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Preliminary Engineering Geologic Map of the Morrison Quadrangle, Jefferson County, Colorado

By

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This report is the fifth of a series of engineering geologic studies of quadrangles along the margin of the Rocky Mountains between Boulder and Littleton, Colo. The work was part of an engineering geologic mapping project requested by the Denver Regional Council of Governments (DRCOG), (then the Inter-County Regional Planning Council) and formerly supported cooperatively by the DRCOG and the United States Geological Survey (USGS). Preliminary reports on the engineering geology of the Boulder quadrangle, the Eldorado Springs quadrangle (Gardner, 1968, 1969[1/]), and the Golden quadrangle (Gardner and others, 1971) have been placed by the U.S. Geological Survey in files open to the public or published.

The chief purpose of the report is to describe the geologic units present in this quadrangle in terms understandable to persons concerned with land use and construction. The map is a guide to the engineering characteristics of the various surficial and bedrock units, and their probable engineering suitability for various uses.

The information presented is necessarily somewhat generalized, and the map, cross section, and tables do not provide an adequate basis for determining exact characteristics at specific localities. Detailed field examination and laboratory investigations by qualified engineering geologists and civil engineers may be necessary for final site or subdivision evaluation.

The report consists of this text, an engineering geologic map with one cross section and an explanation, and three tables. The report is based on several sources of information. Basic geologic data are mainly from published reports by LeRoy (1946), Reichert (1954), Smith (1964), Gable (1968), Scott (1972a-f), and Van Horn (1972, 1976). Fossil zones of the Pierre Shale were described by Scott and Cobban (1965). Descriptive terms for the density or consistency of the surficial deposits and the sedimentary bedrock, and for the classification of these materials, were obtained from reports prepared for clients by consultants in engineering geology and soils engineering. Other geologic data were obtained by the authors of this report through field examination of the various materials and the analysis of samples believed to be typical in character in laboratories of the U.S. Geological Survey.

The tables and this text initially were drafted by Stephen S. Hart, the author of the map, and were prepared for publication by Howard E. Simpson.

[1/]Bibliographic references by author and year are included in the selected bibliography at the end of this report, together with a list of places where the references and topographic-quadrangle base maps may be studied or purchased.

How to use this report

This report is prepared so that useful geologic information can be derived from it by persons with little or no geologic background. A simple procedure for its use is outlined below.

1. Locate on the map the site, parcel of land, or area in which you are interested; note the multiple-letter symbol or symbols in that part of the map. (Reference to the cross section may help the reader understand the three-dimensional distribution of the units that the symbols represent.)

2. Find the same letter symbols in the three columns of boxes in the upper part of the Map Explanation; the name of each engineering geologic map unit is immediately to the right of each box.

3. The heading of each column of boxes indicates the main group of rock or loose earth materials to which a particular map unit belongs; thus it indicates which of the three large tables contains engineering geologic information about the map units in that column. Determine which table you need.

4. On the appropriate table for a particular group of map units, locate in column 1 the name and symbol of the map unit or units in which you are interested.

5. Determine the characteristics of the map unit or units in the several boxes that lie to the right across the table.

6. Because the map shows the distribution of both bedrock map units and the overlying surficial map units, for most localities you will want to determine whether both kinds of map units are present. Symbols of surficial units start with a capital letter. Symbols of bedrock units consist wholly of lowercase letters. For some localities reference to all three tables may be required to obtain information about the several map units present.

Most sedimentary bedrock units extend continuously along the mountain margin until interrupted or cut off by a fault. In many places, however, the units are hidden beneath mantling surficial deposits. Knowledge that the sedimentary bedrock units are essentially continuous enables the map user to infer the extent of those units beneath the surficial deposits; the hidden contacts are generally indicated by dotted contact lines.

Explanatory notes

The engineering geologic map.--Map units on this engineering geologic map are differentiated solely on the basis of texture and composition, whereas map units on basic geologic maps are differentiated chiefly on the basis of geologic age as well as texture and composition. In the manner of a basic geologic map this engineering geologic map shows the area or areas underlain by each engineering geologic map unit. The thin line that encloses each engineering geologic map unit represents the trace of the contact of one unit with adjoining units. Where dashed or queried the lines represent contacts that are less accurately located than those represented by continuous lines.

Dotted lines represent the interpolated position of a contact where hidden beneath an overlying surficial deposit.

A heavier line on the map represents the trace of a fault. These lines are continuous where the location is accurately known, dashed where less well known, and dotted where covered.

Map-unit symbols consisting of two or more letters identify the map unit present in each area on the map. Symbols that consist of a capital letter followed by lowercase letters represent surficial units. The capital letter denotes the dominant texture, the lowercase letters indicate qualifying compositional or textural terms. Thus a particular texture, clay for example, is represented by "C" if dominant, or by "c" if a qualifying term. These symbols are based on the Unified Soil Classification (USC) (U.S. Army Corps of Engineers, Waterways Experiment Station, 1953). Symbols that are wholly lowercase letters represent bedrock units and are patterned on rock names commonly used by engineers.

The letter symbols used on the map and cross section are derived from the soil and rock symbols listed below:

c, clay	cs, claystone	bg, biotitic gneiss
m, silt	sh, shale	gg, granitic gneiss
s, sand	ms, siltstone	bd, dike rocks
g, gravel	ss, sandstone	b, basaltic lava flow
c, cobbles	cgl, conglomerate	g, granitic rocks
b, boulders	ls, limestone	fr, thoroughly fractured rock

The symbol for a landslide deposit consists of the two capital letters LS, commonly accompanied in brackets by one or more other symbols, such as the symbol for the engineering geologic unit that slid. Thus a landslide deposit is a geologic feature rather than an engineering geologic unit. The meaning of the various symbols that may accompany an "LS" is given on the map explanation.

Various graphic symbols represent some characteristic or feature situated at the position of the symbol on the map. Many of the lines, symbols, and names on the map are part of the topographic quadrangle base map on which the engineering geologic map is drawn

The map explanation.--The map explanation shows the letter symbols for each engineering geologic unit on the map, grouped into three columns corresponding to the three principal categories of surficial materials and bedrock. The name of each unit is immediately to the right of the box containing its letter symbol. This upper part of the explanation is a key to cross referencing between the map and the tables.

The lower part of the explanation explains the letter and other graphic symbols shown on the engineering geologic map; each is followed by a brief explanation of the feature or characteristic represented. Additional information about the significance of some of these symbols is found below in the discussion of the engineering geologic tables.

The geologic cross section.--A single geologic cross section portrays the inferred subsurface relations of the map units present along a typical line on the map. The interpretation is based on surface observations and subsurface information obtained from auger holes, excavations, and drilling logs. The profile is drawn at the same horizontal scale as is the map: 1 in. = 2000 ft; there is no vertical exaggeration.

The engineering geologic tables.--The engineering characteristics of each unit shown on the map and cross section are summarized in the three tables. The characteristics of surficial-materials units are summarized in table 1, those of the sedimentary-bedrock units in table 2, and those of the igneous- and metamorphic-bedrock units in table 3. The first five columns of each table are essentially descriptive; the remaining eight columns are mainly interpretive. The following comments may help clarify certain aspects of each column.

Column 1: Engineering geologic map unit and symbol

The name of the engineering geologic map unit reflects its lithologic character, which is described in greater detail in column 3. If a unit on this map can be traced into an adjacent quadrangle, the unit there may have a different name and symbol if its character there is different. Such changes may be made most practically at the joint quadrangle boundary. The origin of the letter symbols is discussed on pages 3, 11, and 12 of these explanatory notes, and the meaning of underlining and overlining is on the map explanation.

Column 2: Equivalent geologic map units or parts of units

The name of each engineering geologic unit in column 1 of each table is followed in column 2 by the name or names of equivalent geologic units or parts thereof as used in selected, published, geologic reports and maps of the area.

In order to best group the materials according to their engineering characteristics, some units on the geologic map were subdivided into two engineering geologic units. In other cases geologic units or parts thereof were combined into a single engineering geologic unit.

Some of the equivalent geologic map units named in column 2 are the fossiliferous zones of the Pierre Shale as differentiated by Scott and Cobban (1965). These zones are continuous downdip, trend roughly parallel to the mountain front, and lie east of the hogback. Within a single fossil zone the clay-mineral composition and particle-size distribution are essentially uniform, but the changes in these characteristics and therefore changes in engineering properties, between the zones, are gradational. The engineering geologic unit contacts thus are drawn, somewhat arbitrarily, parallel to boundaries between the fossil zones.

Column 3: Physical character of the map unit

A brief description of the more significant visible textural, compositional, and structural characteristics, as well as some test data together with evaluations thereof, is given in this column.

a. Lithology: Generally defined as the composition and physical character of rock or earth materials. The dominant type of rock or surficial material is listed first, accompanied by modifying terminology; other major types are then listed in order of decreasing quantity, with their modifiers. This sequence is generally inferred from field observation. Minor additional types of materials then are listed, if present; "some" indicates a distinctly lesser quantity, "a little" indicates considerably less.

The pairs of capital letters enclosed in parentheses indicate the known range in classification of the material (soil) according to the Unified Soil Classification (U.S. Army Corps of Engineers, Waterways Experiment Station, 1953) commonly used by soils engineers and others. Classifications were reported by various private consulting firms and are based on their laboratory tests using standardized methods. Understanding of the symbols is not necessary to understanding and using the map or tables.

b. Subunits: Mappable, separated parts of a map unit. They have the same or similar characteristics.

c. Thickness: The dimension of a unit, subunit or bed measured perpendicular to its contacts or bedding surfaces.

d. General character: Those physical properties that are common to all subunits or lithologies described; these properties are not repeated under each subsequent subheading.

e. Bed: A constituent layer of a sedimentary or surficial unit or subunit that is too thin to map. A bed is essentially homogeneous in composition, texture, internal structure, and color. Somewhat comparable components are present in the metamorphic rocks, where dissimilar bodies that differ in size, form, and composition present can be too small to differentiate on the map or to characterize in the table.

f. Bedding boundaries: A minor interface that represents the dividing surface between two successive layers of sediment or of sedimentary rock. A bedding boundary is not shown on the engineering geologic map, but it can be characterized by describing the rate of change from one bed to the other, and the form of the interface. The same terms are used for describing contacts and are listed there under subhead q, below.

g. Lateral extent: Beds generally are lenticular in form, and pinch out both along their strike and down their dip. They are classified here as:

Term	Value
Persistent	probably extend for more than 2000 ft along strike
Discontinuous	probably extend for less than 2000 ft along strike

h. Grading: The relative content by weight of standard size classes of particles in surficial deposits and sedimentary bedrock. Grading is classified as follows:

Well graded	-	having an approximately uniform distribution of particles in sizes from coarse to fine.
Moderately graded	-	having a fair distribution of particle sizes: some sizes more abundant than others.
Poorly graded	-	having a poor distribution of particle sizes: most particles of about the same size

i. Overconsolidation: Consolidation, especially of fine-grained sedimentary rocks, that is greater than normal for the existing overburden. The overconsolidation is a result of the pressure of overburden that has since been removed by erosion. The now-overconsolidated rocks originally adjusted to the formerly greater load by the squeezing of water from pore spaces in the rocks with an accompanying compaction that resulted in a decrease in the ratio of voids to solid material.

Overconsolidation is an expectable characteristic of the claystone and clay-shale beds, and to a lesser degree of the clayey siltstone beds, in the sedimentary bedrock units.

For each of the sedimentary bedrock units the weight of the overlying sediments, or loading, once consisted of the entire sequence of geologically younger strata. Because the strata became tilted and raised along and near the mountain front, erosion removed much or all of this former load. Other younger deposits subsequently accumulated on the sedimentary bedrock units, but these younger deposits are now partly eroded. Their thickness, and thus their weight, is much less than that which lay on the units at an earlier time.

Therefore the degree of overconsolidation generally is least in the geologically younger units, and increases with increasing geologic age. Thus the degree of overconsolidation may be expected to be lower for units that are at or near the ground surface in much of the eastern part of the quadrangle, and to be greater for those units near the mountain front.

An approximation of the ratio of former loading (the former thickness of overlying strata) to present loading (the present thickness of overlying strata and younger deposits) may be significant. For geologically younger strata such as beds in the upper part of the Pierre Shale or the Laramie Formation, the ratio is roughly 10:1. For older strata such as beds in the lower part of the Pierre Shale, or the Morrison Formation, the ratio might be as great as 100:1.

Rock that has been overconsolidated tends to rebound when the load causing the overconsolidation is removed. The overconsolidation ratios above indicate that there is considerable difference in the degree of overconsolidation of strata in the Morrison quadrangle, and that most of the overconsolidated strata are greatly overconsolidated. This means that they possess the potential for rebound should their degree of confinement be reduced, as by excavation. The rebound can be sufficient to cause heaving of a building foundation, with damage a possible result.

Two factors can tend to modify the amount of rebound that can occur at a locality. One factor is the amount of swelling clay present (see items m: Clay minerals, and n: Potential volume change (PVC), below). Swelling clay tends to magnify rebound, but because the amount and kind of clay can differ locally, its affect on rebound can differ locally. The other factor is the tilted attitude of strata near the mountain front. Rebound tends to be greatest parallel to the loading stress, but in the opposite direction. As the strata were originally flat-lying, the tendency is for rebound to be perpendicular to their contacts and bedding surfaces. Because the strata have been tilted since overconsolidation, an excavation does not release fully the rebound stresses present; they remain partly confined.

Rebound does not appear to be a significant problem in this quadrangle. There are two reasons. One is the physical limitation on rebound just described above, the other is that well-designed lightweight structures now are built with grade-beams spanning caissons. Therefore the disruptive stresses of both rebound and expansive clay are avoided with the same foundation design.

j. Foliation: Schistosity and mineral layering imparted to a metamorphic rock by the parallel orientation of platy and ellipsoidal mineral grains or by the segregation of minerals into parallel layers of differing composition, or by differences in compositional layering in the materials present before metamorphism. Such layering may cause planes of weakness, especially in micaceous schists and gneisses.

k. Cementation: The binding together of sediments or shattered rock by the deposition of a natural cement in pores or fractures. Cementation is important because it increases the strength of the rock and decreases permeability. The amount of increased strength depends on both the kind and amount of cement. Cements in geologic materials of the Morrison quadrangle are, in order of relative decreasing strength, silica ("quartz"), calcium carbonate ("lime"), iron oxides, and clay minerals. In general, the strength of a cemented rock increases as the amount of a given cement increases. Clay-cemented rocks may be weakened if the clay becomes wet.

l. Relative density and consistency: Indices commonly used with other criteria to interpret the bearing strength of soils. Relative density indicates the closeness of packing of material in the sandy or gravelly soil classes (coarse-grained soils) of the Unified Soil Classification (U.S. Army Corps of Engineers, Waterways Experiment Station, 1953). Consistency represents the resistance to deformation of material in the clayey or silty soil classes (fine-grained soils) of that classification (Terzaghi and Peck, 1948, p. 265). These characteristics are determined using the Standard Penetration Test (ASTM D1586, in American Society for Testing and Materials, 1964), in which is found the number of blows of a 140-lb hammer, dropping 30 in/blow, that is required to drive a hollow, cylindrical sampling tool 2 in. in outside diameter, 1 ft into soil. The test is specific, but in actual practice is used, and the results evaluated, without consideration of the affects of weathering, interparticle friction that may occur, or cementation that may be present. 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	Coarse-grained soils (sandy and gravelly soil classes of of the USC (U.S. Army Corps, Waterways Experiment Station, 1953))		Fine-grained soils (clayey and silty soil classes of the USC (U.S. Army Corps, Waterways Experiment Station, 1953))	
	Standard penetration resistance (blows per foot)	Relative density	Standard penetration resistance (blows per foot)	Consistency
Very low	<4	Very loose	<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	>50	Very dense	>100	Very hard

m. Clay minerals: Complex compounds composed mainly of hydrous aluminum silicates, and characterized by platy molecular structure. Certain kinds of clay minerals expand on wetting because of the adsorption of water between the plates, and shrink on drying because of loss of that water. The change in volume that results may cause damage, especially to light structures such as houses, concrete floors, and pavements. The amount of volume change that occurs depends not only on the kinds and amounts of clay minerals present, but also on the amount of water adsorbed and the amount of calcium carbonate ("lime") in the material.

