COLORADO GEOLOGICAL SURVEY

DEPARTMENT OF NATURAL RESOURCES

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GEOLOGIC ASPECTS, SOILS AND RELATED FOUNDATION PROBLEMS, DENVER METROPOLITAN AREA, COLORADO

by

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PREFACE

This study was authorized under a contract between the Department of Natural Resources (Colorado Geological Survey) and Willard Owens Associates, Consulting Engineers and Geologists, Denver, Colorado. The purpose of the study was to provide a non-technical summary of the soils and related geologic problems in the Denver Metropolitan area.

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INTRODUCTION

Denver, Colorado is a rapidly growing city located at the west edge of the Great Plains and the east edge of the Front Range of the Rocky Mountains. Although Denver started as a settlement on the banks of Cherry Creek, the metropolitan area now sprawls onto the foothills of the Front Range to the west, and eastward onto the Plains. The Denver Metropolitan area is constantly growing northward and southward and ultimately will be connected directly to the metropolitan areas of Boulder, Fort Collins, Greeley and Colorado Springs.

As the Denver Metropolitan area expands, building developments are being constructed in localities where the soils and geological conditions are not so favorable as in the central part of the area. An awareness of these conditions permits appropriate design and treatment to avoid possible later detrimental effects to structures and roads.

Recognizing the need for a non-technical summary of the soils and related geologic problems in the Denver Metropolitan area, the Colorado Department of Natural Resources (Colorado Geological Survey) on June 10, 1969 authorized a study by Willard Owens Associates, Consulting Geologists and Engineers. This report describes the results of that study. The study area includes approximately 500 square miles in Township 2 South through Township 5 South and Range 67 West through those portions of Ranges 69 West and 70 West of the 6th P.M. which lie east of the Dakota sandstone hogback (Figure 1).

Many governmental agencies and private firms have made extensive soils and geologic studies of various parts of the area (Appendix), but much of the information is of a technical nature and is not usable to a person with little background in geology and engineering. While many of the reports include much information on specific sites, an overall geologic interpretation was necessary to delineate trends and to permit extrapolation of general soils characteristics into adjacent areas.

Data from published and unpublished sources have been synthesized and incorporated into this report in a form that can be used by the general public, planners, engineers, architects, contractors, governmental agencies, and land developers.

Without the cooperation of numerous agencies and individuals, this report could not have been compiled within the time available. Personnel of the U.S. Geological Survey, the Soil Conservation Service, the Corps of Engineers, and the Bureau of Reclamation were most helpful in providing data. Robert M. Lindvall and the late Maxwell E. Gardner of the U.S. Geological Survey and Robert Dansdill and John Sampson of the Soil Conservation Service, in particular, were invaluable in providing unpublished information. The Colorado Highway Department provided information from its files on depth to bedrock and soils descriptions. The Planning Departments of Adams, Arapahoe, Denver, and Jefferson Counties and the Denver Regional Council of Governments supplied information on their areas of concern. The aid of numerous other individuals in offering suggestions on sources of information greatly facilitated the task of compilation.

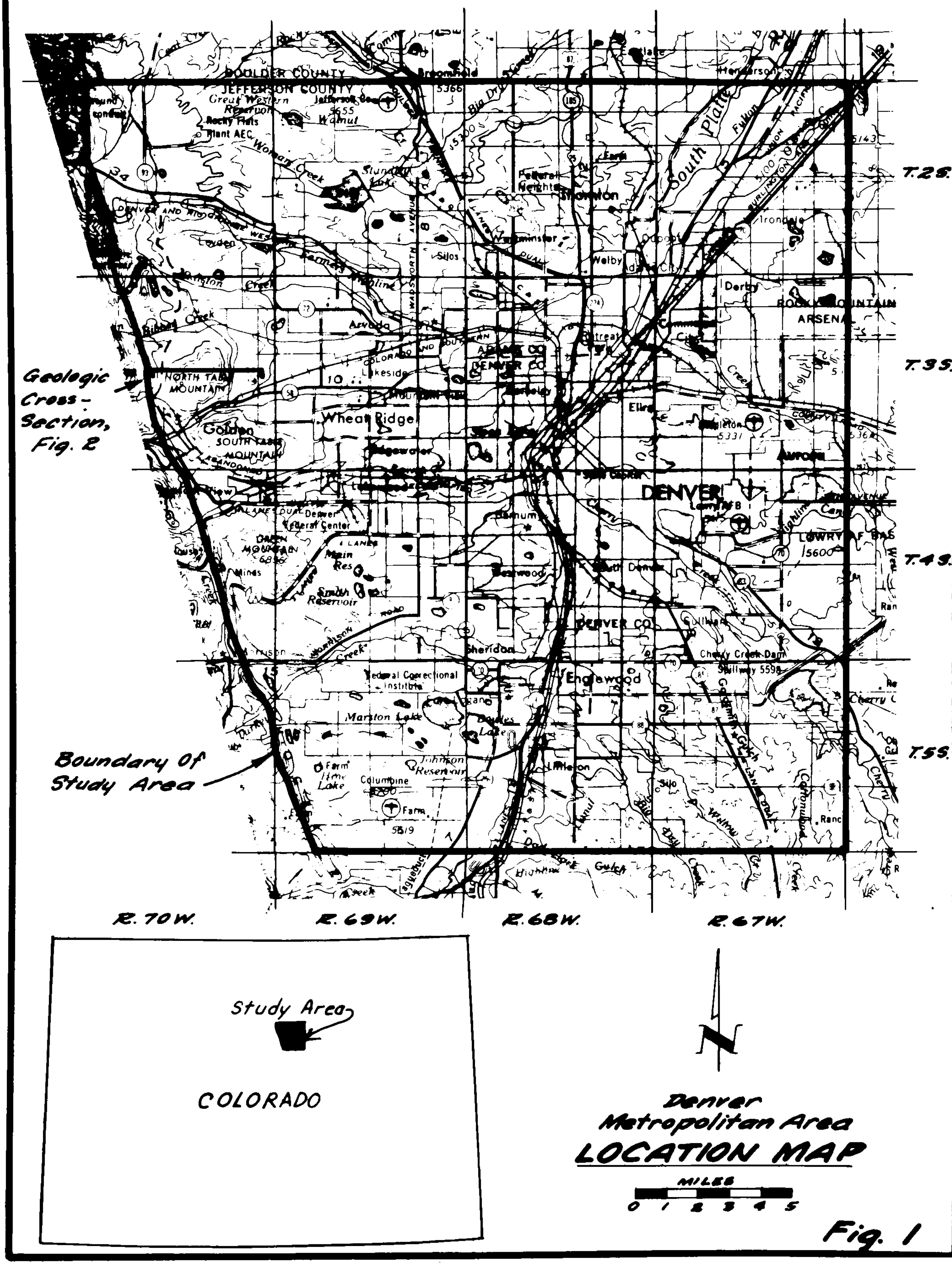
Richard Pearl and W.P. Rogers of the Colorado Geological Survey reviewed the report and contributed many helpful suggestions.

The engineering geologist will find this report somewhat more simplified than the typical geologic report. However, the main purpose of this study and report was to reduce the technical geologic data to a form understandable to the non-geologist. The authors believe that this report is a start toward fulfilling the definite need for a non-technical presentation of soils and geologic conditions in the Denver area and other metropolitan areas. We hope that this report will serve to alert the general public and the construction industry to problems which commonly exist in the Denver Metropolitan area.

SUMMARY

In the Denver Metropolitan area the land surface slopes steeply eastward along the mountain front and gently eastward from the base of the mountains to the South Platte River. Along the western edge of the area, generally north-south trending ridges and broad valleys reflect the different types of bedrock which have been upturned near the mountain front. To the east of the ridges and comprising most of the Denver Metropolitan area is an undulating plain formed on top of the flat-lying Denver and Arapahoe Formations. A few isolated hills occur in the area, notably the Table Mountains near Golden and Green Mountain south of Golden.

In some parts of the area the bedrock is only a few feet below the ground surface and is covered only by a shallow residual soil which was formed by in-place weathering of the bedrock. In other areas, the bedrock surface is covered by stream and wind deposits. The stream deposits, which consist of clay, silt, sand and gravel, range in thickness from a few feet in upland areas to many tens of feet in old stream valleys. The wind deposits, which consist of silt and sand, are found primarily east of the South Platte River.



