaces of sliding, and polished and striated clay surfaces (slickensides). Additional evidence includes tilted trees, curved fence and road alinements, and broken utility lines. Not all landslide deposits are readily identified, especially if they have been stable for many years, because their most distinguishing features are in time concealed, modified, or obliterated. Some old landslide deposits, therefore, may not have been mapped, especially where exposures are poor or absent.

A landslide mass moves along a surface of weakness such as a bedding plane, bentonite surface, clay-filled fracture, or water-lubricated bedrock surface. Generally, it moves because the natural forces which tend to hold the mass in place become less than those forces which, under the influence of gravity, tend to drive the mass downslope. Forces tending to hold the mass in place are weakened by such changes in environment as an increase in water in the subsoil and removal of supporting material from the downhill part of the mass, or they may be overcome by the addition of weight to the uphill part of the mass.

Landslide deposits are a record of past slope failures; relationships to other deposits and ancient soils suggest that most of these failures in the Boulder quadrangle occurred thousands or even tens of thousands of years ago. The landslide deposits are not of themselves proof of present or future slope instability because most of the slope failures probably occurred under a different climatic environment than exists today. Under present natural environmental conditions, including climate, most landslide deposits in this quadrangle are stable; a few small landslides are active, or were recently so.

Each landslide or landslide deposit poses a separate problem. If its present environment is changed indiscriminantly by man, unstable conditions may result. In order to provide information needed for the mitigation or elimination of a potentially hazardous condition, a detailed geological and soil engineering study, including a subsurface investigation, is recommended before development of any areas mapped as "Known," "Possible," or "Inferred landslide deposits (LS)."

Caution is advised also in all sloping areas underlain by surficial deposits or bedrock units that are known or inferred to have failed elsewhere by sliding, especially those sloping areas underlain by claystone and mantled by "Pebbly sand, silt, and clay (SCp)," "Sandstone blocks (B),", or "Earthwork (fe)."

Definitions

Definitions of certain terms that are used explicitly or extensively in this report follow:

Caliche. (kuh-Lee-chee). A white to very light-grayish-brown calcium-carbonate-enriched layer commonly present within a subsoil composed of silt, sand, and gravel. The caliche is deposited in the subsoil as a result of the evaporation of calcium-carbonate-charged soil moisture.

Dip. The angle which a stratum, layer, dike, vein, fissure, fault, or similar geologic feature makes with an imaginary horizontal plane, as measured in a plane perpendicular to the strike.

Dip slope. A sloping surface of the land that conforms approximately with an inclined bedding surface of the immediately underlying rock. A dip slope is usually formed by erosion of weaker rocks and controlled by an exceptionally hard bed.

Foliation. Layering, banding, or lamination of metamorphic rock that resulted from segregation of dark and light minerals during metamorphism.

Hardpan. A hard impervious layer, usually just below the surface of the ground, enriched in clay during the formation of an ancient soil.

Hogback. A sharply crested ridge formed by resistant rock strata that are steeply inclined.

Infiltration. The entry of rainwater or snow water from the ground surface into surficial deposits, bedrock, or weathered bedrock. Commonly expressed in terms of rate of infiltration. The rate of infiltration of different materials is compared under similar conditions of slope, soil moisture, and vegetation.

Overconsolidated. A condition, especially of clay shales, wherein materials have been subjected to pressures greater than those presently imposed by existing overburden. Higher pressures generally were imposed by a formerly thick cover of sedimentary rocks now eroded from the area.

Permeability. The capacity of materials to transmit water under pressure of gravity.

Percolation. As used in this report, the entry of water into a pre-saturated material through an artificial opening in that material. Commonly expressed in terms of rate of percolation and inferred for percolation tests performed at a site to determine the suitability of a material for septic-tank soil-moisture systems.

Soil creep. The slow, generally imperceptible, movement of slope-forming earth material from a higher to lower position.

Solifluction. The slow flowage of water-saturated slope-forming soil and other loose earth material from a higher to lower position.

Strike. The compass direction of an imaginary line formed by the intersection of a stratum, layer, dike, vein, fissure, fault, or similar geologic feature with an imaginary horizontal plane.

Water table. The upper surface of unconfined ground water. Unconfined ground water will stand in a well at this position.

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