There are four kinds of swelling-clay minerals. Of these montmorillonite undergoes the greatest percentage change in volume, mixed-layer illite-montmorillonite somewhat less, illite still less, and kaolinite the least. As more than one kind of clay mineral can occur in a deposit, the relative amounts of the different kinds of clay minerals present is important.

n. Potential volume change (PVC): The potential for the swelling of clay caused by the adsorption of water can be approximated in the laboratory by several methods with differing degrees of accuracy. For this map the swelling potential of clay-rich sedimentary material has been approximated by combining data obtained using the Unified Soil Classification (U.S. Army Corps of Engineers, Waterways Experiment Station, 1953), the PVC test (Lambe, 1960), and X-ray diffraction analysis of clay-size material (Schultz, 1964). The classification of the data follows that of Lambe:

PVC rating	Category	Swell index (lb/ft^2)
<2	Noncritical	<1700
2-4	Marginal	1700-3200
4-6	Critical	3200-4700
>6	Very critical	>4700

Pressures exerted by swelling clays in the Morrison quadrangle differ from one map unit to another, and can differ in a single unit from one part of the map area to another. At present the maximum reported swelling pressure in this quadrangle is about 8000 lb/ft^2. This is enough to cause serious damage to a 2-story brick structure. However, if the potential swelling pressure is determined by an engineering geologist or soils engineer, a building foundation can be designed to avoid significant damage. This is desirable for several map units east of the mountain front.

Commonly the solution used is the placement of grade beams on caissons in holes drilled into unweathered bedrock; this places sufficient structural load on a small area to resist heave of the expansive clay, and may also serve to reduce rebound. (See Overconsolidation, paragraph i above.) If 10 percent or more of a foundation soil is calcium carbonate ("lime"), the potential for swelling is reduced significantly. Thus the presence of calcium carbonate or its addition to an expansive soil, can be beneficial. (For additional information see Scott, 1972c.)

o. Attitude: The position of a planar feature relative to the horizontal, expressed quantitatively by both strike and dip measurements made at a given point on the earth's surface. Attitude is represented on a map by a strike-and-dip symbol. If such a symbol were used to describe a sloping roof, the strike line, the longer line of the symbol, would be parallel to the ridgepole. The dip line, the short line perpendicular to the strike line, would point down the slope of the roof. The number beside the strike-and-dip symbol would give the amount of the dip, or inclination of the roof, in degrees. If the rock layer has been bent so that it is overturned, a somewhat U-shaped dip line is used for the overturned part.

p. Jointing: Joints are more or less planar fractures which lack apparent relative displacement of the two walls in any direction parallel to the wall surfaces. Joints may be random in orientation, but may constitute one or more sets, wherein a set includes all those joints of similar attitude. Various physical features may be used to characterize joints; values given herein are estimated.

Feature	Value
degree of	approximate
openess	opening
inconspicuous	<0.25 in.
conspicuous	>0.25 in.
lateral continuity	approximate length
short	<10 ft long
extensive	>10 ft long
lateral spacing	variation
irregular	obvious
regular	consistent
orientation	similarity
random	little to none
ordered	moderate to great
relative number	approximate distance
few	>15 ft
numerous	<15 ft

q. Contact: An interface that represents the boundary between map units and subunits; it is shown on the engineering geologic map by a thin line. A contact may be drawn at the position of a change in lithology, or it may be drawn arbitrarily at a specific position in a stratigraphic sequence. A description of a contact can characterize the rate of change from one unit to another, and the form of the interface. The same terms can be used for describing bedding boundaries.

Factor	Value
rate of change:	approximate distance:
abrupt	in <1 in.
distinct	in >1 in. but <6 in.
gradational	in >6 in.
form:	approximate degree:
even	planar to nearly planar
uneven	undulatory
very uneven	irregular

Column 4: Topographic expression

The form of the land surface in the Morrison quadrangle is mainly the result of erosional processes acting on tilted layers of sedimentary and metamorphic rocks that differ in composition and other physical characteristics, and partly the result of the deposition of eroded material in valleys and on broad surfaces.

Relatively weak, nearly flat-lying rocks such as claystone, shale, and siltstone underlie most of the gently rolling plains area, whereas more resistant igneous and metamorphic rocks underlie the rugged area of the mountain margin. In the foothills area between the mountains and plains, tilted beds of very resistant sandstone and conglomerate caused the prominent hogback, while less resistant tilted rock units form low, indistinct ridges on either side. South Table Mountain consists of a nearly flat-lying cap of highly resistant igneous rocks lying on relatively thick weak rock. Green Mountain is somewhat similar, but the erosion resistant cap of Green Mountain is composed of permeable sand and gravel.

Other significant although less obvious landforms in the quadrangle are basically constructional rather than erosional. Stream-laid materials constitute most of the surficial deposits. They are characterized by broad nearly flat surfaces between present streams, terraces along and within the valleys of the principal streams, and the floors of most drainage routes.

<u>Column 5</u>: <u>Weathering and weathering effects</u>

Weathering refers to the physical disintegration and chemical decomposition of rock and earth materials to yield finer grained materials generally called soil. Most geologic units weather extremely slow in terms of a human lifetime.

The noun "soil" has come to have at least two significantly different uses. To the agriculturalist, soil is the loose surface material of the earth in which land plants can grow, but to the civil engineer soil includes virtually all earth materials, excluding only those rocks which remain firm after exposure. Specialists in each field classify soil in order to study it more effectively, and to better understand constraints on its use.

The agricultural soil profile commonly consists of four layers called "horizons." The A horizon, or topsoil, contains organic matter and is leached of most soluble minerals. Clay minerals produced by decomposition, together with iron-oxides, are leached by downward-moving water from that horizon and deposited in the underlying B horizon. Similarly, calcium carbonate, also leached from the A horizon, is deposited in the next lower C horizon. Each of these three leached components may act as a cement where it is deposited. The contacts of these horizons are generally abrupt, but the contact of the C horizon with the underlying D horizon, which consists of the parent material on which the profile is developed, is gradational.

The Unified Soil Classification system developed by the U.S. Army Corps of Engineers Waterways Experiment Station (1953) is widely accepted for the classification of engineering soils. The system is based on particle-size, grading, plasticity, and compressibility. Within limitations, classification provides an indication of how the material can be handled and how it is likely to behave in engineering use. The classes of the system are listed below.

Group symbol	Coarse-grained soils (sands and gravels)
GW	Well-graded gravels, gravel-sand mixtures, little or no fines.
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.
GM	Silty gravels, poorly graded gravel-sand-silt mixtures.
GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.
SW	Well-graded sands, gravelly sands, little or no fines.
SP	Poorly graded sands, gravelly sands, little or no fines.
SM	Silty sands, poorly graded sand-silt mixtures.
SC	Clayey sands, poorly graded sand-clay mixtures.
	Fine-grained soils (clays and silts)
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
OL	Organic silts and organic silt-clays of low plasticity.
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
CH	Inorganic clays of high plasticity, fat clays.
OH	Organic clays of medium to high plasticity.
Pt	Peat and other highly organic soils.

Both agricultural soils and engineering soils can have characteristics that might affect engineering and architectural aspects of development in an area. For example, agricultural soils contain differing amounts of humus and those with more than 10 percent humus by weight can be subject to compressibility when built upon; also the B horizon of a soil profile is enriched in clay which can swell on wetting and shrink on drying. Certain classes of engineering soils respond similarly for the same reasons.

Column 6: Workability

The ease with which rock and earth materials may be excavated, compacted, and drilled is termed "workability"; descriptive terms used are relative and nonspecific. Excavation of sedimentary rocks may range from easy in soft claystone to difficult in silica-cemented sandstone and conglomerate such that blasting might be required. Blasting commonly is necessary in all map units of igneous and metamorphic origin.

The same procedures and equipment used for compacting fine-grained and loose soils also can be used for material derived from claystone, shale, and siltstone units. For other sedimentary and all igneous and metamorphic map units, crushing and the addition of a binder material generally are required for compaction.

Suggestions as to the type of equipment that can be used for excavation, emplacement, and compaction of the earth and rock materials are based mainly on equipment observed working such materials in this and adjacent quadrangles, and, in part, on table VI-2, Asphalt Institute (1969). No precise classification based on weight or horsepower, etc., is intended.

Drilling equipment generally preferred is air-percussion or diamond-bit rotary, although cable-tools are used occasionally. Power augers have been used in many foundation boreholes in claystone and shale, and in some siltstone, sandstone, and limestone, to depths as great as from 50 to 90 ft. Rarely, power augers are used for very shallow holes in thoroughly weathered igneous or metamorphic rock.

Column 7: Surface drainage and erodibility

The entry of water from the ground surface into the underlying rock or earth material is infiltration. Runoff is that water on the surface which neither infiltrates nor evaporates into the air; it may cause erosion as it moves downslope.

Infiltration decreases and runoff increases with better grading of material, more compact arrangement of particles, greater degree of cementation, development of a clay-enriched B horizon in the soil, steepness of slope, the presence of swelling clay in the surface material, and other factors that are mainly nongeologic. Material such as claystone that normally provides a very low rate of infiltration may have a higher rate if it contains joints or other fractures which readily permit infiltration.

The relative erodibility of the units is estimated subjectively for material unprotected by vegetation, colluvium, or other cover. For information on historic flooding in the quadrangle see Scott (1972f).

Column 8: Ground-water characteristics

Information on ground-water conditions is based mainly on data published by the Colorado Water Conservation Board (McConaghy and others, 1964). In the sedimentary rocks good yields of ground water are found mainly in sandstone and conglomerate due to their moderate to high permeability--the capacity to transmit water through the rock itself. Yields from siltstone are commonly smaller. Surficial deposits locally yield moderate quantities of water.

Ground water may be described as hard, mineralized, or both. Water that contains ions of calcium-magnesium, iron, or other alkalic metals is described as hard. Mineralized water contains the ions of other elements. Both qualities can be expressed in parts per million. Hard or mineralized water may cause scale in vessels or plumbing, however, water that is hard, or low in mineral content, is commonly preferred for human consumption. The degree of hardness or mineralization of water from a geologic unit can differ somewhat locally, therefore, the terms used herein to describe the quality of water are relative and nonspecific.

Wells in the mountain area commonly produce from joints or other fractures in the rocks. The fractures tend to be less open with increasing depth, and below roughly 300-400 ft, only a very few are sufficiently open to yield significant supplies. Large, dependable yields in the mountains, and in rare cases east of the mountain front, are believed to come from shattered rock along faults. Locally, fair to good supplies are recovered from deeply weathered rock.

Wells produce from below the water table, the upper limit of saturation. The position of the water table varies with changing climatic conditions and changing seasons; it is usually deeper during droughts and in the fall and winter months, and higher during wet years and in the spring and summer months. The water table is not everywhere flat and level. It is generally represented by the surface of ponds and streams, and is closer to the ground surface near those than it is below hilltops. Its level in a fracture may differ from that in an adjacent material of low permeability. The yield of a pumping well can be expressed in gallons per minute; this is the amount of water which can be continuously withdrawn without draining the well. Commonly, however, the yield is an estimate made at the time the well was drilled.

Column 9: Suitability for waste disposal

Suitability of an engineering geologic map unit for septic-tank soil-absorption systems is related chiefly to the rate at which the unit can absorb effluent. The results of percolation tests performed according to procedures of the U.S. Public Health Service (1967, p. 4-8) and interpreted by the State of Colorado and many local health authorities (Jefferson County Department of Public Health, oral commun., 1971) are summarized in the following table.

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

Conditions are generally unsatisfactory where either impervious rock or the water table is within 7 ft of the surface. Conditions also are unsatisfactory where slope and the rock or surficial materials are such that effluent may emerge as seeps, or where the introduction of water into such materials may cause slope instability. Interpretations for this report as to suitability are based chiefly on the texture and geologic character of the bedrock and surficial materials, and on sparse percolation-test data. On-site tests are advisable before starting construction where land use will require a septic system.

Suitability of an engineering geologic unit for installation of a satisfactory septic system does not necessarily eliminate the hazard of polluting a nearby water well. In general, the wellhead should be located upslope from the leaching field and thus upstream on the ground-water gradient. It should be offset laterally from the trend of fractures in or adjacent to the septic field, and in the direction opposite to the direction of dip of foliation or layering. The last two suggestions are made to reduce the hazard of pollution reaching a well through joints, foliation or layering, routes that can pollute even a well located on the opposite side of a topographic ridge.

Waste dumps also may cause water pollution, and the entry or escape of both surface and ground water should be prevented unless the dumped wastes are known to be nonpolluting.

Column 10: Foundation stability

Swelling of earth materials containing expansive clays, compaction or consolidation by loading of materials not fully compacted, compression, on loading, of organic and some clayey materials, and frost heaving in fine-grained materials can all cause damage to foundations and any structures, landfills, or embankments placed on them. In each case, the process is related to, or dependent on, moisture content or a change in that content.

A common problem in foundation stability is placement of a foundation or other structure across the contact of two or more units, subunits, or beds that have different engineering characteristics. Differential movement causing vertical or torsional stress that can produce damage might result.

Collapse of the ground surface over sinkholes in map units consisting partly or wholly of limestone has not been observed in this area. Collapse over now abandoned mines that produced coal mainly during the late 1800's has not been observed either, but there presently is no evidence to prove that the mines will, or will not, cause collapse at some time in the future. Maps of the underground workings of these mines are old and undoubtedly inaccurate, incomplete, or both. The mine locations insofar as known are represented on the map.

Column 11: Slope stability

Slope failure--mainly landslides, mudflows, rockfalls, and rockslides--occurs when the natural forces that tend to stabilize a slope are exceeded by forces, whether natural or man caused, that tend to make the slope fail. The principal factors causing failure include an increase in the water content of the material, which both increases the weight of the mass and reduces its shear strength, addition of weight to the top by filling, construction or both, and removal of a buttressing toe.

In the Morrison quadrangle some recent slope failures have been associated with streams undercutting banks and with heavy, soaking rains following wet, thick snowfalls. Most failures, however, have occurred because of manmade changes in natural slopes. These have included loss of support attributable to cuts for roads, fences, and walls, and to construction of steep-sided, uncompacted landfills that became saturated from lawn sprinkling.

The landslides generally are characterized by the slumping of a mass of rock or earth material along a separation surface that is commonly concave upward. Landslide deposits, masses that have slumped, were identified in the field and on aerial photographs by one or more distinctive characteristics. These include: hummocky terrain, discontinuous benches, undrained depressions, arcuate cracks or lowered ground surface on or at the top of slopes or in paving, seeps and springs on slopes, and tilted trees, fenceposts, or utility poles. A slope-stability investigation by a qualified engineering geologist or civil engineer is generally advisable before design or construction in an area where such evidence is noted (for more information see Scott, 1972b).

The Occupational Safety and Health Agency (OSHA) has published regulations (Title 29 of the Code of Federal Regulations, Part 1926.650 through 1926.653) covering excavations, trenching, and shoring. These regulations essentially supercede the "Rules and regulations governing excavation work," adopted by the Industrial Commission of Colorado on August 23, 1966. The OSHA regulations require support, or excavation to the angle of repose, of the rock or soil remaining, if the depth of the excavation exceeds 5 ft; protection may be required if the excavation is shallower. Special precautions, including flattening of the angle of repose, are required for certain conditions.