Denver Metropolitan Area
LOCATION MAP

Fig. 1

The geologic and soils conditions of the Denver area tend to create several difficulties in construction. The major soil problems consist of swelling soils, settling soils, and potential landslide areas. Soils developed from swelling clays or clay shales increase in volume on exposure to moisture and often cause cracking of sidewalks, streets and building foundations. Common methods of treatment of these soils to prevent swelling are given in Table 1.

Settling soils, primarily those that contain loess (pronounced luss or lo-ess), often cause problems. When saturated, loess loses much of its strength and heavy structures founded on it may settle and crack. River clays sometimes settle under a load even without wetting because of their low inherent strength.

A landslide potential exists on steep slopes in the western portion of the area. On these slopes, either gradual or rapid movement of soil, and sometimes of underlying bedrock, may occur. Several fairly recent landslides have been identified and mapped by soils engineers and engineering geologists in the Denver Metropolitan area.

Additional construction problems often occur because of improper drainage or construction procedures such as improperly placed backfill.

Areas of soils where these problems are expectable are shown on the soils map, Plate I. Table 2 on Pate I lists the characteristics of the soil categories shown. Plate II shows depth to bedrock and bedrock geology. In areas of shallow bedrock (less than 10 feet), the characteristics of the bedrock rather than those of the overlying soil will generally determine which problems are likely to arise. Table 3 can be used in conjunction with Plate II to determine characteristics of the different bedrock formations.

This report also gives suggestions for further studies which should be made to more fully understand and sölve soils problems in the Denver area.

DESCRIPTION OF THE AREA

TOPOGRAPHY

The general form of the land surface in the Denver Metropolitan area consists of steep slopes along the mountain front where the rocks are sharply upturned, grading to a gentle undulating eastward slope toward the South Platte River. This general slope is altered by stream valleys and occasional hills. The elevation ranges from a high of 6,500 feet at the hogback along the western boundary to a low of 5,100 feet along the South Platte River in the northeast corner of the area. At the base of the hogback, and also at the southeastern corner of the area, the elevation is about 5,800 feet; from these points the land surface slopes 400 to 500 feet to the South Platte River.

The South Platte River flows northward through the area. The elevation of the river bed is approximately 5,400 feet where it enters the study area at the middle of the southern boundary and 5,100 feet where it leaves the area near the northeastern corner.

The flood plains of the major streams are from 30 to 150 feet below the adjacent land surface. The South Platte River has a broad valley situated about 50 feet below the surrounding ground surface. Cherry Creek and Clear Creek flow 50 to 100 feet below the surrounding area. East of Kipling Street, Bear Creek has a deep valley 150 feet lower than the adjacent area. Sand Creek has a flood plain which is 30 to 50 feet lower than its surrounding area. These major streams have gentle gradients in the study area and have cut their valleys laterally as well as downward.

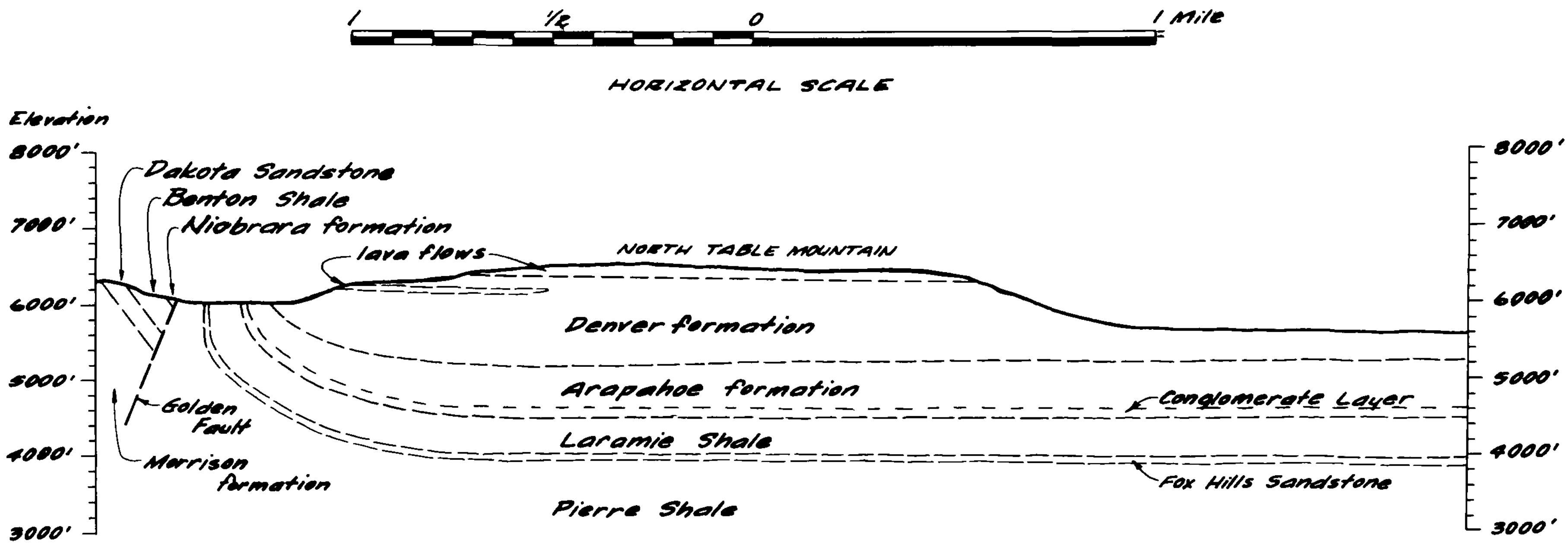
The smaller streams often have much steeper gradients and sharper valley sideslopes than the major streams. In the western portion of the area, these smaller streams are as much as 200 feet below the general level of the land.

Protective bedrock cappings have in places preserved the upper layers of the Denver Formation and have resulted in hills which rise 600 to 800 feet above the surrounding level. These cappings are composed of lava on the Table Mountains north and east of Golden, and of conglomerate (cemented gravel) on Green Mountain south of Golden.

The reader who wishes to study the land surface of the area in a detailed manner is referred to the U.S. Geological Survey Topographic Quadrangle Maps. An index to these maps is given in the appendix, Figure A-1.

GEOLOGIC SETTING

The Denver Metropolitan area is underlain by a series of geologic formations of differing rock types, which are upturned sharply along the mountain front but are flat-lying over most of the area (Figure 2). The upturned weather-resistant Dakota sandstone which forms the prominant north-south ridge, or hogback, just east of the foothills of the Front Range is the western boundary of the study area. Progressively younger rocks are exposed or occur under a thin soil mantle east of the Dakota hogback. The Benton Formation, consisting of claystone shale, forms



LOOKING NORTH

GEOLOGIC CROSS-SECTION

Through North Table Mountain
From Dakota Hogback To McIntyre Street

—After Van Horn, 1957

Figure 2

the toe of the east slope of the hogback as well as part of the gentle valley directly east of it. Also forming part of this valley are the Niobrara Formation, consisting of soft limestone and shale, and the Pierre shale. Overlying the Pierre shale is the Fox Hills sandstone, and the Laramie Formation (shale, sandstone and coal). The shales in these formations form valleys, while the limestones and sandstones generally form small ridges.

This series of ridges and valleys extends eastward from the mountain front for a distance of about one-half mile in the vicinity of Golden and for a distance of two to three miles in the northern and southern portions of the study area. The dip (angle of inclination of the rocks) lessens to the east, and the next overlying formation, the Arapahoe, is approximately flat-lying, as is the still younger Denver Formation. The Denver is the youngest consolidated formation which is exposed at or near the surface and it forms the bedrock under the surficial soils for the major part of the study area.

The geologic map, Plate II, shows where these formations occur at or near the surface.

Many of the shale formations and soils in the Denver Metropolitan area contain bentonite. Bentonite, a clay formed from the decomposition of volcanic ash, is largely composed of the minerals montmorillonite and beidelite. Its color ranges from white to light green or light blue when fresh. On exposure, the color in many cases becomes a light cream gradually changing to yellow, and in some cases to red or brown. Bentonite soils may swell considerably.