Column 12: Probable earthquake stability

No measurable displacement along any fault in this quadrangle is known to have occurred during local historic time, about 120 years. Geologic evidence indicates that two faults near the northwest city limit of Golden and essentially parallel to the Golden fault moved within the last 600,000 years (Scott, 1970). These are the most recent known displacements in the Denver region. Geophysical information, however, suggests that the Golden fault might still be active. Seismic data for the vicinity of Golden during the period 1966-68 inclusive (Simon, 1969) attributed 31 seismic events to activity on the Golden fault in 1967. None of these events caused known damage. The data suggest additional activity associated with the Golden fault might occur in the future, but also suggest that the hazard of serious damage is not great.

Column 13: Known, reported, and possible uses

Local commercial use of all or part of the materials that constitute a map unit is indicated as known, reported, or possible. The economics of production for today's market is not considered. Factors that determine the suitability of a map unit for construction or other development are discussed in other columns (mainly 6, 7, 10, 11, and 12).

Definitions

Given below are definitions for selected terms that are in common geologic or engineering usage, but for which technical definitions might not be available in common desk-top dictionaries. Those readers who wish a technically sound geologic glossary are referred to Gary, McAfee, and Wolf (1972). Other terms are defined in appropriate parts of the Explanatory Notes relating to the map tables, or can be understood from their context.

Bedrock: (Geology) A coherent, naturally formed mass of mineral or organic matter, or both, that may or may not be mantled by essentially noncoherent sediment; the bedrock can be igneous, metamorphic, or sedimentary in origin.

Consolidation: The adjustment of a saturated earth material to an increased load by the squeezing of water from pore spaces and a decrease in the ratio of voids to solid material.

Dip slope: A sloping land surface that approximately conforms to the bedding surface of the tilted underlying rock; it commonly results from the erosional removal of weak rock from above a tilted layer of hard rock.

Earthworks: Deposits of soil or rock either loose or compacted, emplaced by man.

Fault: A fracture distinguished by apparent relative displacement of the two walls parallel to the plane of the fracture.

Fracture: A crack, generally visible to the unaided eye, in rock or earth material; in some places it may consist of a zone containing several fractures; fractures include both joints and faults.

Igneous rock: Rock formed by the cooling and solidification of naturally molten material, commonly distinguished by interlocking crystal grains; examples include granite and basalt.

Interbedded (Interlayered): Beds of different kinds of sedimentary material that lie adjacent and parallel to one another.

Joint: A fracture lacking any apparent relative displacement of the two walls parallel to the plane of the fracture.

Metamorphic rock: Rock formed by the recrystallization of preexisting rocks in response to changes in temperature, pressure, and (or) chemical environment within the earth's crust, commonly distinguished by subparallel orientation of flat, platy minerals in crude mineral layering; examples include gneiss, schist, and amphibolite.

Overturned: Rock beds tilted up to and beyond the vertical, so that the original underside of the bed or unit is now uppermost.

Permeability: The capacity of a rock or surficial material to transmit water; its perviousness. A distinction should be made between the permeability of the rock itself and that of the rock with any fractures present.

Quadrangle: A geographic area on the earth's surface bounded by imaginary lines of latitude and longitude; specifically, the area included in a U.S. Geological Survey topographic map.

Rock: A firm, naturally formed mass of mineral or organic matter, or both; generally has to be blasted for excavation.

Sedimentary rock: Rock that results from the accumulation of particles of sediment at the earth's surface under ordinary conditions of temperature and pressure, deposited by wind, water, or ice, and commonly distinguished by the presence of compositional layering, the noninterlocking contact of particles, and interparticle pore space; examples are shale, sandstone, and limestone.

Soil: (Engineering): A loose to coherent naturally formed mass of mineral matter; generally can be excavated by power equipment including rippers. (Agricultural): Earth material so acted upon by physical, chemical, and biological agents that it will support rooted plants.

Surficial deposit (Surficial material): A noncoherent, naturally formed mass of mineral material that overlies bedrock; examples include clay, silt, sand, and gravel.

Trace: A line on the ground surface, or a map thereof, that represents the intersection of the ground surface with another surface.

Selected references

This list of references includes items referred to in the preceeding text and references for standard test procedures followed in the laboratory.

All the references listed are available for examination and study in the U.S. Geological Survey Library, Denver West Office Park, Bldg. III, 1526 Cole Boulevard, Golden, Colo. Most of them are available in or can be borrowed from public or college libraries including Arthur Lake Library, Colorado School of Mines, Golden, Colo.; Denver Public Library, Denver, Colo.; and Norlin Library, University of Colorado, Boulder, Colo. Copies of all the U.S. Geological Survey maps and reports in print or public files can be purchased or examined at the U.S. Geological Survey Public Inquiries Office, Federal Building, 1961 Stout Street, Denver, Colo. 80202.

American Society for Testing and Materials, 1964, Procedures for testing soils (4th ed.): Committee D-18, Soils and Rocks for Engineering Purposes, 540 p.

Asphalt Institute, 1969, Soils manual: College Park, Md., 269 p.

Gable, D. J., 1968, Geology of the crystalline rocks in the western part of the Morrison Quadrangle, Jefferson County, Colorado: U.S. Geological Survey Bulletin 1251-E, 45 p.

Gardner, M. E., 1968, Preliminary report of the engineering geology of the Boulder Quadrangle, Boulder County, Colorado: U.S. Geological Survey open-file report, 9 p.

______1969, Preliminary report on the engineering geology of the Eldorado Springs Quadrangle, Boulder and Jefferson Counties, Colorado: U.S. Geological Survey open-file report, 9 p.

Gardner, M. E., Simpson, H. E., and Hart, S. S., 1971, Preliminary engineering geologic map of the Golden Quadrangle, Jefferson County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-308 [1972].

Gary, Margaret, McAfee, Robert, Jr., and Wolf, C. L., eds., 1972, Glossary of geology: Washington, American Geological Institute, 805 p.

Lambe, T. W., 1960, The character and identification of expansive soils: U.S. Federal Housing Administration Technical Studies Report FHA-701, 51 p.

LeRoy, L. W., 1946, Stratigraphy of Golden-Morrison area, Jefferson County, Colorado: Colorado School of Mines Quarterly, v. 41, no. 2, 115 p.

McConaghy, J. A., Chase, G. H., Boettcher, A. J., and Major, T. J., 1964, Hydrogeologic data of the Denver Basin, Colorado: Colorado Water Conservation Board Ground-Water Series Basic-Data Report 15, 224 p.

Reichert, S. O., 1954, Geology of the Golden-Green Mountain area, Jefferson County, Colorado: Colorado School of Mines Quarterly, v. 49, no. 1, 96 p.

Schultz, L. G., 1964, Quantitative interpretation of mineralogical composition from X-ray and chemical data for the Pierre Shale: U.S. Geological Survey Professional Paper 391-C, 31 p.

Scott, G. R., 1970, Quaternary faulting and potential earthquakes in east-central Colorado, in Geological Survey research 1970: U.S. Geological Survey Professional Paper 700-C, p. C11-C18.

______1972a, Geologic map of the Morrison Quadrangle, Jefferson County, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-790-A.

______1972b, Map showing landslides and areas susceptible to landsliding in the Morrison Quadrangle, Jefferson County, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-790-B.

______1972c, Map showing areas containing swelling clay in the Morrison Quadrangle, Jefferson County, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-790-C.

______1972d, Map showing potential source areas for non-metallic mineral resources, Morrison Quadrangle, Jefferson County, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-790-D.

______1972e, Map showing some points of geologic interest in the Morrison Quadrangle, Jefferson County, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-790-E.

______1972f, Map showing watercourses and areas inundated by historic floods in the Morrison Quadrangle, Jefferson County, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-790-F.

Scott, G. R., and Cobban, W. A., 1965, Geologic and biostratigraphic map of the Pierre Shale between Jarre Creek and Loveland, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-439.

Simon, R. B., 1969, Seismicity of Colorado--Consistency of recent earthquakes with those of historical record: Science, v. 165, no. 3896, p. 897-899.

Smith, J. H., 1964, Geology of the sedimentary rocks of the Morrison Quadrangle, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-428.

Terzaghi, Karl, and Peck, R. B., 1948, Soil mechanics in engineering practice: New York, John Wiley, 566 p.

U.S. Army Corps of Engineers, Waterways Experiment Station, 1953, The unified soil classification system: U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Memorandum 3-357, v. 1, 30 p., app. A, v. 2, 9 p.

U.S. Bureau of Reclamation, 1963, Earth manual--A guide to the use of soils as foundations and as construction materials for hydraulic structures (1st ed., revised): Washington, U.S. Government Printing Office, 783 p.

U.S. Public Health Service, 1967, Manual of septic-tank practice: Pub. 526, 92 p.

Van Horn, Richard, 1972, Surficial and bedrock geologic map of the Golden Quadrangle, Jefferson County, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-761-A.

______1976, Geology of the Golden Quadrangle, Colorado: U.S. Geological Survey Professional Paper 872, 116 p.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials

By Howard E. Simpson and Stephen S. Hart

[Fw, unit 1]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Sanitary landfill. Fw	Artificial fill (in part).	Wastes, some interbedded earth; proportions differ greatly from place to place. Thickness: as much as 60 ft; waste beds 1-8 ft thick, earth beds 1-3 ft thick. Beds discontinuous, level to moderate dip; boundaries gradational to distinct, uneven to very uneven. Materials uncompacted to partly compacted, noncoherent. Wastes: mainly household, some commercial and industrial, locally somewhat sorted by composition (e.g. wood, tires); noncoherent, compressible. Earth: medium consistency, obtained adjacent to landfill; consistently clay- and silt-rich soil; deposited at least daily to cover waste. Unit attitude: level to moderate dip. Jointing: none. Contacts: abrupt to distinct.

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies flat, level to gently sloping areas as large as 50 acres. Commonly located in natural drainageways and abandoned claypits.	Weathers chiefly by oxidation. Can yield metallic and organic compounds to ground water.	Excavation: easy to difficult with power equipment[4]. Material can change abruptly either horizontally or vertically. Compaction: moderately difficult because of compression and rebound. Generally improved by addition of water during placement, and use of special compactors. Drilling: generally easy, locally difficult because of wood, metal, and concrete fragments.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Fw, unit 1]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: generally rapid, moderate where unit covered by clayey earthfill. Runoff: generally slow, moderate on side slopes. Erodibility: trash resistant to moderately resistant; earth material easily eroded by gullying and sheetwash unless vegetated.	Permeability: high through trash, moderate through earth. Water table: depth varies. Water may puddle in depressions on the underlying surface. Yield to wells: undeveloped. Quality: generally polluted. Use: none reported; may be useful for wetting down deposit during compaction.	Septic systems: unsatisfactory as percolation too rapid for sufficient aeration; excavation locally difficult. Dump site: should be evaluated relative to character of underlying map unit; if permeable, should be sealed before use.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Very poor; surface can settle excessively and unevenly. Foundation investigation recommended before construction.	Very poor.	Very poor; for seismically active areas, maximum damage reported in structures on this kind of material.

13. Known, reported, and possible uses of material
None reported or known.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Fe, unit 2]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Earthwork. Fe	Artificial fill (in part).	Soil, some rock. Includes engineered emplacements (e.g.: some earthfill dams, some transportation embankments) and dumped deposits (e.g.: spoil piles, some landfills). Thickness: 3-120 ft. Emplacements built in beds (lifts) 4 in. to a few feet thick; boundaries even, abrupt; compacted to specifications; attitude level to gently dipping. Material density, grading, and homogeneity greater than in dumped deposits, but density lower near margins. Bedding of deposits poor to absent, very uneven. Particles from clay-size to cobbles in plains area, from sand-size to boulders in mountains. Unit attitude: varies. Jointing: none. Contacts: abrupt, even to uneven.

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Ridgelike to terracelike landforms as large as several acres. Commonly located in natural drainageways and adjacent to excavations on slopes.	Not yet weathered in present location. Material may have weathered at source locality.	Excavation: Mainly easy with most power equipment[4/]; only moderately easy with heavy equipment in material containing stones larger than 1 ft in diameter. Compaction: easy to moderately easy with sheepsfoot and rubber-tire equipment. Drilling: easy in most areas; locally difficult because of large stones.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Fe, unit 2]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: varies according to lithology of material. Runoff: same. Erodibility: generally easily eroded by gullying, sheetwash, and stream scour except where protected by vegetation or riprap; locally moderately resistant because of coarseness of material.	Permeability: varies greatly among and within deposits, varies much less for emplacements. Transportation embankments generally permeable near base. Water table: generally absent unless puddled in depressions on underlying surface beneath landfills; varies within dam embankments. Yield to wells: undeveloped. Quality: unknown. Use: unknown.	Septic systems: unsatisfactory in most emplacements as percolation too slow; unsatisfactory in most deposits because of potential landsliding if other factors marginal. Dump sites: poor to good in or on landfills or against embankments, depending on permeability; evaluate underlying map unit to avoid ground-water pollution.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Varies; commonly poor for heavy structures, and poor to fair for light structures on uncompacted earthworks as natural compaction with time can cause settlement; good on compacted fills for light to heavy buildings.	Generally good if compacted, poor if uncompacted. Side slopes of 1.5 horizontal to 1 vertical generally stable if well drained and compacted. Uncompacted margins of compacted landfills should be trimmed back to compacted part. Load-bearing fills on slopes should be keyed into underlying unit to reduce hazard of landsliding. Stability investigations prior to construction recommended for deposits on slopes steeper than about 11° (20 percent) and on deposits >30 ft high.	Generally poor, especially where thick, where placed on a hillside or where deposit overlies alluvium or landslide material. Major damage reported from seismically active areas for structures on this kind of material.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Fe, unit 2]

13. Known, reported, and possible uses of material
Source of poor to good quality earthfill material.

[Gs, unit 3]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Sandy gravel with cobbles. Gs	Louviers Alluvium (in part). Post-Piney Creek alluvium (in part).	Silty, sandy gravel (GW[2], GM, some GP), cobbly to bouldery, with some silt and silty sand (ML, some SM). Thickness: from 9 to 35 ft, average 20 ft. Beds 1-4 ft thick, discontinuous, boundaries uneven, distinct, attitude nearly level. Gravel: medium to very dense, noncoherent. Sand: medium density, noncoherent to friable. Locally contains some clay and organic material (soil) at ground surface; dark gray to light reddish brown. Unit attitude: nearly level. Jointing: absent. Contacts: abrupt; even to uneven.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Gs, unit 3]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Broad, nearly flat surfaces longitudinally parallel to Bear Creek. Surfaces slope about 90 ft/mi downstream	Ancient zonal soil profile on terrace deposits. "A" horizon moderately well developed, humus rich; locally removed by erosion. Underlying "B" horizon, clay rich, as much as 2.5 ft thick. Underlying "C" horizon, calcium carbonate enriched, as much as 4 ft thick. Valley floor deposits have no ancient zonal profile, but uppermost 1-2.5 ft locally is humus rich.	Excavation: generally easy with power equipment[4]; moderately difficult for light backhoes and trenchers within 1 mi of mountain front because of numerous large boulders which decrease in diameter and frequency eastward. Compaction: moderately difficult unless boulders removed; vibratory compactors suggested. Drilling: moderately difficult because of numerous large stones.

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: generally moderately rapid to rapid; very rapid where clay-rich B horizon absent. Runoff: slow; water may puddle on surface temporarily in shallow depressions underlain by clay-rich B horizon; susceptible to flooding adjacent to streams. Erodibility: moderately resistant to gullying, sheetwash, and stream scour.	Permeability: high. Water table: from 3 to 18 ft below ground surface; estimated average 9 ft. Yield to wells: 6-50 gal/min, estimated average 23 gal/min. Quality: moderately to highly mineralized. Use: domestic.	Septic systems: unsatisfactory as percolation too rapid and water table too shallow; great risk of polluting both ground and surface water. Dump sites: generally unsatisfactory owing to great risk of polluting both ground and surface water.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Gs, unit 3]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally good below depth of about 2 ft; heavy structures founded on lenses of compressible humus-rich silt can settle unevenly; clay-enriched B horizon of soil can swell on wetting, or frost heave.	Good, newly cut vertical slopes as much as 15 ft high commonly stand for months in gravel pits, but ravel or landslide to about 30^{o} (55 percent) slope after wetting and drying over several years, or if below water table.	Fair; poor on or near steeper slopes or near margin of deep excavation.

13. Known, reported, and possible uses of material
Source of fair to very good quality aggregate, pervious shells for earthfill dams and dikes, and crushed road metal.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Smb, Gmb} Sm, unit 4]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Silty sand or gravel, some boulders. Smb, Gmb} Sm	Nussbaum(?) Alluvium. Rocky Flats Alluvium. Verdos Alluvium. Slocum Alluvium. Louviers Alluvium (in part). Broadway Alluvium. Post-Piney Creek Alluvium (in part). Eolian (windblown) sand.	Clayey to silty, pebbly to bouldery, sand and bouldery sand and gravel (SM[2], GM, SP, SC, some CL, GW), a little silt, a little volcanic ash. Thickness: from 3 to 35 ft. Beds from 1-5 ft thick, discontinuous, nearly level; boundaries uneven, distinct; loose to very dense; noncoherent to friable; generally well graded. Mainly derived from metamorphic and igneous rocks, in part from sedimentary rocks. Stones present locally, angular to subround, from 1 to 6 ft diameter, average diameter 6 in. Unit generally in 2 parts: Upper: clayey to pebbly silt, commonly 1-4 ft thick (soil); dark gray to reddish or yellowish brown. Lower: sand and gravel, uppermost 1-7 ft weakly to strongly cemented by calcium carbonate (caliche). Unit toward west mainly silty sand with boulders (Smb) or silty sand and gravel with scattered boulders (Gmb); grade eastward into sand lacking boulders (Sm). Unit attitude: nearly level. Jointing: absent. Contacts: abrupt to gradational, even to uneven.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Smb, Gmb } Sm, unit 4]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies broad, nearly flat, stream-dissected, mesalike remnants of formerly extensive landforms, and terracelike features that slope eastward about 50-600 ft/mi. Unit also underlies small, concave upward surfaces along lower sides of some mountain valleys, and forms small alluvial-fan deposits at mouths of some intermittent mountain streams.	Ancient zonal soil profile on deposits 25 ft and more above nearby stream moderately to well developed. Both humus-rich A horizon and clay-rich B horizon generally 6 in. to 2.5 ft thick, but locally removed by erosion. Underlying calcium carbonate-rich C horizon generally 1-4 ft thick. Stones of metamorphic and basaltic composition near top of unit generally decomposed ("rotted") more than granitic stones; all stones in upper part at some localities coated with calcium carbonate. Ancient soil profile lacking on deposits less than 25 ft above nearby stream, but upper 1-2.5 ft can be humus rich.	Excavation: generally easy to moderately easy with power equipment[4/]; moderately difficult for light backhoes and trenchers within 1 mi of the mountain front because of numerous large boulders; these decrease in frequency and diameter eastward. Compaction: moderately easy to moderately difficult; vibratory compactors and rubber-tire rollers commonly used; compaction easier if boulders removed. Drilling: moderately difficult where cobbles and boulders numerous; moderately easy elsewhere.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Smb / Gmb } Sm, unit 4]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: same as map unit Gs above. Runoff: same as map unit Gs above. Erodibility: moderately resistant where gravel content high; moderately easy by gullying, sheet-wash, and stream scour where sandy.	Permeability: moderate to high. Water table: 2-20 ft or more; estimated average 9 ft. Yield to wells: 1-30 gal/min; estimated average 14 gal/min. Quality: generally highly mineralized: very hard; calcium and sodium content high, sulfate content locally very high. Use: stock, domestic, some commercial.	Septic systems: generally satisfactory; locally unsatisfactory as percolation too rapid in gravels or too slow in clay-rich zone of ancient soil; great risk of pollution of both ground- and surface-water. Dump sites: same as map unit Gs above.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally good below clay-rich B horizon of soil, which may swell on wetting and shrink on drying.	Fair; newly cut vertical slopes as much as 10 ft high commonly stand for months in borrow pits, but ravel or slump to about 30° (55 percent) slope on wetting and drying over period of several years, or if below water table. Slopes higher than 10 ft may be stable at about 33° (66 percent) where subsoil is well drained.	Same as map unit Gs above.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Smb / Gmb} Sm, unit 4]

13. Known, reported, and possible uses of material
Source of poor to good quality road metal and embankment fill.

[Smo, unit 5]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Organic silty sand and gravel. Smo	Piney Creek Alluvium.	Organic, clayey to silty sand (SM[2], SC), some silty gravel (GM), some pebbly to cobbly sand and gravel (GW). Thickness: from 3 to 20 ft, average 6 ft. Beds from 1 in. to 2 ft thick, dip gently to moderately; discontinuous; boundaries even to uneven, distinct. Material loose to medium density; noncoherent to friable; well graded; coarse fraction mainly of metamorphic and igneous origin; stones subround, nearly equidimensional, maximum diameter 10 in. Generally two parts. Upper: humus-rich silt (ML, OL) (soil), from 1 to 5 ft thick; dark gray to reddish brown. Lower: sand and gravel, thickness from 2 to 18 ft. Unit attitude: level to moderate dip. Jointing: rare. Contacts: distinct to gradational, uneven to very uneven.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Smo, unit 5]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies nearly flat floors of most valleys, and terrace surfaces 10-20 ft above nearby stream. Toward valley sides surfaces slope upward, and grade into map units Cm and Scb; locally overlies map units Sm and Gs.	Ancient zonal soil profile underlies surface, is weakly developed and locally removed by erosion. Humus-rich A horizon and clay-enriched B horizon generally 6 in. to 1 ft thick, grayish brown; underlying C horizon 1-3 ft thick is sandy to pebbly silt containing pinhead-size spots of white calcium carbonate.	Excavation: easy with power equipment[4/]. Compaction: moderately easy; vibratory compactors and sheepsfoot rollers commonly used; adheres when wet. A horizon of soil, if more than 10 percent humus by volume, should be removed before excavation for use elsewhere, or before placement of fill material. Drilling: easy.

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: moderate. Runoff: moderate; susceptible to flooding near adjacent stream; not covered by most seasonal floods, might be covered by 50- to 100-year flood. Erodibility: moderately easy by gullying, sheetwash, and stream scour where sandy; easy where organic content high.	Permeability: moderate. Water table: 1-12 ft, estimated average 12 ft. Yield to wells: 3 gal/min reported from 1 spring, generally less; less yield to wells. Quality: highly mineralized: hard to very hard; iron content locally very high. Use: stock, domestic, some commercial.	Septic systems: same as map unit Sm above. Dump sites: same as map unit Gs above.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Smo, unit 5]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally good below humus-rich A horizon of soil; unit can compress under load if humus content high, or when moisture content increases. Foundation investigation recommended before construction.	Same as map unit Sm above.	Same as map unit Gs above.

13. Known, reported, and possible uses of material
Humus-rich A horizon of soil a source of topsoil for landscaping if pebbles removed.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Scb, unit 6]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Sand, silt, and clay, with boulders. Scb	Colluvium (in part). Talus. Landslides.	Clayey, silty, sand and sand-and-gravel (SM[2/], SC, some GC), some clay (CH, CL). Thickness: from 5 to 15 ft. Bedding generally absent or crude. Material density varies greatly; noncoherent to firm; well to poorly graded; derived mainly from sedimentary rock, some metamorphic rock, a little igneous rock; stones angular to subangular, tabular to equidimensional, as large as 6 ft in diameter. PVC[3/] rating 0.2-3.5; noncritical to marginal; swell index 300-2,500 psf; medium gray to reddish brown. Unit attitude: varies, can be steeply inclined. Jointing: present as ruptures in landslide material, commonly absent in colluvium.

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Locally underlies slopes on flanks of South Table Mountain, the Dakota Hogback, the mountain front, and valley walls of mountain streams. Surfaces smooth to very uneven, commonly concave upward; slopes as steep as 30° (58 percent).	Ancient zonal soil profile weakly to strongly developed, locally absent because of erosion; reddish-brown iron-stained or calcium carbonate-rich C horizon generally developed in upper 1-3 ft.	Excavation: moderately difficult with heavy scrapers[4/] in mountain valleys and along the mountain front because of boulders; moderately easy elsewhere, although boulders can be present locally. Compaction: moderately easy to moderately difficult with rubber-tire rollers in mountain valleys and along the mountain front; moderately easy with sheepsfoot rollers elsewhere. Drilling: moderately easy; moderately difficult where large boulders numerous.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Scb, unit 6]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: varies; slow to moderate on fine-grained deposits; slow to rapid on landslides; rapid on talus. Runoff: varies; rapid to moderate on fine-grained deposits; rapid to slow, and might puddle temporarily on surface of some landslides; absent to slow on talus. Erodibility: moderately easy to easy by gullying and sheetwash on most deposits, talus little affected.	Permeability: slow to moderate, generally; fast in talus. Water table: generally absent; present but variable in landslides. Yield to wells: undeveloped. Quality: unknown. Use: unknown.	Septic systems: unsatisfactory; most deposits lack sufficient thickness and lateral extent; moderate risk of polluting both ground and surface water; can increase risk of landsliding of slopes. Dump sites: unsatisfactory as deposits lack sufficient thickness and lateral extent; moderate risk of polluting both ground and surface water.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Poor to fair; lenses of sandy clay can expand and shrink on wetting and drying.	Poor because of potential for landsliding. Nearly vertical cuts as much as 10 ft high commonly stable where material well drained and not heavily loaded; potential for landsliding greater in poorly drained cuts higher than 10 ft. Stability investigations recommended before grading.	Generally poor; very poor on landslides or talus adjacent to major cuts, or below rock ledges.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Scb, unit 6]

13. Known, reported, and possible uses of material
Source of fair quality embankment fill.

[Sc, unit 7]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Clayey sand. Sc	Saprolite (weathered) zone on metamorphic rock.	Silty, clayey sand (SC[2/], SM), some clayey, gravelly sand with boulders (GC). Thickness: generally exceeds 8 ft. Bedding absent. Material: very loose to dense; noncoherent to friable; well graded, derived from weathering of metamorphic rock; stones rounded to subangular; diameter from 1 in. to 2 ft; generally well to moderately decomposed ("rotted") by weathering; reddish brown to dark brown. Unit attitude: none; can possess relicts of former rock structures. Jointing : random, irregular, short inconspicuous fractures yield gravel-like texture; can possess relicts of joints in former rock. Contacts: gradational, very uneven.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Sc, unit 7]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies broad, gently rolling, locally nearly flat, surface on Lookout Mountain (in northwest part of map area).	Ancient zonal soil profile weakly to strongly developed; locally removed by erosion. Humus-rich A horizon is dark brown, 6 in. to 2 ft thick; overlies clay-enriched B horizon of clayey sand 2-4 ft thick. Unit developed in place by weathering and alteration of metamorphic bedrock that underlies the unit. Some original foliation preserved in weathered rock at depth greater than 4-5 ft.	Excavation: moderately easy with power equipment[4/]; becomes more difficult with depth. Compaction: moderately easy; rubber-tire and sheepsfoot rollers suggested. Drilling: moderately easy; becomes more difficult with depth in less weathered rock.

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: moderate to high. Runoff: slow to moderate; increases with increasing slope. Erodibility: moderately easy by gullying and sheetwash.	Permeability: moderate to high. Water table: 5-7 ft in only well reported. Yield to wells: 6 gal/min in only well reported. Quality: moderately hard, iron content high. Use: domestic.	Septic systems: generally unsatisfactory as risk of pollution of ground water moderate to high because of high premeability. Dump sites: generally unsatisfactory because of insufficient thickness, high permeability, and moderate to high risk of pollution of ground water.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Sc, unit 7]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally good below about 5 ft (the approximate lower limit of frost heave).	Poor to good; poor to fair on slopes steeper than about 11° (20 percent). Stability investigation recommended before grading. Good on slopes of less than about 11° (20 percent).	Generally good.

13. Known, reported, and possible uses of material
Possible source of good quality embankment fill.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Cm, unit 8]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Silty clay with stones. Cm	Colluvium (in part).	Silty to sandy, pebbly to cobbly, clay (CL[2], CH, some SC). Thickness: from 2 to 18 ft, average 6 ft. Bedding generally absent; discontinuous, even to uneven, boundaries gradational where present. Material stiff to very stiff, generally well graded; derived mainly from sedimentary rock upslope. Clay minerals varied, mainly illite, mixed-layer illite-montmorillonite, some montmorillonite; stones angular to subrounded, mainly from other surficial deposits (sm) and sedimentary bedrock (ls, ss-ms-cs); PVC rating 0.8-5.4: noncritical to critical; swell index 800-4300 psf; dark gray to reddish brown. Unit attitude: gently to moderately inclined. Jointing: absent. Contacts: gradational even to uneven.

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies gently rolling terrain in eastern half of quadrangle; slopes generally <10°.	Ancient zonal soil profile weakly to strongly developed; locally removed by erosion. Reddish-brown, iron-stained B horizon or calcium carbonate rich C horizon developed in upper 1-3 ft of deposit.	Excavation: easy with most power equipment[4]; adheres when wet. Compaction: easy; sheepsfoot and smooth-tire rollers suggested; adheres when wet. Drilling: easy; may tend to clog toothed bits.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Cm, unit 8]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: negligible to slow. Runoff: generally rapid but water can temporarily puddle in surface depressions. Erodibility: very easy by gullying; slopewash, and stream scour; upper few inches to feet subject to slow downhill soil-creep and soil-flow; rate of flow increases with increasing slope and moisture content. Moderately easy by wind deflation where dry and loosened by activity on surface.	Permeability: negligible to low. Water table: depth varies, deeper under steeper slopes; ground water can move in thin zone at top of underlying bedrock surface. Yield to wells: undeveloped. Quality: unknown. Use: unknown.	Septic systems: generally unsatisfactory because of slow percolation; can increase risk of landsliding of adjacent slopes. Dump sites: moderately good; excavation easy, and moderately low risk of polluting ground water.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Cm, unit 8]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Poor to fair; can expand excessively and exert high pressure on wetting; can shrink on drying; swell pressure generally a little less than that of parent material. Heavy structures can settle unevenly. Foundation investigation recommended before construction.	Same as map unit Scb above.	Same as map unit Scb above.

Table 1.--Generalized description of the engineering geologic characteristics of the surficial materials--Continued

[Cm, unit 8]

13. Known, reported, and possible uses of material
Source of poor-quality embankment fill, except good where source of impermeable core material for earthfill dams if large stones absent or removed.

[1]Unified Soil Classification (U.S. Army Corps of Engineers, Waterways Experiment Station, 1953).

[2]Relative density and consistency by standard penetration test (American Society for Testing and Materials, 1964, D1586, with classification from Terzaghi and Peck, 1948, p. 294 and 300).

[3]Potential volume change (Lambe, 1960).

[4]Based mainly on equipment observed in use, and in part on table VI-2, Asphalt Institute (1969).