SURFACE DEPOSITS

In some localities, especially in the western one-third of the area, weathered-in-place bedrock forms a surface layer of residual soil. In most of the area, however, the bedrock has been covered by stream and wind-deposited soils. Over millions of years streams flowing from the mountains wore down the rocks and deposited mixed, unconsolidated materials in their beds. Ancient streams often flowed in channels different from those of present streams, leaving their deposits throughout the area. At localities near the mountain front where the streams eroded horizontally as well as vertically, they formed gently sloping surfaces called pediments, covering the underlying bedrock surface with a mixture of clay, slit, sand and gravel. Where winds have been strong, the finer materials have blown away, leaving only gravel and cobbles, as on Rocky Flats between Golden and Boulder. Where a sudden decrease in slope of the stream bed occurred at the base of the mountains, coarse gravels were deposited.

These deposits are extensive and extremely variable in thickness. In the ancient channel of Cherry Creek the deposits are nearly 100 feet thick. In many other areas, however, these stream deposits are only a few feet thick.

Wind-blown silt (loess) and sand which cover much of the area east of the South Platte River overlie residual soil, stream deposits or older wind-blown deposits.

GEOLOGIC HISTORY AND STRUCTURE

HISTORY

The oldest rocks exposed in the study area, the Dakota sandstone, were deposited about 135 million years ago as a beach and near-shore deposit of an ancient sea. As the sea encroached over the area, the Benton, Niobrara and Pierre Formations were deposited. Slow rising of the land to the west then caused the sea to withdraw and beach sands were again deposited, forming the Fox Hills Formation. The sandstone, clay and coal of the Laramie Formation were later deposited on a coastal plain. As the land to the west rose at a faster rate, mountains began to form.

As the mountains slowly rose through geologic time, the material which formed the Arapahoe, Denver and Dawson Formations were deposited by streams running from the rising mountains and spreading out over the plains. Even though slight uplift of the mountains has probably continued, the past 50 million years have been characterized mainly by erosion of the mountain surfaces, deposition of materials by streams as they spread out on the plains, and formation of soils from in-place weathering. The fine materials originally deposited by the streams or developed from weathering have been blown by winds to greater distances from the mountains, where they accumulated as loess deposits.

STRUCTURE

Two major structural features, the Denver Basin and the Golden Fault Zone, are part of the study area. The Denver Basin is an asymmetrical syncline, or fold, in which the rocks dip inward from both sides toward the center. The approximate center of the Basin lies beneath the City of Denver. The dip (angle of inclination) of the rocks on the western edge of the basin is quite steep, but a few miles east of the western edge it becomes gentle, resulting in nearly flat-lying areas under most of the study area (Figure 2). The dip on the eastern side of the basin is very gentle. Formations which are upturned and outcrop along the mountain front lie thousands of feet below the surface under the City of Denver.

The Golden Fault Zone extends in a north-sound trend along most of the western edge of the study area (Plate II). The fault, which dips steeply toward the west, (Figure 2) is a compressional or reverse fault in that the rock formations on the western side of the fault are displaced upward and eastward with respect to those rock formations on the eastern side. The location of the Golden Fault Zone determines the varying width of the Pierre shale outcrop in the Golden area, because overthrusting of older rocks over the Pierre shale has caused the older rocks to cover much of the lower part of the Pierre shale in places. Several smaller but distinct faults are associated with this fault zone.

SOIL AND GEOLOGIC CONDITIONS OF THE DENVER AREA

GENERAL SOIL PROBLEMS

In recent years the problem soils of the Denver area have received much local publicity. Much of this publicity has concerned the swelling of clay-rich soils after extensive watering. Another problem is the settling or consolidation of soils. These "settling" soils consist of loess and river clays. Loess (wind-blown silt) found mostly east of the South Platte River, may settle under the weight of structures if it gets wet. The river clays, which were deposited in the pre-existing stream beds and in the present flood plains, often settle under heavy load. A third problem, which is encountered along steep slopes, is the potential of landslides when natural slopes are disturbed and water is applied for lawn irrigation.

Areas where swelling soils, settling soils, and landslide conditions exist in the Denver area are shown on the Engineering Soils Map Plate I.

SWELLING SOIL PROBLEMS

The problems of swelling soils have been extensively studied by many investigations. Suggested references concerning these soils are included in the bibliography.

The amount of swelling which may occur in a clay-rich soil depends upon its mineral composition, moisture content and density. The swelling potential of a clay soil is controlled by the percentage of the mineral montmorillonite present, with soils predominately montmorillonite having the highest swell potential.

However, the actual swelling of the soil is determined by the soil moisture content and density. Adsorption of water by the clay mineral is necessary for swelling to occur and, generally, as more water is adsorbed more swelling will occur. In some instances the expansion of a surface layer of a high-swelling soil may seal off the lower layers of the montmorillonite-rich soil and prevent water from reaching them. Therefore, clays with high swell potential may not necessarily experience higher actual "bulk" swelling than clays with moderate-swelling potential.

Exposure of or reduction of load, (weight), on a clay soil (as in an excavation) permits the clay to adsorb additional moisture and to expand. Drying of water-saturated swelling clays usually results in shrinkage. These factors are important when soils are excavated and then built upon.

The density of soils is determined by the closeness of the particles. The higher the density, the greater is the volume of solid particles per unit volume. In dense soils, numerous clay particles are packed into a small unit volume, and each clay particle can adsorb water. Since there are more clay particles in these dense soils, there can be greater total expansion, provided there is sufficient moisture and time.

Published articles list several methods of treatment of foundations and of foundation design to prevent structures from being damaged by swelling soils or bedrock. These methods are summarized in Table 1, with comments on the methods also summarized and referenced. Each article referenced on the table should be reviewed for a more complete explanation of comments given.

Table 1 is provided for general information only. Often a combination of methods may be used, and methods effective in one situation may not be effective in another. Actual design of a foundation should be made by a registered professional engineer experienced in soil mechanics and foundation design.

SETTLING SOIL PROBLEMS

The major settling problems in the Denver Metropolitan area occur in soils composed of loess. The structure of loess is such that when dry it provides sufficient support for moderately heavy structures. However, when wetted, it rapidly loses its supportive strength. In the Denver area, the loess is sufficiently thin so that a firm foundation for piers or piles can generally be found at shallow depths below it. The problem of settling of loess can be avoided if structure foundations are taken down to a firm bearing stratum instead of being placed on the loess itself. For lightweight slabs, such as driveways and patios, care must be taken to avoid wetting of the soil during and after construction. This can be done by installing proper drainage away from the edge of the slab.

TABLE 1

TYPES OF FOUNDATION TREATMENT AND DESIGN FOR SWELLING SOILS*

FOUNDATION TREATMENT

1. **Saturation of Soil.** Soil must be completely saturated during construction and kept in wet condition throughout the life of structure.[b] This may be impractical; it is difficult to saturate soil completely in a reasonable time.[a,b,c] Saturation of foundation for 30 days after excavation, then drying and pouring a slab has been used.[d]

2. **Proper Compaction.** Compact at low densities and high moisture but at sufficient density to avoid settlement.[a] Compact to higher density than that of surrounding soil.[d]

3. **Use of Granular Mat Below Foundation.** Probably ineffective as drainage medium.[a] Little is known about thickness required.

4. **Replacement with Non-Swelling Soil of Sufficient Thickness to Provide Necessary Load to Prevent Swell of Under-lying Clay.** Material should be placed at density which permits some compression between structure base and foundation clay.[c] Thickness required may be too great for lightly loaded structures.[c]

5. **Drainage.** Peripheral drains in wet areas around foundations to channel surface drainage away from all structures, place tiles in swales to carry water rather than filling in.[d]

6. **Timing.** Do not allow excavation to stand open for a long time before construction.[d]

7. **Use of Waterproof Membrance.** Effective in hydraulic structures.

8. **Treatment of Soil with Lime or Cement.** [c,e]

9. **Shut Off all Sources of Water to the Area.** Generally impractical.[e]

*This table is provided for general information only. Actual design of a foundation should be made by a registered professional engineer experienced in soil mechanics and foundation design.