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock

By Howard E. Simpson and Stephen S. Hart

[ms-ss-cgl, unit 1]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Siltstone and sandstone and conglomerate. ms-ss-cgl	Green Mountain Conglomerate. Denver Formation (excluding basaltic lava flows). Arapahoe Formation.	Lithology: clayey to sandy siltstone, silty claystone, silty to pebbly sandstone, and conglomerate; relative quantities locally differ greatly; conglomerate dominant in basal 100 ft and on crest of Green Mountain, ancient mudflows numerous. Thickness: generally from 1300 to 1500 ft; from 1900 to 2100 ft on Green Mountain. General character: Beds from one to several tens of feet thick, discontinuous, boundaries uneven, distinct to gradational. Siltstone and claystone: soft where weathered to hard where nonweathered; poorly graded; clay minerals mainly montmorillonite, some mixed-layer illite-montmorillonite, and illite; PVC rating 0.8-9.5, noncritical to very critical, swell index 850-8600 psf; silt grains mainly quartz, feldspar, and calcite; light gray to very dark, mottled in mudflows. Sandstone: locally crossbedded; loose to dense; poorly graded; grains mostly quartz and feldspar, some amphibole and biotite, well to poorly cemented by calcium carbonate, iron oxides, zeolites, and clay; yellowish brown to dark brown. Conglomerate: loose to very dense, generally well graded, matrix mainly clay and silt; contains stones averaging 8 in., and as large as 2 ft, in diameter; stones mainly of metamorphic and igneous origin, on Green Mountain some of sedimentary origin; well to poorly cemented by calcium carbonate, clay, and zeolites; light brown to black. Attitude: strike about north, dip from 3° eastward to vertical. Jointing: inconspicuous, short, irregular, random, few. Contacts: generally distinct; abrupt with map unit $\overline{bf}_2$ and $\overline{bf}$; uneven.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-ss-cgl, unit 1]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies a moderately rolling surface mantled by alluvium, also the colluvium-mantled flank of South Table Mountain, and the colluvium-mantled crest and slopes of Green Mountain; slopes as steep as 25° (47 percent); exposures mainly in roadcuts and valley walls.	All rock types weather significantly to a depth of from 2 to 4 ft, becoming lighter in color. Siltstone and claystone mainly disintegrates to MH, CH, ML; dries to angular blocks as much as 1.5 in. in diameter. Sandstone becomes weaker, more friable as cement is removed. Conglomerate matrix weakened, loosening boulders, which are weathered to depth of about 0.25 in.	Excavation: easy in claystone, some siltstone, and some sandstone; moderately easy to moderately difficult in some sandstone and siltstone, with most power equipment[5/] including tractor-drawn scrapers and backhoes; moderately difficult to very difficult in cemented conglomerate, even with heavy rippers and scrapers; blasting probably required locally. Claystone and some siltstone may adhere when wet. Compaction: easy in most weathered rock, sheepsfoot rollers commonly used; difficult in some sandstone and conglomerate; generally requires mixing with binder material; steel-wheeled rollers generally used. Claystone and some siltstone may adhere when wet. Drilling: easy in claystone, siltstone and most sandstone, may tend to clog toothed bits; moderately difficult in cemented sandstone and conglomerate; some stones larger than 12 in. in diameter.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-ss-cgl, unit 1]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: slow in siltstone and claystone, moderate to rapid in sandstone and conglomerate; rapid through fractures. Runoff: moderate to rapid on siltstone and claystone, moderate to slow on sandstone and conglomerate. Erodibility: Eroded by gully- or sheetwash; and stream scour; weathered claystone and siltstone easily eroded, most sandstone moderately easily eroded and cemented sandstone and conglomerate difficult to erode.	Permeability: very low to low in claystone, and siltstone, moderate to high in sandstone and conglomerate, high through fractures. Water table: varies greatly from place to place; artesian pressure causes rise of water level in many wells; pressure gradient slopes eastward from area of outcrops. Yield to wells: average is 17 gpm, as much as 70 gpm reported. Quality: moderately to highly mineralized, hardness moderate to very hard; sodium content generally high, iron and sulfate content locally high. Use: primarily for domestic and irrigation needs, locally for commercial, construction, and livestock supply.	Septic fields: Generally unsatisfactory in claystone and siltstone as percolation too slow; unsatisfactory in sandstone and conglomerate as risk of pollution of ground water high, also unsatisfactory in conglomerate as difficult to excavate. Dump sites: Good in claystone and siltstone, generally unsatisfactory in sandstone and conglomerate because excavation difficult and risk of pollution of ground-water supply high.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-ss-cgl, unit 1]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Claystone and siltstone very poor to good, as locally expansive clays exert very high swelling pressure on wetting and shrink on drying; sandstone poor to good for same reason; conglomerate good to excellent. High risk of differential swelling or settlement if foundation placed on different rock types. Foundation investigation before building recommended.	Poor to very poor on steep slopes or adjacent to steep slopes higher than about 15 ft; risk of landsliding also high if beds dip into excavation or if crest of slope is loaded excessively. Landslides and their deposits numerous on flanks of Green Mountain and consist mainly of materials derived from this map unit; some rock falls occur from overlying basalt. Only one landslide active in 1969 but others can be reactivated; one new landslide initiated in 1973 along road excavation for subdivision development. Stability investigation of this unit and any map unit upslope recommended before building on slopes of more than about 8° (15 percent).	Poor on steep hillsides, and at top high cuts; fair to good on gentler slopes.

13. Known, reported, and possible uses of material
Source of poor quality impervious fill and binder material.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ss-cs, unit 2]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Sandstone and claystone. ss-cs	Laramie Formation. Fox Hills Sandstone.	Lithology: clayey to silty sandstone and sandy to silty claystone; some coal, mainly near middle. Thickness: from 750 to 1200 ft; apparent thickness greater because of dip. General character: beds from several inches to 25 ft thick, persistent to discontinuous, boundaries even and distinct; overconsolidated. Sandstone: medium density where weathered to very dense where nonweathered; locally crossbedded; moderately graded; sand grains subangular to rounded, mainly quartz and chert; light gray to reddish brown. Claystone: very soft where weathered to hard where nonweathered; poorly graded; clay minerals mainly montmorillonite in basal and upper-middle part of map unit, kaolinite dominant elsewhere, some illite present throughout unit, PVC rating 0.8-7.7, noncritical to very critical, swell pressure from 800 to 6200 psf, swelling clays most abundant in upper 75 percent of unit in beds associated with coal. Coal: lignite to subbituminous; 2-5 beds from 6 in. to 4 ft thick, discontinuous along strike and down dip. Attitude: strike generally a little west of north, dip from 45° eastward to 76° westward (overturned). Jointing: Sandstone: conspicuous, extensive, somewhat regular, ordered, numerous; consists of three nearly perpendicular sets. Claystone: inconspicuous, short, irregular, random, few. Contacts: gradational with map units ms-cs below (west), abrupt with map unit ms-ss-cgl above (east) and overlying units; uneven.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ss-cs, unit 2]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies moderately rolling surface generally mantled by alluvium and colluvium; locally forms low ridge east of Dakota Hogback; slopes as steep as 45° (100 percent); exposures mainly in claypits in unit, a few natural exposures along the ridge.	Sandstone: commonly case-hardened where naturally exposed. Claystone: two horizons formed by weathering downward from the eroded surface of the unit. Upper horizon yellowish-gray clay (CL, CH, MH, some ML) from 1 to 3 ft thick. Lower horizon yellowish-brown to gray claystone, broken into angular fragments 0.25-1.5 in. in diameter that increase in size with depth; from 4 to 8 ft thick. Claystone weathers more rapidly than sandstone.	Excavation: easy with most power equipment to base of weathered fractured material; increasingly difficult with depth; adheres when wet. Moderately difficult in most sandstone with heavy rippers and scrapers; blasting may be required locally. Compaction: easy for claystone, earthmoving equipment and sheepsfoot and smooth-tired rollers suggested; moderately difficult for sandstone, steel-wheeled rollers suggested; coal may compress and rebound. Drilling: easy in claystone to moderately difficult in sandstone; claystone tends to clog toothed bits.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ss-cs, unit 2]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: negligible into claystone, moderate into sandstone; rapid through fractures. Runoff: rapid on claystone, moderate on sandstone. Erodibility: moderately resistant to resistant to gully- and sheetwash and stream scour. Difficult to reestablish vegetation on slopes steeper than 25° (47 percent).	Permeability: moderate to high in sandstone, negligible in claystone; high through fractures. Water table: varies greatly from place to place; artesian pressure causes rise of water level in most wells, pressure gradient slopes eastward from area of outcrop. Yield to wells: average 53 gpm; maximum reported as much as 100 gpm. Quality: moderately mineralized; soft; sodium content high in some wells. Use: domestic, commercial, irrigation, and livestock use.	Septic fields: generally unsatisfactory: rate of percolation in claystone too slow; in sandstone, risk of pollution of ground-water supply moderate to high, and excavation is difficult. Dump sites: poor in sandstone as difficult to excavate and risk of pollution of ground-water supply moderate to high; good in claystone provided all sandstone layers are sealed off before use.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ss-cs, unit 2]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Claystone: good to poor, as some beds swell excessively and exert high pressure when wetted, and shrink when dried. Sandstone: excellent to good. High risk of differential swelling or settlement if foundation is placed on differing rock types. Clay beds excavated, then refilled with trash or earth materials, have high risk of differential or excessive settlement. Foundation investigation recommended before building.	Generally good; poor to very poor in cuts higher than 20 ft and on slopes steeper than 45° (100 percent) or where bedding surfaces dip into cut; very poor in claypits with steep cuts, or faces formed by sandstone beds. Stability investigations recommended before building.	Generally good; poor at top of high cuts and on steep hillsides.

13. Known, reported, and possible uses of material
Source of good clay for brick and tile, fair source of lichen-covered landscape rock. Formerly a major source of coal; at least nine mines are reported to have operated formerly in the quadrangle.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-cs, unit 3]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Siltstone and claystone. ms-cs	Pierre Shale (Upper transition member downward through the *Baculites grandis* Zone).	Lithology: clayey to very sandy siltstone, silty claystone; a little fine-grained sandstone. Thickness: from 1 to 1500 ft; locally thinned by ancient faulting; apparent thickness greater because of dip. General character: beds several inches to several feet thick, persistent, boundaries even, gradational; soft where weathered, hard where nonweathered; overconsolidated; contains scattered lenses of hard, brittle, calcareous ironstone concretions as much as 2 ft in diameter; clay minerals mainly montmorillonite and mixed-layer illite-montmorillonite; poorly graded; grains mainly quartz, some feldspar, a little calcite and dolomite. Siltstone and sandstone: PVC rating 0.4-3.4, noncritical to marginal, swell index 500-2800 psf; mainly very fine silt to fine sand, grains include some of gypsum; yellowish brown to reddish brown. Claystone: PVC rating 2.0-4.2, marginal to critical, swell index 1700-3300 psf; olive gray to dark gray. Attitude: strike varies from northwest to slightly west of north, dip from 45° eastward to 70° westward (overturned). Jointing: inconspicuous, random, short, irregular, numerous. Contacts: gradational with map unit cs-ms below (west) and ss-cs above (east), distinct with any overlying surficial units; even.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-cs, unit 3]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies nearly flat to gently rolling surface generally mantled by alluvium and colluvium; slopes as steep as 22° (40 percent). Exposures mainly in roadcuts and valley walls.	Two horizons formed by weathering of the exposed cross section of the unit. Upper horizon yellowish-brown clay and silt (CH, CL, MH, ML, some SM) from 1 to 3 ft thick, commonly eroded. Lower horizon yellowish-gray stained claystone and siltstone broken into angular fragments 0.5-1.5 in. in diameter, that increase in size with depth; from 3 to 6 ft thick. Claystone weathers somewhat more rapidly than siltstone. Where basal 200 ft of unit is exposed at ground surface, weathering yields gypsum crystals.	Excavation: easy to base of weathered, fractured material with most power equipment including tractor-drawn scrapers and backhoes; increasingly difficult with depth, requiring heavy equipment where nonweathered. Difficult in siltstone and sandstone beds, and in concretion horizons. Adheres when wet. Compaction: easy for claystone and most siltstone, moderately easy for some siltstone and sandstone; sheepsfoot and rubber-tired rollers suggested; adheres when wet. Drilling: easy generally, may be moderately difficult drilling through concretion horizons; clay component tends to clog bits.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-cs, unit 3]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: negligible through rock, negligible to slow through fractures. Runoff: generally rapid; water may accumulate in scattered shallow depressions for as long as a week. Erodibility: easily eroded by gully- and sheetwash, and by stream scour; moderately easily eroded by wind where loosened by plowing or construction; difficult to reestablish vegetation on slopes steeper than 20° (36 percent).	Permeability: negligible to very slow in claystone and siltstone; slow in sandstone beds; rapid through fractures. Water table: varies greatly from place to place. Yield to wells: not reported, probably small; better yield probably from base of overlying surficial material. Quality: very highly mineralized, very hard; calcium, magnesium and sulfate content very high; may react with some types of concrete, and corrode iron pipe. Use: single reported well used for domestic supply.	Septic fields: generally unsatisfactory as percolation too slow, and may pollute any water supply present. Dump sites: generally excellent except in sandstone beds and concretionary beds where excavation may be moderately difficult, and risk of ground-water pollution is moderate.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-cs, unit 3]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally fair to poor. Locally expands excessively and exerts moderate swelling pressure on wetting, and shrinks on drying; siltstone and sandstone least affected; high risk of differential swelling or settlement if foundation placed on differing rock types. Foundation investigation recommended before building.	Generally good, locally poor to very poor where cuts are more than 20 ft high, or where beds dip downward into excavations, or where cuts are steeper than about one horizontal to one vertical. Stability investigations recommended before building.	Generally good, locally poor at top of high cuts and on steep hillsides.

13. Known, reported, and possible uses of material
Possible source of claystone for manufacture of lightweight aggregate, and of impervious fill or binder material that is poor to very poor because of swelling potential.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cs-ms, unit 4]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Claystone and siltstone. cs-ms	Pierre Shale: (includes two parts: (1) from the base of the Baculites grandis Zone down to top of Hygiene Sandstone Member, and (2) from base of Hygiene Sandstone Member down through B. asperiformis Zone).	Lithology: silty claystone, and clayey to sandy siltstone; a little sandstone. Subunits: two (separated by map unit ms-ss). Eastern subunit mainly claystone, siltstone dominant at base; western subunit mainly claystone. Thickness: eastern subunit from 1 to 2600 ft, western subunit from 1 to 800 ft; locally thinned by ancient faulting; apparent thickness greater because of dip. General character: beds persistent, boundaries even, distinct; overconsolidated; contains numerous layers of many hard, brittle, calcareous concretions of ironstone as large as 3 ft in diameter; poorly graded; clay minerals mainly montmorillonite and mixed-layer illite-montmorillonite; silt and sand grains mainly quartz and calcite, some feldspar, dolomite, and gypsum. Claystone: beds from 1 in. to several feet thick; medium consistency where weathered to hard where nonweathered; PVC rating 1.2-5.0, noncritical to critical, swell index 1070-3590 psf; olive gray to mottled medium gray to black. Siltstone and sandstone: beds generally less than 2 ft thick; soft where weathered to very stiff where nonweathered; PVC rating 0.5-2.9, noncritical to marginal, swell index 550-2400 psf; cemented, partly by calcium carbonate, partly by clay; yellowish brown to dark olive gray. Attitude: strike varies, consistently west of north, dip 54°-60° eastward. Jointing: inconspicuous, random, short, irregular, numerous. Contacts: gradational with map unit ms-ss below (west) and map unit ms-cs above (east), and with map unit ms-ss between the subunits; distinct with any overlying surficial units; even.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cs-ms, unit 4]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies nearly flat to gently rolling surface mantled by alluvium and colluvium; hillside slopes as steep as 22° (40 percent).	Two horizons formed by weathering of the exposed cross section of the unit. Upper horizon brown to gray, structureless, clay and silt (CH, MH, CL, some ML), from 1 to 3 ft thick, commonly eroded. Lower horizon olive-gray to mottled gray and black claystone and siltstone broken into fragments from 0.5 to 1.5 in. in diameter that increase in size with depth, generally from 3 to 8 ft thick. Claystone weathers more rapidly than siltstone. Gypsum crystals develop on weathering in basal 100 ft of western subunit.	Excavation: same as map unit ms-cs above. Compaction: same as map unit ms-cs above. Drilling: same as map unit ms-cs above.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cs-ms, unit 4]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: same as map unit ms-cs above. Runoff: same as map unit ms-cs above. Erodibility: same as map unit ms-cs above.	Permeability: negligible through rock, negligible to slow through fractures. Water table: varies greatly from place to place. Yield to wells: no wells reported; very small amounts may be available from rock fractures and sandy beds; better yield may be from base of overlying surficial material. Quality: highly mineralized; iron and sulfate content high; locally may react with some concrete and corrode iron pipe. Use: may be useful for domestic or livestock needs.	Septic fields: same as map unit ms-cs above. Dump sites: generally excellent as excavation easy, but may pollute any water supply present unless sandstone beds sealed.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Very poor to fair; locally clay expands excessively and exerts high swelling pressure when wetted, and shrinks on drying. Differential expansion, and differential settlement, likely if foundation is placed on differing rock types.	Same as map unit ms-cs above.	Same as map unit ms-cs above.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cs-ms, unit 4]

13. Known, reported, and possible uses of material
Same as map unit ms-cs above.

[ms-ss, unit 5]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Siltstone and sandstone. ms-ss	Pierre Shale (Hygiene Sandstone Member only).	Lithology: clayey siltstone and silty claystone; some clayey sandstone (dominant near top of unit). Thickness: from 1 to 900 ft; locally thinned by ancient faulting; apparent thickness greater because of dip. General character: beds from several inches to 2 ft thick, persistent, boundaries even to uneven, distinct to gradational; overconsolidated. Siltstone and sandstone: medium consistency where weathered to dense where nonweathered; silt- to fine-sand-size grains mainly quartz and mica, some glauconite and iron oxides, a little organic material; light gray to yellowish brown. Claystone: soft where weathered to hard where nonweathered; clay mineral mainly illite, some mixed-layer illite-montmorillonite, PVC rating 0.3-1.7, noncritical, swell index 400-1450 psf; light to dark gray. Attitude: strike varies, generally a little west of north; dip from 54° to 60° eastward. Jointing: inconspicuous, random, short, irregular, numerous. Contacts: gradational with map unit cs-sh below (west) and cs-ms above (east); distinct with any overlying surficial units; uneven.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-ss, unit 5]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies gently rolling alluvium and colluvium mantled plains; slopes as steep as 19° (34 percent) on low hills south of Turkey Creek. Exposures scattered, mainly in valley walls and roadcuts.	Surface of sandstone case-hardened in natural exposures. Rock weakened where weathered. Siltstone more resistant than claystone; claystone weathers rapidly to yield clayey silty sand (SM, SC) to depth of about 2 ft.	Excavation: easy in claystone, moderately easy in siltstone and sandstone with heavy equipment, increasingly difficult with depth. Adheres when wet. Compaction: moderately easy with sheepsfoot and rubber-tired rollers. Adheres when wet. Drilling: easy to moderately easy, tends to clog bit.

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: moderate to slow in siltstone, slow to negligible in claystone; slow to moderate through fractures in either. Runoff: Generally moderate to rapid. Erodibility: moderately resistant to gully- and sheetwash, moderately easy by stream scour; vegetation difficult to reestablish on cut slopes steeper than about 19° (35 percent).	Permeability: same as map unit cs-ms above. Water table: same as map unit cs-ms above. Yield to wells: same as map unit cs-ms above. Quality: same as map unit cs-ms above. Use: same as map unit cs-ms above.	Septic systems: generally unsatisfactory as percolation rate low to marginal, locally satisfactory where deeply and well weathered; risk of pollution of ground-water supply moderate. Dump sites: fair, as excavation moderately easy, excavated material can be used for cover; however, risk of pollution of ground-water supply moderate.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-ss, unit 5]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally fair; locally poor where foundation rests on two or more distinctly different kinds of rock because of risk of differential settlement or heaving.	Generally good; may be poor if beds dip downward into opencut or excavation; stability investigation recommended.	Good to fair on gentle slopes; poor on steep hillsides and at top of high cuts.

13. Known, reported, and possible uses of material
Reported source of olive-gray landscape rock.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cs-sh, unit 6]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Claystone and shale. cs-sh	Pierre Shale (from base of *Baculites asperiformis* Zone downward to base of lower transition member). Graneros Shale and Greenhorn Limestone.	Lithology: silty claystone, locally silty shale, some sandy limestone, and a little calcareous sandstone. Subunits: two (separated by map units ls and ms-sh). Eastern subunit mainly silty claystone, a little calcareous sandstone at base; western subunit mainly silty shale in basal two-thirds, sandy limestone in upper one-third. Thickness: eastern subunit from 1 to 650 ft, western subunit from 1 to 280 ft; locally thinned by ancient faulting, apparent thickness greater because of dip. General character: beds from 1 in. to several feet thick, persistent, boundaries even, gradational, overconsolidated; poorly graded; clay minerals mainly mixed-layer illite-montmorillonite, some illite and kaolinite; contains scattered layers 0.25-1.0 in. thick of montmorillonite (bentonite), silt grains mainly quartz. Claystone: soft where weathered to hard where nonweathered; PVC rating 2.5-3.1, marginal, swell index 2100-2500 psf; light gray to dark brown. Shale: stiff where weathered to very hard where nonweathered; PVC rating 0.8-1.8, noncritical, swell index 800-1550 psf; mottled gray to black. Limestone: thin-bedded; hard. Sandstone: thin-bedded, dense, sand grains mainly quartz; cemented by calcium carbonate. Attitude: strike varies, consistently west of north, dip from 35° eastward to 52° westward (overturned). Jointing: generally inconspicuous, random, irregular, short, numerous. Contacts: gradational with map units ss-ms-cs below (west), map unit cs-ms above (east), and map unit ms-sh between; distinct with any overlying surficial units; uneven.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cs-sh, unit 6]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies gently rolling surface at base of east flank of Dakota Hogback, locally underlies that flank. Exposures mainly scattered along roadcuts and drainageways.	Two horizons formed by weathering of the exposed cross section of the unit. Upper horizon light-gray clay (CL, CH, MH) from 2 to 4 ft thick, commonly eroded away. Lower horizon brown to black claystone and shale broken into irregular angular fragments from 0.5 to 6 in. in diameter that increase in size with depth; from 2 to 8 ft thick. Claystone weathers more rapidly than sandstone or limestone.	Excavation: easy, to base of weathered, fractured material with most power equipment including tractor-drawn scrapers and backhoes; moderately difficult where nonweathered, or in limestone or sandstone beds; these require heavy equipment including heavy rippers and scrapers. Compaction: same as map unit cs-ms above. Drilling: same as map unit cs-ms above.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cs-sh, unit 6]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: same as map unit cs-ms above. Runoff: same as map unit cs-ms above. Erodibility: same as map unit cs-ms above.	Permeability: low in limestone and sandstone, negligible in claystone and shale, high through fractures. Water table: as shallow as 6 ft locally, but varies greatly from place to place. Yield to wells: a single reported well yields 9 gpm, with artesian flow during winter. Quality: hard to very hard; iron content high. Use: single reported well used for domestic needs.	Septic fields: same as map unit cs-ms above. Dump sites: generally excellent except where risk of ground-water pollution is moderate, as in some limestone and sandstone beds.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Poor to fair. Locally clay expands excessively and exerts high swelling pressure when wetted, and shrinks on drying. Differential swell or settlement likely if foundation is placed on differing rock types. Foundation investigations recommended before building.	Same as map unit cs-ms above.	Same as map unit cs-ms above.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cs-sh, unit 6]

13. Known, reported, and possible uses of material
Same as map unit cs-ms above.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-sh, unit 7]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Siltstone and shale. ms-sh	Niobrara Formation (Smoky Hill Shale Member only). Carlile Shale.	Lithology: siltstone, silty to sandy shale, and claystone (clayey chalk); a little silty sandstone and shaly to sandy limestone. Subunits: two, separated by other map units. Thickness: eastern subunit from 50 to 250 ft; western subunit from 50 to 250 ft; apparent thickness increased by dip; locally thinned by ancient faulting. General character: beds thin, persistent, boundaries even, gradational; overconsolidated; poorly graded. Siltstone and sandstone: medium consistency where weathered to firm where nonweathered; grains mainly quartz, feldspar, and calcite; well to poorly cemented by calcium carbonate; yellowish brown to dark gray. Shale and claystone: soft where weathered to very firm where nonweathered; mainly clay minerals, illite more abundant than mixed-layer illite-montmorillonite, PVC rating 0.0-0.9, noncritical, swell index to 850 psf; light gray to black. Chalk and limestone: chalk mainly calcareous organic matter, weak where weathered to firm where nonweathered, limestone weathered or nonweathered; light brown to yellowish orange. Attitude: strike a little west of north, dip 33° eastward to 54° westward (overturned). Jointing: inconspicuous numerous, short, irregular, random. Contacts: gradational with map unit cs-sh below (west) and above (east), and with map unit ls below (west) of upper eastern subunit, distinct with map unit ls above (east) of the lower (western) subunit, distinct with any surficial units; even.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-sh, unit 7]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies flat to gently rolling bedrock surface mantled by alluvium and colluvium; slopes locally as steep as 24° (47 percent). Exposures well scattered, mainly in roadcuts and valley walls.	Rock weak where weathered. Two horizons formed by weathering of the exposed unit. Upper horizon of clayey to sandy silt (ML, CL) from 1 to 2 ft thick but commonly eroded; yellowish brown to olive brown. Lower horizon of siltstone and shale, broken into irregular, angular fragments that increase in size with depth; from 2 to 6 ft thick; irregularly mottled yellowish gray; base of each horizon gradational.	Excavation: easy to base of weathered rock with most power equipment including tractor-drawn scrapers and backhoes; adheres when wet. Increasingly difficult with depth, requires heavy equipment including rippers where little fractured. Difficult in beds of strong sandstone and limestone. Compaction: easy for shale, claystone, and siltstone with sheepsfoot and rubber-tired rollers; moderately easy for sandstone and limestone with steel-wheeled rollers. Adheres when wet; trafficability poor when wet.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-sh, unit 7]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: same as map unit cs-ms above. Runoff: same as map unit cs-ms above. Erodibility: same as map unit cs-ms above.	Permeability: same as map unit cs-ms above. Water table: same as map unit cs-ms above. Yield to wells: same as map unit cs-ms above. Quality: moderately mineralized, sulfate content high, locally may react with some concrete and corrode steel pipe. Use: probably useful for livestock.	Septic fields: same as map unit cs-ms above. Dump sites: same as map unit cs-ms above.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally good.	Same as map unit cs-ms above.	Same as map unit cs-ms above.

13. Known, reported, and possible uses of material
Possible source of good quality impervious fill and binder material.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[$\overline{\text{ls}}$, unit 8]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Limestone. $\overline{\text{ls}}$	Niobrara Formation (Fort Hays Limestone Member only). Lykins Formation (Forelle Member only--the Glennon Limestone Member of LeRoy (1946), as used in the engineering geology map of the adjacent Golden quadrangle by Gardner, Simpson, and Hart (1971)).	Lithology: clayey to silty limestone. Subunits: two (separated by other map units). Eastern belt mainly clayey limestone, western belt mainly silty limestone. Thickness: eastern belt about 30 ft; western belt from 10 to 21 ft; apparent thicknesses greater because of dip. General character: Clayey limestone: beds from 1 to 4 ft thick, persistent; boundaries even and distinct; includes beds of calcareous claystone as much as 4 ft thick, and a basal bed of very sandy limestone from 1 to 2 ft thick; hard; light gray to yellowish gray. Silty limestone: beds generally less than 0.25 in. thick, discontinuous boundaries uneven ("crinkled") and abrupt; hard; mainly calcite and dolomite, a little quartz filling small cavities; white to light gray or pink. Attitude: strike a little west of north; dip 22°-77° eastward. Jointing: moderately conspicuous, random, irregular, short, moderately numerous. Contacts: distinct with map unit ms-sh below (west) and above (east) the eastern subunit, and with map unit ms below (west) and above (east) the western subunit, distinct with any overlying surficial units; even.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[$\overline{ls}$, unit 8]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies two low rounded discontinuous ridges; the eastern ridge lies along the base of the eastern flank of the Dakota Hogback; the western ridge is between the hogback and the mountain front. Exposures commonly mark crests of ridges.	Surface generally rounded and pitted by weathering and solution; otherwise moderately resistant to weathering; rock of eastern belt yields shaly chips.	Excavation: eastern belt moderately difficult to difficult; may be workable locally with heavy tractor-drawn rippers; western belt probably moderately easy, probably workable with heavy rippers, perhaps with heavy scrapers. Compaction: eastern belt may require crushing and mixing with binder material before compaction. Steel-wheeled rollers and earthmoving equipment suggested. Western belt may not require processing; rubber-tired rollers or earthmoving equipment suggested. Drilling: moderately difficult, eastern belt; and easy, western belt.

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: slow through rock, moderate through fractures. Runoff: moderate to rapid. Erodibility: moderately resistant in both belts to sheet- and gully-wash, and to stream scour; low resistance to solution in eastern belt, moderately high in western belt.	Permeability: low through rock, high through fractures and along bedding boundaries. Water table: not known, probably varies greatly from place to place. Yield to wells: not known, probably small. Quality: not known, probably hard. Use: possibly useful for domestic or livestock needs.	Septic fields: unsatisfactory as difficult to excavate, makes poor cover material, risk of polluting possible ground-water supply. Dump sites: very poor, for same reasons as above.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[$\overline{ls}$, unit 8]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Excellent if building wholly within one subunit; poor due to differential heave or settlement if structure is partly founded on an adjacent map unit.	Generally good; risk of rockslide if bedding boundaries or fractures dip downward into a cut or excavation; some risk of rockslide on dip slopes; inspection of rock exposures upslope of building sites recommended.	Good; some risk of rocksliding caused by natural or manmade vibrations.