FOUNDATION DESIGN

1. **Use of Drilled and Under-reamed Foundation.** Bottom of foundation should be below line of seasonal moisture change. Upward pressure of soil on piles requires use of extra-reinforcement. Bond breaking between soil and pier (e.g., by use of double sonotube) may be effective.[b]

2. **Placement of Grade Beams, Slabs and Other Portions of Structure Well Above Clay Soil.** Use of cardboard forms to leave eight to twelve inch spacing.[b] Use of baled hay.[c]

3. **Loading Soil with Sufficiently High-unit Pressures.** Only effective with heavy buildings.[a] Concentrate pressures on spread footing for moderately heavy structures.[c]

4. **Sufficient Reinforcement in Foundation Mat to Produce Rigid Structure.**[b]

5. **Design Structures for Movement.**[c] Separation of grade beam slabs and other portions of structures from the footings or piers.[a,b]

6. **Accept Probability of Floor Slabs Breakage and Plan to Replace it at a Later Time.**[a]

FOOTNOTES:**

a. Means, R. E., 1969, Buildings on expansive clay: Colorado School of Mines Quart. v. 54, no. 4, p. 1-31.

b. Dawson, R. F., 1969, Modern practices used in the design of foundations for structures in expansive soils: Colorado School of Mines Quart. v. 54, no. 4, p. 67-87.

c. Holz, W. G., 1969, Expansive clays — properties and problems: Colorado School of Mines Quart. v. 54, no. 4, p. 89-117.

d. Holtz, W. G.; and Gibbs, H. J., 1956, Engineering properties of expansive clays: American Soc. Civil Engr. Trans. v. 121, paper 2814, p. 641-677.

e. Scott, G. R., 1969, General and engineering geology of the northern part of Pueblo, Colorado: U.S. Geol. Survey Bull. 1262, 131 p.

**Footnoting to a particular author does not necessarily imply his advocacy of that particular treatment or design.

River clay soils occur to a limited extent in the Denver area. These soils possess low inherent strength and will settle under heavy loads. Strength of the soil in these areas should be determined by a soils engineer prior to construction.

LANDSLIDE PROBLEMS

Special attention should be paid to construction in hillside areas to prevent slope instability and to avoid landslide problems. The term landslide, as used here, means any downslope movement of soil, including slowly creeping or abruptly moving soil.

The United States Geological Survey has mapped numerous landslides around the flanks of North and South Table Mountains and has indicated some slides on Green Mountain. Some of these slides are presently moving while others are dormant. Other areas of steep slopes on stream banks as well as hillsides, while not landslides at present, may slide in the future under certain conditions.

In an existing or potential landslide, removal of material at the toe (lower part) of the slope decreases support of the upper part and can precipitate movement of the whole hillside surface. Loading the head of the slide or potential landslide by soil fill or heavy structures may also precipitate or increase movement. Increase in water content of the soil by heavy rains, lawn watering, or seepage from irrigation ditches may cause otherwise stable areas to slide.

Active slides exhibit cracks or fissures, and a rough, rumpled or hummocky surface. They may offset fences, power lines and roads. Recent slides may still show a slip face or steep scarp along their upper edge. Nearly all slides show a concave depression or trough at their upper edge where material was removed and a convex bulge or linear mound at their lower edge where material came to rest.

In areas modified by grading and landscaping, the landslide surface may be masked and may be difficult for even an experienced engineering geologist to discern. Any area where such grading has been done on steep slopes composed of clay or shale is an area of potential landslide hazard.

Soil slips (gradual movements) may also occur on steep slopes, especially when a clay layer or a shale underlies the surface soil. Such gradual soil creep may damage foundations and entire structures.

It is recommended that an engineering geologist investigate each proposed construction site in areas of landslide potential. He can recommend areas in which construction should be avoided and suggest methods of preventing soil movement in other areas.

RELATED SOIL PROBLEMS

Construction and maintenance problems may arise because of conditions other than those mentioned above. These conditions include low strength of soil, changes (generally increases) in ground water and surface water, and improper planning of sewage facilities. Also, some construction operations themselves may result in the development of, or increase in, detrimental soils conditions. Consideration of strength of soil has been excluded from this report, because its determination is considered, for purposes of this report, to be a soils engineering, rather than a geologic, problem.

Most of the swelling, settling and landslide problems are related to water and drainage. Often, water level changes occur after construction has been completed, as excess lawn irrigation water infiltrates the soil. If the soils are protected from water during construction and if proper drainage is provided, the potential of having such problems is considerably decreased.

Problems may also arise when new residential construction results in a change in existing drainage conditions. Watering of lawns in previously unirrigated areas often increases the water content and decreases the capacity of the soil to accept additional water. Where the ground-water level was fairly close to the surface before residential construction took place, lawn watering often causes a rise in water level sufficient to cause flooding of basements, especially in valleys, at the base of slopes, and in lower portions of broad, rolling drainage areas. The presence of numerous paved streets, sidewalks, and roofs increases runoff of water during storms.

Declines in ground-water level may also cause problems. In flood plains, high ground-water levels have kept areas of potentially swelling clays continually saturated. A decline in ground-water level, or any other drying of the soils, permits shrinking of the upper layers of the clays which then swell upon subsequent rewetting.

Residential areas are sometimes equipped with septic tank systems in areas where the soil or geologic conditions are unsuitable for long range introduction of the sewage effluent. If an impermeable clay or shale layer is located at a shallow depth the soil cannot absorb all the effluent from a septic tank. Therefore, sewage may back up into basements, onto lawns, or may seep out onto hillsides. Placement of leaching fields in certain clay types also prevents proper aeration and bacterial action on the sewage, thus increasing maintenance and pollution problems.

Soil conditions may be affected by construction operations in several ways. In residential developments, considerable cut-and-fill work may be done locally. During such cut-and-fill work, residual soils may be covered over, depth to bedrock increased, or decreased, or swelling clays moved into other areas.

Improper construction procedures can cause building foundations to crack. If the backfill is not sufficiently compacted before placement of concrete slabs, later consolidation of the soil may leave void spaces between concrete and soil, allowing settlement and cracking to take place. Water-placed ("puddled") backfill using swelling clays is likely to shrink excessively upon drying, leaving void spaces which can cause foundation settlement. Another improper procedure is placement of sand backfill within clays; the sand then acts as a drain, conducting water to the clay which may then expand beneath slabs and foundations. While these problems are related to the type of soil, they are primarily caused by improper construction procedures.

Because of the variability of soil conditions and construction procedures in the Denver area and the possibility of encountering or creating soil-related problems, it is strongly recommended that a soils engineer be consulted during the planning stage before any construction commences. Testing by the soils engineer will determine specific soil properties. Based on the results of these tests and his engineering experience in the Denver area, he can recommend suitable treatment of specific problems at a particular site.

EXPLANATION OF SOILS MAP

As a major part of this initial study, information obtained from numerous published agricultural soils maps and surficial geologic maps was analyzed and combined into one map. The results of the analyses are shown on the accompanying soils map (Plate I). This map shows the areal distribution of the following nine categories of possible problems soils.

1. Residual soil (Bedrock weathered to soil). (Swelling)
2. Non-residual and non-loessial soil (Swelling clay)
3. Loess (wind-blown silt). (Settling)
4. River clays. (Settling)
5. Loess over residual soil. (Mixed but primarily swelling)
6. Loess and swelling clay. (Mixed but primarily swelling)
7. Loess over weathered loessial soil. (Mixed but primarily swelling)
8. Flood plains. (Varied problems)
9. Potential landslide areas. (Includes rockslide areas)

These nine problem soil categories were established in order to subdivide the problem soils into types for which the characteristics could be more easily understood by the non-technical person.

The soils and surficial geologic maps used in compilation of Plate I are in general agreement as to type of surface material present at any given location. Where discrepancies existed the soils maps were generally used because of their more detailed descriptions of soil properties.

Agricultural maps were based on investigations which extended to a depth of only five feet below ground surface. Because of this, areas where problem soils are found slightly below a five-foot depth may not be indicated. Bedrock may be encountered only a few feet below this five foot depth and foundation excavations may expose swelling shales.

Probing with a hand auger for a depth of approximately five feet below the base of the foundation excavation should reveal whether bedrock is sufficiently deep.

In contrast to these problems soil areas, the area denoted as sandy soil located in the northeastern portion of the area is expected to be one where few construction problems will be encountered. Blank areas on the map denote locations where available data indicate the problem soils as defined in this report are likely to occur only locally. Because of the preliminary nature of this report, these blank areas should not be assumed to be entirely free from problem soils. Further investigation may reveal areas of previously unmapped problem soils.

Unconsolidated deposits which contain swelling clays may be buried under thin surface deposits composed of non-problem soils. At the present time not enough data are available to delineate these problem areas.

Three areas where there is a scarcity of data on soils characteristics are shown on the soils map. Here, information permitted mapping only of the residual soils and areas of landslide potential. Swelling clays and shales may be expected to occur lower on the slopes of Green Mountain at shallow depths under other deposits, and locally surface soils may be somewhat swelling. However, few problems are anticipated unless bedrock is close to the surface or extensive landsloping is done.

Table 2, which gives a description of the soil in each category, includes information on the sources, occurrence, thickness and underlying material for each soil category. This table also describes the problems encountered in each soil category.

TABLE 3

CHARACTERISTICS OF ROCK TYPES

(From West to East and In Ascending Order)

Formation Name	Rock Type	Distinguishing Characteristics	Topographic Occurrence	Engineering Problems
Dakota sandstone	Sandstone with shale and some conglomerate layers	Resistant to erosion	Prominent hogback at edge of mountain front	Excavation sometimes difficult
Benton shale	Chalky to silty shale with bentonite, and some sandstone and limestone	Dark colored bare slopes, sparse vegetation	East slope of Dakota hogback	Swelling of bentonite, and possible landslides
Niobrara Formation Ft. Hays limestone (member)	Limestone with silty shale and bentonite	Very thin outcrop in area	Generally forms small ridge between valleys formed on Benton and Smoky Hill shales	Excavation difficult
Smoky Hill shale (member)	Chalky shale with several thick beds of chalky limestone, and some bentonite	Very thin outcrop in area	Valley	Swelling of bentonite clay lenses
Pierre shale Lower part	Clayey shale with some bentonite beds	Characteristics fairly uniform within portion	Broad, flat, or gently rolling valley	Slight to moderate swelling
Hygiene sandstone (member)	Shaly sandstone	Characteristics fairly uniform within portion	Often forms a ridge	None
Upper part	Bentonitic clay shale	Characteristics fairly uniform within portion	Broad, flat, or gently rolling valley	Moderate to high swelling
Fox Hills sandstone	Interbedded sandstone and shale, upper part massive sandstone	Very thin outcrop exposure in metropolitan area	Lower-Valley at western base of small hogback Upper-Small hogback	Shales highly expansive None
Laramie Formation	Claystone, siltstone and sandstone with coal layers in lower part	Extensively mined coal and clay layers	May form hogback	Coal zones and their underclays, highly expansive. Slopes locally subject to landsliding, and settlement in coal mine areas
Arapahoe Formation	Basal conglomerate and sandstone overlain by sandy to clayey shale, and claystone with some sandstone	Exposed surfaces highly weathered	Gentle, rolling surface	Swelling of clays, slopes subject to landsliding
Denver Formation	Andesitic[1] shale and siltstone with some sandstone and conglomerate	Extremely variable composition; thin lenses of highly expansive clay; shale occurs interbedded with non-expansive material	Gently rolling, underlies most of area	Differential settlement likely. Shales expansive where exposed on slopes, subject to landslides
Green Mountain conglomerate	Cemented cobbles and boulders of igneous and metamorphic rocks	Resistant to erosion	Caps Green Mountain	Excavation difficult
Dawson arkose	Conglomerate, sandstone and claystone	Sandier than Denver Formation, with fewer expansive clay, shale lenses	Gently rolling surface	Slight to moderate swelling
Intrusive	Monzonite[2]	Resistant to erosion	Ralston dikes, (Sec. 4 and 5, T3S, R70W)	Excavation very difficult
Lava flows	Latite[3]	Resistant to erosion	Top of Table Mountains	Excavation very difficult

1. Andesite is a volcanic rock composed chiefly of feldspar with some dark minerals.

2. An igneous intrusive rock that contains feldspar and dark minerals, but little quartz.

3. Volcanic rock that contains feldspar and dark minerals; that contains less than 5% quartz.

EXPLANATION OF GEOLOGIC MAP

The rock types in the Denver Metropolitan area are quite varied in their physical properties. Often these different rock types can be distinguished by the topographic form which they take. The resistant sandstones form hogbacks or ridges while the more easily eroded shales form either valleys or the lower slopes of ridges. Because of the upturning of the formations along the mountain front, these ridges and valleys have a general north-south trend.

The geologic map, Plate II, shows the approximate depth to bedrock as well as the extent of the various formations. A geologic cross-section (Figure 2) shows the subsurface relationship and approximate thickness of the geologic formations. The location of this cross-section is shown on Plate II.

The depth-to-bedrock contours on Plate II are based on a composite of bore-hole information and soils data obtained by previous investigators. In the central Denver Metropolitan area a depth-to-bedrock contour map was prepared by the American Society of Civil Engineers Committee on Denver Sub-soils (1954). Their map was utilized with modifications based on additional data obtained since its publication. For this report the mapping of residual soils areas is within the accuracy of 10 foot contours. The time and financial budgets of the study do not permit further refinement of soil thickness at this stage, but such refinement should be done. In many areas where a 10 foot contour line is given, the depth to bedrock will actually be five feet or less.

The bedrock contours on the accompanying Plate II are generalized and should not be taken as indicating the exact depth at any particular location. Buried stream valleys and other erosional characteristics of the bedrock surface, as well as effects of present topography, may cause considerable local variation in the depth to bedrock. Even within an individual building site, depth to bedrock may vary ten feet or more from one end of the excavation to the other. A soils investigation should be required at the site to obtain more detailed information on soil type and on the depth-to-bedrock for proper foundation design.

Where the depth to bedrock is shallow, foundation conditions in excavations will be governed more by the character of the bedrock than by the overlying soils. The most common distinguishing characteristics of each bedrock type are given in Table 3.

Most excavations in bedrock in the metropolitan area will encounter the Denver Formation. This formation is extremely variable in composition. Even where most of the formation is a non-swelling siltstone or sandstone, lenses of highly swelling claystone often occur. The swelling characteristics of the claystone are similar to those of swelling clays. Foundation borings made at random spacings in a development may not encounter a detrimental condition existing in a specific location as conditions at a particular site cannot be determined to any degree of certainly until the foundation excavation has been completed. It is recommended that a soils engineer investigate each excavation and determine the suitability of the proposed foundation design at that site. Any foundation designed only on the assumption of overall favorable soil conditions will be inadequate in areas where an individual foundation rests on locally swelling material.

NEEDS AND RECOMMENDATIONS FOR FURTHER STUDY

The present report has been limited to an analysis of presently available information in the Denver Metropolitan area and a compilation and evaluation of this information relative to construction problems. This study was necessarily preliminary. The results of investigations relative to this report indicate that there are areas where additional studies are needed in order to give the public a more precise knowledge of conditions.

The soils map (Plate 1) in this report shows general areas where soil problems occur. The study program needs to be expanded to include the detailed mapping of problem soils areas. Information from private engineering and geologic firms should be obtained, analyzed, and interpreted in the context of information presented in the present report.

A more comprehensive study and interpretation of data relative to existing surficial geologic maps is necessary in order to determine specific areas where the geologic materials depicted on these maps may be expansive. Most of the existing surficial geologic maps separate the alluvial deposits by age and not by those characteristics which may adversely affect construction. A re-analysis of the existing geologic data will be necessary to prepare maps which show these characteristics.

Swelling claystone lenses frequently occur within the Denver and Arapahoe Formations. Delineation of those areas where claystone lenses are concentrated would be helpful in planning for foundations, although the random variability of locations of these lenses may make mapping of these areas impracticable. Further studies should determine if such mapping is feasible, and, if so, subsequent mapping should include delineations of those areas of swelling clay lenses.

A detailed discussion of the relationship of water and drainage to soil conditions is beyond the scope of this report. Because most of the soil problems encountered in the Denver area are caused or intensified by changes in water content, this aspect should be investigated in further studies. These studies should include identification of the water-holding capacity of the soils.