13. Known, reported, and possible uses of material
Reported former source of building stone, foundry (smelter?) flux, and agricultural lime. Oil show reported in Lillie Pallaoro 1 well, drilled in NE 1/4 NW1/4 sec. 7, T. 5 S., R. 69 W.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[$\overline{ss}$-ms-cs, unit 9]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Sandstone, and siltstone and claystone. $\overline{ss}$-ms-cs	Dakota Group: South Platte Formation and Lytle Formation.	Lithology: sandstone, siltstone, and silty to sandy claystone, some conglomerate; conglomerate and sandstone dominant in basal (westernmost) 30-100 ft, siltstone in middle part, sandstone in upper (easternmost) part. Thickness: from 1 to 300 ft, locally thinned by ancient faulting, apparent thickness greater because of dip. General character: beds from a few inches to 50 ft thick, discontinuous, boundaries even to uneven, distinct to abrupt; overconsolidated. Sandstone: loose where weathered to very dense where nonweathered; poorly graded, locally crossbedded and ripple marked; mainly fine to medium grained, rounded to subrounded, almost wholly quartz; cement mainly silica, some iron oxides; light yellowish brown to light gray. Siltstone: similar to sandstone above but finer grained. Claystone: soft where weathered to very hard where nonweathered; clay minerals mainly kaolinite, illite, and mixed-layer illite-montmorillonite, PVC rating 0.1-0.3, noncritical, swell index 250-400 psf; dark gray to greenish gray. Conglomerate: similar to sandstone but contains stones as much as 3 in. in diameter of quartz, chert, and granite. Attitude: strike varies, consistently somewhat west of north; dip from 26° eastward to 53° westward (overturned). Jointing: conspicuous, in two principal sets, short, moderately numerous; yields blocky stones as much as about 12 ft on a side. Contacts: gradational with map unit ms-cs-$\overline{ls}$ below (west), distinct with unit cs-sh above (east), and any overlying surficial units; even to uneven.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[$\overline{ss}$-ms-cs, unit 9]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies crest and eastern flank of Dakota Hogback; slopes as steep as 35° (70 percent). Natural exposures generally along crest, on flank, and in roadcuts and valley walls.	Where naturally exposed, sandstone surface generally case-hardened; claystone and siltstone generally weathers to silty, sandy clay (CL, some SC). Sandstone and conglomerate much more resistant to weathering than claystone and siltstone.	Excavation: difficult with heavy rippers and bulldozers; blasting may be required locally, especially in cliff-forming beds of sandstone and conglomerate; siltstone and claystone somewhat easier. Compaction: moderately difficult, generally requires mixing with binder material before compaction; earth-moving equipment and steel-wheeled rollers suggested; rubber-tired rollers may be useful. Drilling: difficult, especially in sandstone and conglomerate.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[$\overline{ss}$-ms-cs, unit 9]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: generally slow in siltstone and claystone, slow to moderate in sandstone and conglomerate; rapid through fractures. Runoff: moderate to rapid. Erodibility: resistant to stream scour, gully- and sheetwash.	Permeabiliity: slow to moderate through rock, high through fractures. Water table: varies from place to place. Yield to wells: as great as 25 gpm, average 14 gpm; all wells east of outcrop area show artesian rise; one reports artesian flow; pressure gradient slopes eastward from outcrop area. Quality: slightly mineralized, moderately hard to hard; iron content generally very high. Use: primarily for domestic needs, also for livestock and irrigation.	Septic fields: unsatisfactory because difficult to excavate, and high risk of polluting ground-water supply. Dump sites: same as above.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[$\overline{ss}$-ms-cs, unit 9]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Excellent, provided slope stability satisfactory (see column 11).	Very poor. Debris and loose blocks may slide or fall from cliffs or ledges along steeper western slopes of hogback ridges. On gentler eastern slopes debris and blocks slide readily on east-sloping bedding surfaces, especially on thin clay layers between coarse-grained layers that yield blocks. Blocks can fall from cut faces, and slide into excavations where bedding surfaces slope downward into them. Inspection of site, and of exposures upslope, recommended before building.	Excellent where risk of damage from rockfalls and rockslides absent.

13. Known, reported, and possible uses of material
Source of clay for brick, firebrick, and tile products; formerly used for nonrefractory grade china; a source of "lichen-rock" for landscaping.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-cs-$\overline{ls}$, unit 10]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Siltstone, claystone, and limestone. ms-cs-$\overline{ls}$	Morrison Formation. Ralston Creek Formation.	Lithology: siltstone and sandy claystone; some sandstone and dolomitic, silty limestone and silty gypsum; sandstone mainly in middle part, gypsum present only in basal 50 ft south of Bear Creek. Thickness: from 350 to 400 ft; apparent thickness greater because of dip. General character: beds from several inches to 50 ft thick, persistent to discontinuous, boundaries even to very uneven, overconsolidated. Siltstone and sandstone: siltstone stiff where weathered to hard where nonweathered, sandstone dense, moderately well graded; sandstone locally crossbedded; grains mainly quartz, some calcite, dolomite, and chalcedony; moderately well to well cemented by calcium carbonate and silica; light gray or yellowish brown to light red. Claystone: soft, where weathered to hard where nonweathered; poorly graded; clay minerals mainly illite and mixed-layer illite-montmorillonite, kaolinite dominant in scattered beds, PVC rating 0.4-1.1, noncritical, swell index 500-1000 psf; pink or light gray to light green. Limestone: beds less than 1.5 ft thick; hard to very hard. Gypsum: soft to stiff; generally light gray to white, locally black. Attitude: strike varies, mainly a little west of north, dip from 38° eastward to 75° westward (overturned). Jointing: inconspicuous, random, short, irregular, numerous. Contacts: distinct with map unit ms below (west), gradational with $\overline{ss}$-ms-cs above (east); distinct with any overlying surficial units; uneven.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-cs-$\overline{\text{ls}}$, unit 10]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies west flank of Dakota Hogback; steepest slopes about 25° (47 percent); exposures, other than those of hard layers, are scattered in roadcuts and valley walls.	Where naturally exposed surface of siltstone and sandstone beds commonly case hardened. Siltstone and claystone generally weakened in weathered zone; limestone surface roughened and pitted by solution, gypsum surface roughened and darkened; claystone generally altered to silty sandy clay at surface, and broken into angular fragments that increase in size to a depth of from 3 to 6 ft.	Excavation: generally moderately easy with most power equipment including tractor-drawn scrapers and backhoes, becomes increasingly difficult with depth; sandstone and limestone beds moderately difficult with heavy ripers and scrapers; blasting may be required locally. Claystone may adhere when wet. Compaction: easy for claystone and most siltstone, sheepsfoot- and rubber-tired rollers commonly used; moderately difficult for some siltstone, sandstone, and limestone, steel-wheeled rollers suggested. Claystone may adhere when wet. Drilling: easy in most rock types to moderately difficult in sandstone and limestone; claystone may clog toothed bits.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-cs-$\overline{ls}$, unit 10]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: slow in sandstone and limestone, negligible in claystone and siltstone; rapid through fractures. Runoff: moderate to rapid. Erodibility: moderately resistant to sheetwash, moderately easily eroded by gully-wash and stream scour; difficult to reestablish vegetation on steep slopes.	Permeability: low in sandstone, negligible in other rock types. Water table: not reported. Yield to wells: no wells known. Quality: probably highly mineralized. Use: probably useful for livestock needs.	Septic fields: generally unsatisfactory because percolation rate commonly negligible; may be satisfactory locally in sandstone. Dump sites: poor because slopes too steep, and locally difficult to excavate. Risk of ground-water pollution moderate.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally fair, may be poor locally where foundation rests on beds of different rock types because of possibility of differential settlement. Gypsum beds near base of unit south of Turkey Creek might be unsuitable for foundations because of potentially high solution rate.	Generally good as beds dip into slope; locally hazardous because of risk of rockfalls from exposed ledges within this map unit, or from ledge of sandstone ($\overline{ss}$-ms-cs) unit upslope. Stability investigation recommended.	Generally good, might have risk of rockfalls from ledges upslope.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms-cs-ls, unit 10]

13. Known, reported, and possible uses of material
Source of poor-quality clay for brick and tile; gypsum has been mined south of Turkey Creek. Source of fill satisfactory for general use.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms, unit 11]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Siltstone. ms	Lykins Formation (only upper and lower parts).	Lithology: clayey to sandy siltstone, a little sandstone and limestone. Subunits: two (separated by map unit ls). Thickness: eastern subunit 280-290 ft, western subunit 100-125 ft; apparent thickness greater because of dip. General character: Siltstone: beds 1 in. to 4 ft thick, persistent, boundaries uneven, distinct; overconsolidated; soft where weathered to hard where nonweathered; poorly graded; clay minerals chiefly illite, some mixed layer illite-montmorillonite, PVC rating noncritical; sand and silt grains mainly quartz, calcite, and mica; moderately cemented, mainly by clay and iron oxides; light gray to dark red. Sandstone: beds generally less than 1 ft thick, locally more than 5 ft; soft where weathered to hard where nonweathered; generally fine grained, pebbly near base of western subunit; sand grains mainly quartz, calcite and mica; well cemented by clay and iron oxides. Limestone: beds thin; hard; yellowish brown to pink. Attitude: strike varies from northwest to nearly north, dip ranges from 22° to 77° eastward. Jointing: commonly conspicuous, random, short, numerous. Contacts: distinct with map unit ss below (west), map unit ms-cs-ls above (east), with map unit ls between subunits, and with any overlying surficial units; uneven.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms, unit 11]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies shallow valley between west flank of Dakota Hogback and mountain margin. Poorly exposed, mainly in walls of drainageways; maximum slopes about 30° (58 percent).	Generally weathered to clayey sandy silt to depth of 2-6 ft; sandstone and limestone weather a little slower than the siltstone.	Excavation: Generally easy to base of weathered material with most power equipment including tractor-drawn scrapers and backhoes; increasingly difficult with depth, may require heavy equipment where nonweathered, very hard beds may require blasting locally, may adhere when wet. Compaction: generally easy, locally moderately easy, with earthmoving equipment and smooth-tired rollers; may adhere when wet. Drilling: generally moderately easy, hard limestone may be more difficult.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms, unit 11]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: negligible to very slow through rock, rapid through fractures. Runoff: generally rapid. Erodibility: moderately easily eroded by gully-wash and stream scour, and easily eroded by sheetwash, where weathered; moderately resistant to all where nonweathered.	Permeability: negligible to very low through rock, rapid through fractures. Water table: probably varies greatly from place to place. Yield to wells: single reported well yielded 177 gpm, in part from artesian flow; source of that supply apparently at contact of this map unit with underlying map unit ($\overline{ss}$) at a depth of more than 600 ft. Quality: not known, iron content probably high. Use: single reported well used for commercial purposes.	Septic field: generally unsatisfactory as locally difficult to excavate, and rate of percolation too slow; may be satisfactory where deeply weathered. Dump sites: generally satisfactory as unit is of low permeability; layers of sandstone and limestone should be sealed to prevent leakage.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[ms, unit 11]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally good; fair if foundation placed on multiple rock types which could cause differential settlement.	Generally good; poor to very poor if beds dip downward into excavations.	Good.

13. Known, reported, and possible uses of material
Possible source of fill of fair quality.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[$\overline{ss}$, unit 12]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Sandstone. $\overline{ss}$	Lyons Sandstone.	Lithology: sandstone and conglomerate; conglomerate mainly in upper (eastern) one-third of unit. Thickness: from 115 to 200 ft; apparent thickness greater because of dip. General character: beds from several inches to several feet thick, discontinuous, boundaries uneven, distinct to abrupt; locally crossbedded. Sandstone: dense where weathered to very dense where nonweathered; generally poorly graded, locally moderately well graded; some beds more than 5 ft thick, locally crossbedded; sand mainly medium grained, subrounded, frosted, composed mainly of quartz; well to poorly cemented by silica; light gray to light yellowish brown. Conglomerate: distinguished by rounded, equidimensional stones of quartz and chert as much as 3 in. in diameter. Attitude: strike a little west of north; dip 21°-71° eastward. Jointing: conspicuous; spacing, orientation, and continuity all vary locally. Contacts: gradational with map unit $\overline{cgl\text{-}ms}$ below (west), distinct with map unit ms above (east), and with any overlying surficial units; uneven.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[$\overline{ss}$, unit 12]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies crest of low ridge between mountain front and Dakota Hogback. Exposures numerous, scattered along ridge crest; have rounded profile.	Weathering weakens cementation to shallow depth, yields thin veneer of sand to pebbly sand (SM, SP-GP).	Excavation: difficult, has been worked with heavy tractor-drawn rippers, locally requires blasting. Compaction: difficult, generally requires mixing with binder material before compaction, earthmoving equipment and smooth-tired rollers suggested, perhaps steel-wheeled rollers. Drilling: moderately difficult.

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: moderate, rapid through fractures. Runoff: moderate. Erodibility: resistant to sheet- and gully-wash, and to stream scour.	Permeability: moderate, high through fractures, and where weathered. Water table: not known; probably varies greatly from place to place, may locally contain water under artesian pressure at depth. Yield to wells: 6 gpm reported in single well. Quality: probably moderately mineralized. Use: domestic and livestock.	Septic fields: unsatisfactory; difficult to excavate, possibly insufficient cover material available, rapid percolation through fractures with insufficient aeration, risk of effluent surfacing, and risk of pollution of possible water supply. Dump site: poor, for same reasons as above.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[$\overline{ss}$, unit 12]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Excellent.	Debris and blocks may slide on dip slope; risk of rock-slide on bedding planes or fractures if they dip downward into opencut or excavation; inspections for loose rock above building sites recommended.	Excellent where risk of rockslide absent.

13. Known, reported, and possible uses of material
Possible source of landscape rock.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cgl-ms, unit 13]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the physical character of the engineering geologic map unit
Conglomerate, and siltstone. cgl-ms	Fountain Formation.	Lithology: conglomeratic sandstone and conglomerate, some siltstone; siltstone mainly interbedded in lower (western) part. Thickness: 1000-1650 ft; apparent thickness greater because of dip. General character: beds from a few inches to several tens of feet thick, discontinuous; boundaries uneven, abrupt; dense. Conglomeratic sandstone and conglomerate: commonly crossbedded, numerous filled stream-channels; dense, firm to friable; well graded; sand-size grains chiefly quartz and feldspar, pebbles, and cobbles as much as 10 in. in diameter, of granite, pegmatite, quartzite, and gneiss; well to poorly cemented, mainly by calcium carbonate and iron oxides; moderate reddish brown to yellowish gray. Siltstone: similar to above, but much finer grained; beds a few inches thick; micaceous; locally mud-cracked; dark reddish brown. Attitude: strike a little west of north; dip 31^{o}-55^{o} eastward. Jointing: conspicuous, short to extensive, irregular, random, few. Contacts abrupt with map units gg and bg below and west, gradational with map unit ss above (east); distinct with any overlying surficial units; uneven.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cgl-ms, unit 13]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Mainly underlies moderately steep rolling slopes of alluvium and colluvium along mountain margin; bare erosional remnants form massive "monuments" in Red Rocks Park and elsewhere.	Effect on bare rock same as map unit ss. Where overlain by surficial materials, uppermost 3 ft commonly leached of cement and disintegrated to silty clayey sand and gravel (SC, GC, SM, GM). Unit overlies metamorphic rock (map units bg and gg) which is locally deeply weathered so as to yield silty clayey sandy gravel also.	Excavation: difficult, probably requires blasting locally in upper part; may be workable locally with heavy tractor drawn rippers. Compaction: difficult, generally requires crushing and mixing with binder material before compaction; earthmoving equipment and steel-wheeled rollers suggested. Drilling: difficult.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cgl-ms, unit 13]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: moderate to slow, rapid through fractures. Runoff: moderate to rapid. Erodibility: very resistant to sheet- and gully-wash, and to stream scour.	Permeability: generally low to moderate in rock, moderate to high in weathered part; high in fractures. Water table: not known, probably varies greatly from place to place. Yield to wells: 13 gpm in single well reported; springs in Red Rocks Park along basal contact yield from 1 to 15 gpm. Quality: highly mineralized, very hard; sodium; iron, sulfate, and chloride content high; spring water has little mineral content. Use: domestic and livestock.	Septic fields: generally unsatisfactory; percolation through fractures too rapid, and risk of possible pollution of ground-water supply. Dump site: very poor, because of risk of polluting ground-water supply, and difficulty of excavation.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Excellent.	Generally good to excellent; risk of rockslide on bedding planes or fractures if dip is downward into open-cut or excavation; inspection for loose rock above building sites recommended.	Excellent where risk of rockslides absent.

Table 2.--Generalized description of the engineering geologic characteristics of the sedimentary bedrock--Continued

[cgl-ms, unit 13]

13. Known, reported, and possible uses of material
Possible source of landscape rock.

1/For detailed discussion of fossil zones in the Pierre Shale (see Scott and Cobban, 1965).

2/Relative density and consistency determined by Standard Penetration test (American Society for Testing and Materials, 1964, D1586) performed in the laboratories of various private consulting firms practicing in the fields of engineering geology and civil engineering.

3/Potential volume change (Lambe, 1960).

4/Unified Soil Classification (U.S. Army Corps of Engineers, Waterways Experiment Station, 1953).

5/Based mainly on equipment observed in use and in part on Table VI-2 (Asphalt Institute, 1969).