Recommended measures for preventing damage to foundations from swelling clays include placement of foundations below the zone of seasonal moisture change. In many areas, however, the lower limit of this zone is not known. Foundations may inadvertently be placed within this zone, resulting in the possibility of movement as moisture content changes and as the soil or claystone shrinks or swells. Any ground water studies in the area should include the attempt to locate or develop criteria for locating the lower limit of the zone of seasonal moisture change.

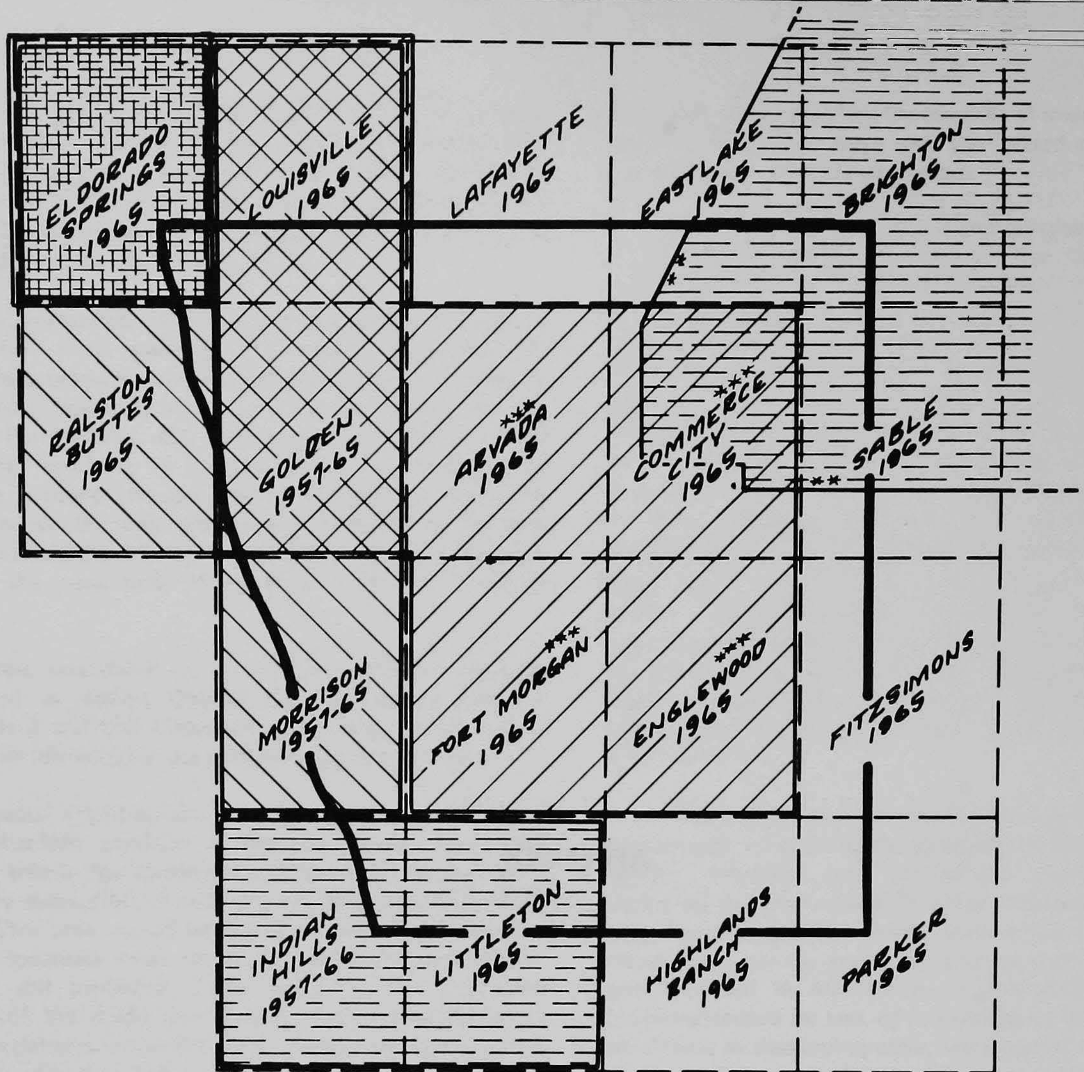
Areas unsuitable for septic tank systems have been delineated in Adams County by the County Planning Department and Soil Conservation Service, but such areas need to be identified in the remaining parts of the area.

Special attention should be directed to investigation of unurbanized portions of the study area. The undeveloped area in the southwest portion of the study area is especially susceptible to problems owing to the steepness of slopes. This area should be mapped in detail to determine specific localities most likely to encounter landslide or swelling soil problems. Steep slopes in the northwest portion of the study area should also be investigated in detail to determine specific areas of potential landslides. If locations of soils which will cause construction problems are determined before development, planning can be utilized to promote good land usage, thus avoiding many difficulties. The avoidance of difficulties will benefit the general public as well as the individual home builder and contractor, by preventing the expense of maintaining public roads in unsuitable areas and the hazard to health from unsuitable sewage disposal systems.

It is recommended that a second phase of the study of soils and related geology in the Denver area be undertaken. This study should encompass the same area as the present study in order to utilize information already obtained. The second phase should result in a more comprehensive report which would include maps delineating all surface soils and underlying soils to a depth of 10 or 15 feet where this can be determined. These maps would be a refinement of the soils map included in this report and should include the separation of areas composed primarily of sand, primarily of gravel and primarily of mixed deposits, as well as the categories designated in this report. Slope maps, locating areas where slopes exceed certain grades, should be prepared to delineate landslide hazard areas more precisely. The second phase should also expand the geologic map to include more detailed information on depth to bedrock and characteristics of bedrock materials such as swelling potential in areas where depth to bedrock is 10 feet or less.

The studies for this report have shown that there is a general lack of information available to the non-technical person. Industrial and commercial expansion is also beginning to occur rapidly in other areas of the state, and extensive urbanization of land such as has occurred in the Denver area can be expected to occur soon in these other areas. To aid in minimizing or alleviating construction problems caused by lack of knowledge of soil and geologic conditions in developing areas, we recommend that studies similar to this one be initiated in other urban or projected urban areas of Colorado. Existing government maps and reports can be used as bases for the preparation of reports which can be understood and used by people who are not fully familiar with geologic and engineering terminology and map symbols.

APPENDIX



MAPS AVAILABLE FROM THE U.S. GEOLOGICAL SURVEY

- Topographic Maps: Available For All Quadrangles (Identify By Quadrangle Name).
- Boundary Of Study Area.
- Geologic Map (Combination Bedrock & Surface).
- Bedrock Geology Map.
- Surface Geology Map.
- Engineering Geology Map.

Eldorado Springs Engineering Geology Map And Golden Surface Geology Map Are On Open File.

** In U.S.G.S. Water Supply Paper 1658.

*** Surface Geology Map In Hunt, U.S.G.S. Bulletin 996-C (Out Of Print).

INDEX MAP

Fig. A-1

RELATED STUDIES OF THE AREA

A major part of this study has entailed a compilation of information obtained from investigations made or being made by other organizations. A large problem in initiating or continuing any study is the discovery of what information has already been obtained, in order to minimize duplication of effort as well as to make use of related information from other fields. Many investigations are concerned with only one area or problem, and yet, when the results of these investigations are combined, much of the information can be extended to other areas and problems. This was done in the initial stage of the present study.

Appropriate information obtained from the studies mentioned below has been used in the preparation of this report. The information has been analyzed, evaluated, compared, related and summarized.

The soils of the Denver Metropolitan area have been studied by federal governmental agencies, such as the U.S. Geological Survey and the Soil Conservation Service, by state agencies, by county planning agencies and by private groups.

The U.S. Geological Survey has made extensive investigations in the area. Topographic maps for the entire study area have been prepared (Figure A-1). Bedrock geology maps of the western portion of the area, where there is a variety in the bedrock formations, have also been prepared. Suficial geologic maps show the soil deposits overlying the bedrock in the central and northeastern as well as the western portions of the study area. An engineering geologic map of the Eldorado Springs quadrangle has been released to open-file at the U.S. Geological Survey Public Information Office. This map shows interpretations of the general behavior of soil and rock on the basis of engineering properties and geologic conditions. The engineering geology map of the Eldorado Springs quadrangle includes a generalized description of engineering geology aspects of sedimentary bedrock in that quadrangle. This description also applies generally to the same bedrock formations or the same parts of formations throughout the study area. The surficial geologic map of the Golden quadrangle (Van Horn, 1968), also on open-file at the U.S. Geological Survey, includes a summary of materials test data (mechanical analysis, soil classification and plasticity). A geologic report of the Pueblo area (Scott, 1969) published by the U.S. Geological Survey, contains much information applicable to the Denver area. A report on the soils of the northern half of the study area (Harper, et al, 1932) was published by the U.S. Department of Agriculture, Bureau of Chemistry and Soils. The Soil Conservation Service has updated the agricultural soils studies in Adams County (Adams County Planning Department, 1969). The Colorado State University Experiment Station and the Soil Conservation Service in cooperation with the soil conservation districts, have prepared a preliminary report (Larson, et al, 1968) on agricultural soils in Arapahoe County. These studies, while primarily designed for agricultural use, also analyze the soils relative to construction.

Studies of the area by various organizations are being continued. A project is now underway by the U.S. Geological Survey to update the surficial geologic maps of the central metropolitan area. Further engineering geologic studies are in progress on a cooperative basis between the U.S. Geological Survey and the Denver Regional Council of Governments. We understand that a cooperative study of the area using remote sensing equipment is being undertaken by the U.S. Geological Survey. However, the information has not yet been released for public use.

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Arapahoe Co. Index sheet, YH-4, YH-5

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Series:
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GS-VBBL Scale of individual photos: 1:17,400, 1964

City and County of Denver. Traffic Engineering Department

Area within city boundaries.

Mark Hurd Aerial Surveys Inc.

Flown Oct. 1970. Scale of individual photos: 1:80,400.
Scale of rectified photo quadrangle sheet 1:24,000. Available: Inspection or use at Colorado Geological Survey, purchase from Mark Hurd Aerial Surveys Inc., 345 Pennsylvania Ave., Minneapolis, Minn. 55426.

DEPARTMENT OF NATURAL RESOURCES
COLORADO GEOLOGICAL SURVEY
JOHN W. ROLD, DIRECTOR

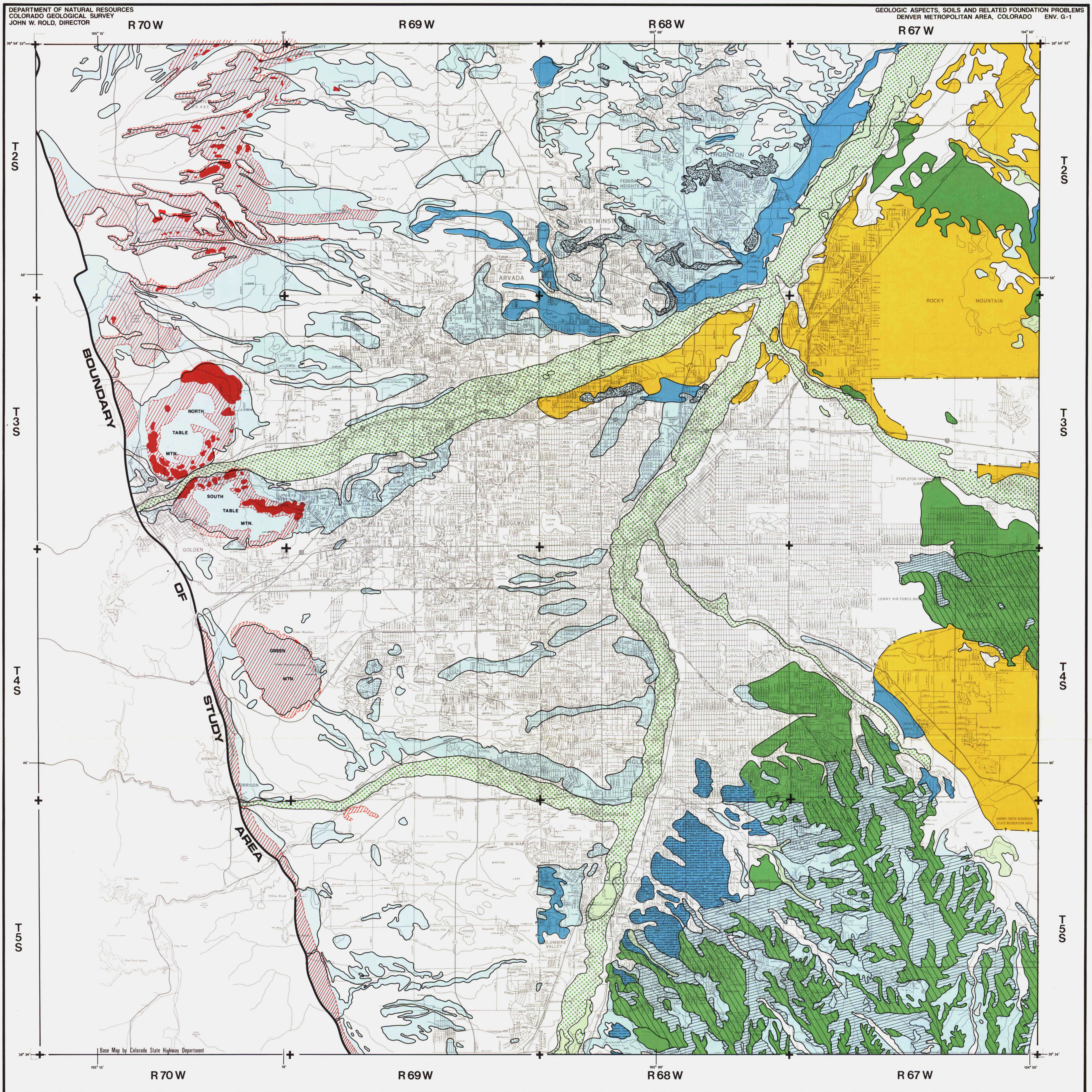


TABLE 2

Description, Occurrence, and Construction Problems of Soil Categories

Map Symbol	Soil Category	Source	Description	Occurrence	Thickness	Underlying Material	Primary Problem	Other Problems
	Swelling Soils							
	Residual Soil (includes colluvium)	*In-place weathering of shale and some sandstone (incl. slopewash)*	*Clay with weathered inclusions of under-lying bedrock. (mixture of clay, silt, sand and pebbles in slopewash.)*	*Side slopes of stream valleys, hogbacks and some hilltops*	*Generally less than 5 feet*	*Generally shale, some areas sandstone, sandy shale, or conglomerate*	*Swelling of clay and underlying shale after wetting*	*Shales become soft on extensive exposure to air. Clay tends to creep downhill on slope. When very wet (as in puddle backfill), shrinks greatly on drying*
	With thin gravel cap							
	Swelling clay, (non-residual, non-loessial)	*Water-laid deposits*	*Silt and clay*	*Variable*	*Generally more than 3 feet*	*Variable*	*Swelling after wetting*	
	Settling Soils							
	Loess (wind-blown silt)	*Wind deposit, blown from other soil deposits*	*Silt and fine sand with root holes and blocky structure*	*On hilltops; primarily east of South Platte River, scattered areas west of South Platte River*	*Generally greater than 5 feet. Thicker on east side (leeward) of hills than on west (windward)*	*Alluvium (silt and clay, sometimes mixed with sand and gravel)*	*Settlement under load after wetting*	*Where source is swelling clay, may expand upon wetting if insufficiently loaded. Erodes easily in in non-vertical cuts*
	River Clay (often organic)	*Water-laid deposits in river cut-offs*	*Clay, some organic material*	*River bottoms*	*Variable*	*Variable*	*Settlement under load*	
	Mixed Properties							
	Loess over weathered residual soil	*Wind deposit, blown from other soil deposits*	*Upper layer silt and fine sand with root holes and blocky structures, lower layer clay*	*On hilltops; primarily east of South Platte River, scattered areas west of South Platte River*	*Generally less than 5 feet loess over swelling clay. Thicker on east side of hills than on west*	*Weathered shale and some sandstone*	*Swelling after wetting except upper few feet (loess) may settle under load*	*Differential settlement if loads on footings differ or thickness of of loess varies greatly. Erodes easily in non-vertical cuts*
	Loess over swelling non-residual soil	*Mixed wind and water laid deposits*	*Silt and clay, becomes sandier at depth*	*Narrow band along east side of South Platte River in southeastern portion of area*	*Variable*	*Variable*	*Generally swelling after wetting, locally may settle*	
	Loess over weathered loessial soil	*Wind deposit, blown from other soil deposits*	*Silt and fine sand with root holes and blocky structures*	*On hilltops; primarily east of South Platte River, scattered areas west of South Platte River*	*Generally less than 5 feet. Thicker on east side of hills than on west*	*Weathered loess*	*Settlement if heavily loaded, expansion if lightly loaded after wetting*	*Differential settlement if loads on footings differ or thickness of loess varies greatly. Erodes easily in non-vertical cuts*
	Varied Problems							
	Flood Plain	*Stream valley deposits*	*Mixed clay, silt, sand and gravel*	*River valleys*	*Variable*	*Variable*	*Flooding potential*	
	Landslide Areas							
	Potential	*In-place weathering*	*Generally clay and silt, may contain gravel and cobbles, no apparent layering*	*Hillsides (mainly in western portion of area)*	*Variable*	*Variable but generally shale*	*Land Movement*	
	Actual							