Table 3.-- Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock

By Howard E. Simpson and Stephen S. Hart

[gt, unit 1]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Granitic rocks. gt	Gneissic quartz monzonite and granodiorite. Quartz diorite.	Feldspar- and hornblende-rich igneous rock, contains some biotite and quartz; in part metamorphosed; extends downward to great depth; massive; hard, very tough; medium to coarse grained; in part foliated; black and white to gray. Contains numerous discontinuous tabular dikes with differing attitudes and from several feet to several tens of feet thick, composed of feldspar- and quartz-rich igneous rock; hard, very tough; very coarse grained; grayish orange. Jointing: distinct, generally two sets and locally three, principal set trends northwest, dips steeply eastward. Contacts: distinct, uneven.

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies rolling surface on crests of low mountains; locally well exposed in canyons and valley walls.	Generally well weathered ("rotted"). Locally disintegrated, decomposed, and oxidized yielding silty to clayey sand and gravel, stained orange brown with iron oxides. Grades downward into disintegrated and oxidized sand and gravel, stained yellowish brown to orange brown, that retains general appearance of unweathered rock; farther downward grades into unweathered rock. Depth to base of weathered zone varies greatly.	Excavation: very difficult where unweathered, generally requires blasting; easy to moderately easy where well weathered, may be excavated with front-end loaders[1/]; heavy rippers may be useful where less well weathered. Compaction: very difficult if unweathered, may require crushing and mixing with binder material; steel-wheeled rollers commonly used. Moderately easy with rubber-tired rollers if disintegrated. Drilling: moderately easy where disintegrated, moderately difficult where unweathered.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[gt, unit 1]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: negligible into unweathered rock, slow to moderate where weathered; moderate to high along fractures. Runoff: high where unweathered, moderate where weathered. Erodibility: generally very resistant to sheetwash, gullywash, and stream scour where unweathered; moderately resistant where weathered.	Permeability: negligible in unweathered rock, moderate to high through fractures and where weathered. Water table: varies greatly from fracture to fracture. Yield to wells: undeveloped. Quality: unreported. Use: unreported.	Septic systems: probably unsatisfactory. Percolation through rock negligible; too fast through joints, so effluent aeration insufficient, may cause pollution of ground-water supply; risk of effluent surfacing moderate to great; excavation difficult unless rock well weathered; sufficient material for cover may be lacking. Dump sites: unsatisfactory. Excavation difficult unless rock well weathered; fast percolation through joints may cause pollution of ground water; risk of effluent surfacing moderate to great; satisfactory material for cover probably absent.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Excellent in unweathered rock; good where weathered.	Good to excellent; locally hazardous as risk of rock falls and small rock slides moderate along steep-walled valleys; safe angle of cut slope locally controlled by orientation of major joint sets.	Excellent where rockfall and rock-slide hazard absent.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[$\overline{gt}$, unit 1]

13. Known, reported, and possible uses of material
Possible local source of good quality crushed aggregate and riprap; access commonly very difficult.

[$\overline{bf}_3$ / [$\overline{bf}_2$ | $\overline{bf}$, unit 2]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Basaltic lava-flow rock. $\overline{bf}_3$ / $\overline{bf}_2$ | $\overline{bf}$	Table Mountain Shoshonite. Monzonite.	Feldspar- and pyroxene-rich igneous rock; thickness ranges from 50 to 150 ft; hard, very tough; consists of mineral grains as much as 0.25 in. in diameter in a matrix of very minute grains; homogeneous; specific gravity 2.8 to 2.9; medium dark gray to grayish or greenish black. Constitutes two lava flows: the upper ($\overline{bf}_3$), locally removed by erosion, as much as 60 ft thick; lower flow ($\overline{bf}_2$), as much as 90 ft thick (the lowermost flow, $\overline{bf}_1$, is not present in this quadrangle). Jointing: conspicuous, short, irregular, random, numerous; form moderately crude columns from 1 to several feet in diameter. Contacts: abrupt, very uneven.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[$\overline{bf}_3$ / $\overline{bf}_2$ | $\overline{bf}$, unit 2]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Underlies mesa surface which is undulatory to nearly flat and inclined gently toward southeast; margins steep to vertical.	Weathers to light brown and light gray where exposed; covered by as much as 2 ft of sandy clay consisting of disintegrated and weathered basaltic rock intermixed with windblown sediment.	Excavation: very difficult, requires blasting. Compaction: difficult, generally requires crushing and mixing with binder material; steel-wheeled rollers suggested if material coarse, rubber-tired rollers if fine. Drilling: difficult.

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: negligible into rock, moderate to high into fractures. Runoff: moderate to rapid. Erodibility: very resistant to stream scour, gully- and sheetwash.	Permeability: negligible through rock, moderate to high through fractures. Water table: not reported, may be absent, especially near margin, but may be present near center of mesa at or near base of unit, perched on underlying unit. Yield to walls: unreported. Quality: unreported. Use: unreported.	Septic systems: unsatisfactory. Percolation through rock negligible, too fast through joints, so effluent aeration insufficient, thus may cause pollution of ground-water supply; risk of effluent surfacing at mesa margins moderate to great; excavation difficult; sufficient material for cover lacking. Dump sites: unsatisfactory. Excavation difficult; fast percolation through joints may pollute ground water; risk of effluent surfacing at mesa margins moderate to great; satisfactory material for cover absent.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[$\overline{bf}_3$ / $\overline{bf}_2$ | $\overline{bf}$, unit 2]

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally excellent; caution advised within 25 ft of margins of excavations or natural steep faces because of hazard of instability.	Generally good; locally moderate because of risk of rocks rolling and bounding downslope for as much as a few hundred feet, from natural faces, or from margins of large excavations.	Generally good, except for risk of rock falls within 25 ft of margins of large excavations and natural steep faces because of either natural or manmade vibrations.

13. Known, reported, and possible uses of material
Potential source of crushed aggregate and road metal; formerly a source of riprap and dimension stone; has high specific gravity and strength.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[$\overline{d}$, unit 3]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Basaltic dike rock. $\overline{d}$	Shonkinite. Diabase. Biotite latite. Lamprophyre. Hornblendite.	Feldspar- or hornblende-rich igneous rock, locally contains some quartz, biotite, or pyroxene. Occurs as tabular dikes as much as several feet thick and half a mile long, and irregular lenticular bodies as much as 250 ft wide and 500 ft long. May extend downward to great depth; massive; hard, tough to very tough; in part medium to coarse grained, in part very fine or very coarse grained; specific gravity about 2.8; individual dikes homogeneous; medium dark gray to reddish gray to greenish black. Jointing: inconspicuous, extensive, irregular, random, numerous. Contacts: abrupt, uneven.

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Low ridges and broad flattened areas that stand a few feet higher than the adjacent terrain.	Weathering causes hairline fractures near surface and oxidation of surface minerals to moderate reddish-brown color.	Excavation: very difficult; generally requires blasting. Compaction: very difficult; binder material may be needed, steel-wheeled rollers suggested. Drilling: very difficult.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[$\overline{d}$, unit 3]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: negligible into rock, slow into fractures. Runoff: rapid. Erodibility: resistant to very resistant to sheet- and gully-wash; resistant to stream scour.	Permeability: negligible through rock, negligible to low through fractures. Water table: unreported. Yield to wells: undeveloped. Quality: unreported, probably very high iron content. Use: unreported.	Septic systems: same as map units $\overline{bf}_2$ and $\overline{bf}_3$ above. Dump sites: same as map units $\overline{bf}_2$ and $\overline{bf}_3$ above.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Excellent.	Generally excellent, locally may be subject to rock fall.	Excellent where hazard of rock fall absent.

13. Known, reported, and possible uses of material
Possible source of crushed aggregate, road metal and riprap, with high specific gravity and strength.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[$\overline{bg}$, unit 4]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Biotitic gneiss. $\overline{bg}$	Garnetiferous biotite-quartz plagioclase gneiss. Biotite-quartz-plagioclase gneiss.	Quartz- and feldspar-rich metamorphic rock with some biotite and, locally, garnets; extends downward to great depth; massive; brittle to tough; fine to medium grained, garnets as much as 3 in. in diameter; moderately distinct light and dark banding from 1 to 2 ft thick, characterized by uneven, roughly parallel mica flakes (foliation) that strike nearly east and dip 20^{o}-80^{o} southward. Contains numerous discontinuous tabular bodies (dikes) of pink medium- to coarse-grained granite and black amphibole-rich gabbrolike rock, from 6 in. to 2 ft thick and from 10 to 150 ft long, and oriented parallel to foliation. Jointing: conspicuous to inconspicuous, short, irregular, random, numerous; 1 or 2 sets, mutually perpendicular, principal set trends north, dips steeply westward. Contacts: generally gradational, with dikes abrupt; uneven.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[$\overline{bg}$, unit 4]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Strongly rolling hills, with many low rounded exposures of rock.	Most exposed rock, weathered reddish- to yellowish-brown. On hilltops disintegrated and decomposed to dense clayey sand and gravel, stained reddish brown with iron oxides (constitutes map unit Sc where more than 5 ft thick); grades downward into thoroughly fractured, strongly oxidized rock, progressively less fractured and oxidized rock, and finally unweathered rock. Base of weathered rock very uneven; oxidation may extend downward several tens of feet along major fractures.	Excavation: generally moderately difficult to difficult with heavy rippers and scrapers where well weathered; blasting probably required where not well weathered. Compaction: very difficult; may require crushing and mixing with binder material, steel-wheeled and rubber-tired rollers suggested. Drilling: moderately difficult to difficult.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[$\overline{bg}$, unit 4]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: negligible into rock, moderate to high through fractures. Runoff: rapid where unweathered, moderate where weathered. Erodibility: very resistant to gully- and sheetwash, and to stream scour, where unweathered; moderately resistant where weathered.	Permeability: moderate to high through fractures and where weathered, negligible below depth of a few hundred feet. Water table: commonly 30-50 ft below surface. Yield to wells: ranges from less than 1 gpm to more than 15 gpm. Quality: moderately mineralized, soft to very hard; iron content high to very high. Use: domestic.	Septic systems: same as map unit $\overline{gt}$ above. Dump sites: same as map unit $\overline{gt}$ above.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Excellent in unweathered rock; good where weathered.	Hazardous to fair; risk high of rock falls and rock slides along steep valley sides; regular inspection for movement of rocks upslope of buildings recommended. Safe angle of cut slopes locally controlled by attitude of foliation, compositional layering, and fractures. Hazardous where these are undercut, particularly where fractures are parallel to layering and foliation. Stable highway backslopes cut nearly vertical are common in unweathered rock.	Excellent away from steep slopes; rock fall hazard great along steep slopes and canyon walls.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[bg, unit 4]

13. Known, reported, and possible uses of material
Possible source of crushed aggregate and riprap where unweathered.

[gg, unit 5]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Granitic gneiss. gg	Migmatitic quartzo-feldspathic gneiss.	Quartz- and feldspar-rich metamorphic rock, with some biotite, muscovite, and quartz; extends downward to great depth; massive; hard, tough to very tough; fine to medium grained; in part foliated; not homogeneous; grayish orange to gray to off white. In northern one-third of area contains amphibole-rich rock that forms broad, parallel layers; very hard, very tough; dark gray to black. Contains scattered, locally numerous, quartz- and feldspar-rich very coarse grained lenses and tabular dikes from a few inches to several tens of feet wide and long; hard, tough. Foliation attitude varies: in north half trends east, dips 30°-80° southward; in south half trend varies but commonly south-southeast, dips 20°-80° westward. Jointing: same as map unit bg above. Contacts: generally gradational, abrupt for lenses and dikes, uneven.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[$\overline{gg}$, unit 5]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Strongly rolling hills, with many low, rounded exposures of rock.	Same as map unit $\overline{bg}$ above.	Excavation: same as map unit $\overline{bg}$ above. Compaction: same as map unit $\overline{bg}$ above. Drilling: same as map unit $\overline{bg}$ above.

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: same as map unit $\overline{bg}$ above. Runoff: same as map unit $\overline{bg}$ above. Erodibility: same as map unit $\overline{bg}$ above.	Permeability: negligible through rock, moderate to high through fractures and where weathered, negligible below depth of a few hundred feet. Water table: from 5 to 25 ft below surface, in fractures. Yield to wells: from 1 to 15 gpm, average 3 gpm. Quality: soft to hard, generally moderately hard. Use: domestic.	Septic systems: same as map unit $\overline{bg}$ above. Dump sites: same as map unit $\overline{bg}$ above.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Same as map unit $\overline{bg}$ above.	Same as map unit $\overline{bg}$ above.	Same as map unit $\overline{bg}$ above.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[gg, unit 5]

13. Known, reported, and possible uses of material
Source of good quality crushed aggregate and riprap.

[fr, unit 6]

1. Engineering geologic map unit and symbol	2. Equivalent geologic map units or parts of units	3. Description of the lithologic character of the engineering geologic map unit
Thoroughly fractured rock. fr	Brecciated fault zone.	Thoroughly broken and crushed rock, generally of map unit gg; locally may include other metamorphic rocks and perhaps igneous rock. Constitutes bands as much as 1000 ft wide, extends to great depths. Material ranges from boulder-size fragments to clayey fault-gouge; stones angular, irregular in shape, surfaces commonly striated. Jointing: conspicuous to inconspicuous, short, irregular, random, numerous; locally plugged by fault-gouge or recemented. Contacts: gradational over several tens of feet into nonfractured rock; very uneven.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[fr, unit 6]

4. Topographic expression	5. Weathering and weathering effects	6. Workability
Generally characterized by alined segments of streams, valleys, and other drainage ways, and with saddles in ridges. Best exposed in Bear Creek valley roadcuts.	Generally deeply weathered; locally disintegrated and decomposed to dense to very dense silty to clayey stony sand (SM[2], GM, SC, GC), oxidized orange brown; probably progressively less weathered with increasing depth.	Excavation: ease varies greatly from place to place; moderately easy with rippers and scrapers where well fractured and weathered; difficult where fracturing and weathering less intense; may require blasting where coarsely broken, or where fractures are recemented. Compaction: moderately easy, if well fractured and weathered, with rubber-tired and sheepsfoot rollers; moderately difficult where unweathered and coarsely broken, steel-wheeled rollers suggested. Drilling: moderately easy to moderately difficult, depending on fracturing and weathering.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[fr, unit 6]

7. Surface drainage and erodibility	8. Ground water characteristics	9. Suitability for waste disposal
Infiltration: generally moderate through fractures, negligible through rock. Runoff: moderate. Erodibility: moderately easy where pulverized and not recemented or where well weathered; elsewhere moderately resistant to gully- and sheetwash, and stream scour.	Permeability: negligible through rock, high where thoroughly fractured, moderate where well weathered, low where fractures are recemented. Water table: varies greatly, depends on intensity and openness of fracturing plus content of silt- and clay-size material. Yield to wells: generally 1-3 gpm; large yields (under 75 gpm) may be encountered. Quality: moderately hard, iron content varies from low to moderately high. Use: domestic.	Septic systems: satisfactory where thoroughly fractured and well weathered; probably unsatisfactory where little weathered or recemented; possibly unsatisfactory where difficult to excavate or percolation rate too fast for sufficient aeration of effluent, thus may cause pollution of ground-water supply; risk of effluent surfacing locally moderate to great. Dump sites: possibly unsatisfactory because excavation may be difficult, sufficient cover material commonly lacking, risk of pollution of ground-water supply moderate to high.

10. Foundation stability	11. Slope stability	12. Probable earthquake stability
Generally good to excellent.	Generally fair to good, moderate risk of rock fall or rock slide along steeper valley walls and roadcuts; stability investigations recommended for large open excavations and cuts.	Fair to good.

Table 3.--Generalized description of the engineering geologic characteristics of the metamorphic and igneous bedrock--Continued

[fr, unit 6]

13. Known, reported, and possible uses of material
Source of fill material, and of concrete aggregate and road metal, where well fractured but not well weathered; crushing may be needed locally. Reportedly contains uranium in Sawmill Gulch.

1/ Based mainly on equipment observed in use and in part on Table VI-2, Asphalt Institute (1969).

2/ Unified soil classification (Corps of Engineers, U.S. Army, 1953).