Minimal-Problems Areas

Sandy Soils (primarily ancient dunes)

Soils problems, if any are localized and varied

prepared for
COLORADO GEOLOGICAL SURVEY

by
WILLARD OWENS ASSOCIATES

drafted by
PETROMOTION

base map from
COLORADO STATE HIGHWAY DEPARTMENT

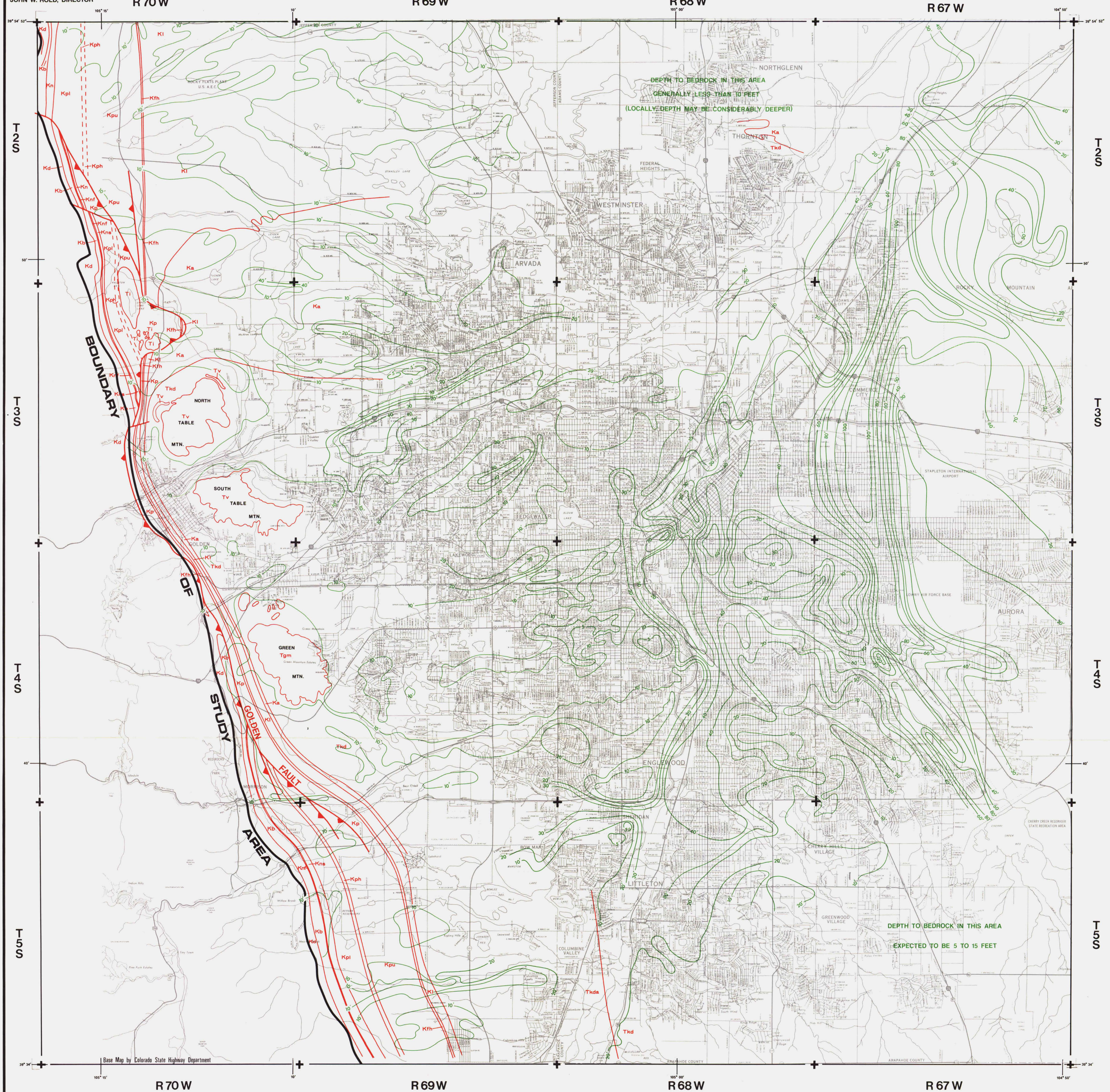
ENGINEERING SOILS MAP

Geologic Aspects, Soils and Related Foundation Problems
Denver Metropolitan Area

ADAMS, ARAPAHOE, DENVER, & JEFFERSON COUNTIES

COLORADO

SCALE

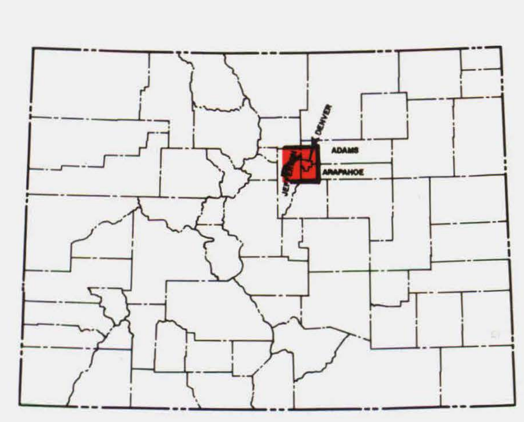


EXPLANATION

- DEPTH TO BEDROCK CONTOUR LINE (NUMERALS INDICATE APPROXIMATE DEPTH BELOW GROUND SURFACE. CONSIDERABLE VARIATION FROM THESE CONTOURS MAY OCCUR LOCALLY)
- FORMATION CONTACT
- FAULT

ROCK TYPES

Ti	INTRUSIVE IGNEOUS ROCK
Tv	LAVA FLOWS
Tgm	GREEN MTN. CONGLOMERATE
Tkd	DENVER FORMATION
Tkda	DAWSON ARKOSE
Ka	ARAPAHOE FORMATION
Kl	LARAMIE FORMATION
Kfh	FOX HILLS SANDSTONE
Kp	PIERRE SHALE
Kpu	UPPER PART
Kph	HYGIENE SANDSTONE
Kpl	LOWER PART
Kn	NIOBRARA FORMATION
Kns	SMOKY HILL SHALE MEMBER
Knf	FORT HAYS LIMESTONE MEMBER
Kb	BENTON SHALE
Kd	DAKOTA SANDSTONE



INDEX MAP
COLORADO

prepared for
COLORADO GEOLOGICAL SURVEY
by
WILLARD OWENS ASSOCIATES

drafted by
PETROMOTION

base map from
COLORADO STATE HIGHWAY DEPARTMENT

N

GEOLOGY MAP and DEPTH to BEDROCK

Geologic Aspects, Soils and Related Foundation Problems
Denver Metropolitan Area

ADAMS, ARAPAHOE, DENVER, & JEFFERSON COUNTIES
COLORADO

SCALE