Environmental Geology 4

Engineering Geology Report for Planning District 9, State of Colorado

Prepared for the Colorado Geological Survey
and the Colorado Diviision of Planning

By F. M. Fox & Associates

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
1974

COLORADO GEOLOGICAL SURVEY

DEPARTMENT OF NATURAL RESOURCES

STATE OF COLORADO

RECONNAISSANCE ENGINEERING GEOLOGY REPORT FOR PLANNING DISTRICT 9 STATE OF COLORADO

DOI: https://doi.org/10.58783/cgs.eg04.omle8141

PREPARED FOR

THE COLORADO GEOLOGICAL SURVEY

AND

THE COLORADO DIVISION OF PLANNING

This document was financed, in part, through an urban planning grant from the Department of Housing and Urban Development under the provision of Section 701 of the Housing Act of 1954, as amended.

ENVIRONMENTAL GEOLOGY NO. 4

TABLE OF CONTENTS

*In pocket at back of report

SUMMARY

There is a possibility that natural resources may be discovered or further developed in any of the geologic units delineated by the principal map. Therefore, consideration must be given to the diverse future needs in areas of high development potential. The following examples point up the multiple use potential for some of the map units.

1. Alluvial deposits are a primary source for construction materials, such as sand and gravel, and are commonly found in stream valleys which are suitable for agricultural and residential development. Abandoned quarries can be developed into recreation sites.

2. Sedimentary rocks are host for fuel and energy resources (uranium, coal, gas and oil), and these rocks underlie many existing large communities in the Planning District.

3. Igneous, metamorphic and volcanic rocks locally yield significant amounts of metallic minerals. These areas are also attractive to recreational community developers.

Massive land movements or other unstable surface conditions are found most commonly in areas having moderate to extreme topographic relief and abundant moisture. However, this generalization is too restrictive for Planning District 9. The Mancos and Lewis shales are potentially troublesome even in areas of low topographic relief. These clay-rich rocks are seen to creep or move slowly down gentle slopes where they are poorly drained and/or altered by construction. The potential for unstable surface conditions must be evaluated carefully for every proposed development site.

The need for soil investigations at all construction project sites is seen dramatically throughout the District. Many public and private buildings have structural damage which has been caused, at least in part, by swelling or settling soils. The life of any structure can be prolonged significantly by proper foundation design based on good soil engineering data.

General areas of flood danger or erosional hazards are found in association with all drainage basins located within Planning District 9. The history of flooding within the District may fail to properly emphasize the importance of this observation. However, as the population density increases, so will the number of structures situated on flood plains. Planning efforts must take this fact into consideration and regulate development on flood plains to prevent future tragedies and economic loss.

Areas of high water table, both permanent and seasonal, are found throughout the District. This troublesome feature is related directly to geology and precipitation. Little control is available for regulating precipitation, but geologic investigations will delineate areas where rock materials have poor permeability and can point up corrective measures which will enable developers to make safe use of such land.

The text of the report clearly points up the fact that not all rocks nor physical settings are suitable for solid waste disposal sites. Geologic evaluations must be made to determine whether the rock material in question is workable and will provide an effective seal, and whether there is any danger of pollution to a community water supply. With these guidelines, planners can be aware of special studies needed to meet public health standards.

There is a distinct possibility that mine dumps found throughout the District may be contributing to environmental pollution or presenting hazards to the unwary developer. The intensity of the problem will be related to the type of mine (such as the subsidence or the water contamination potential associated with coal mines) and the proximity of the mine to streams or water bearing rock units. Thorough investigations and reclamation projects may have to precede development work in some of the intensively mined areas within the District.

Many critical geologic factors affecting planning and development are explained in the text of the report. This information provides guidelines to those responsible for protecting public interests within the District. Application of this data will help to ensure safe, efficient and environmentally sound land use decisions. In summary, the need is stressed for site-oriented geologic and engineering investigations to evaluate problems and provide solutions for specific land use proposals.

INTRODUCTION

This report presents the results of a comprehensive investigation of the geology and engineering geology of Planning District 9, State of Colorado. Included with the text are maps, illustrations and other pertinent information as it relates to the geology and engineering geology of the subject area.

PURPOSE AND SCOPE

The purpose of the investigation is to identify within the Planning District specific geologic factors which should be taken into account to insure safe, efficient environmentally sound land use decisions. This has been done on a reconnaissance basis and the factors have included, but are not limited to, the following:

a. Mineral resources which affect land use decisions;

b. Massive land movements or other unstable surface conditions;

c. Areas of swelling or settling soils or other soil factors that will affect foundation construction;

d. General areas of flood danger and/or erosional hazards;

e. Areas of high water table, both permanent and seasonal;

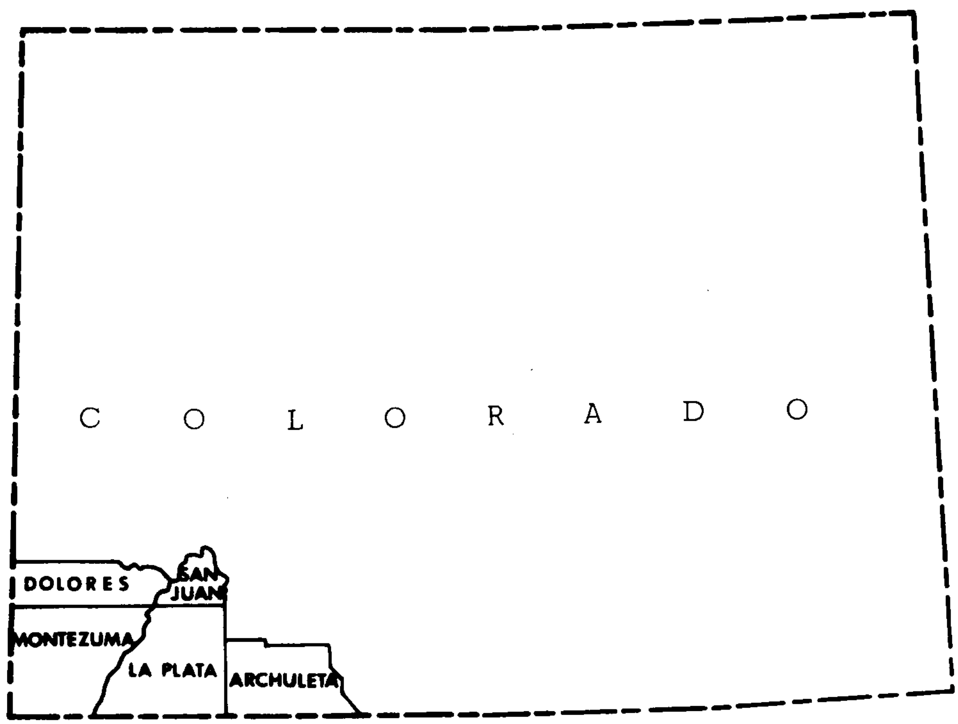
f. General geologic constraints that will affect selection and operation of solid waste disposal sites;

g. Pollution potential and other possible hazards associated with old mine tailing dumps; and

h. Other critical factors which may become evident during the course of the study.

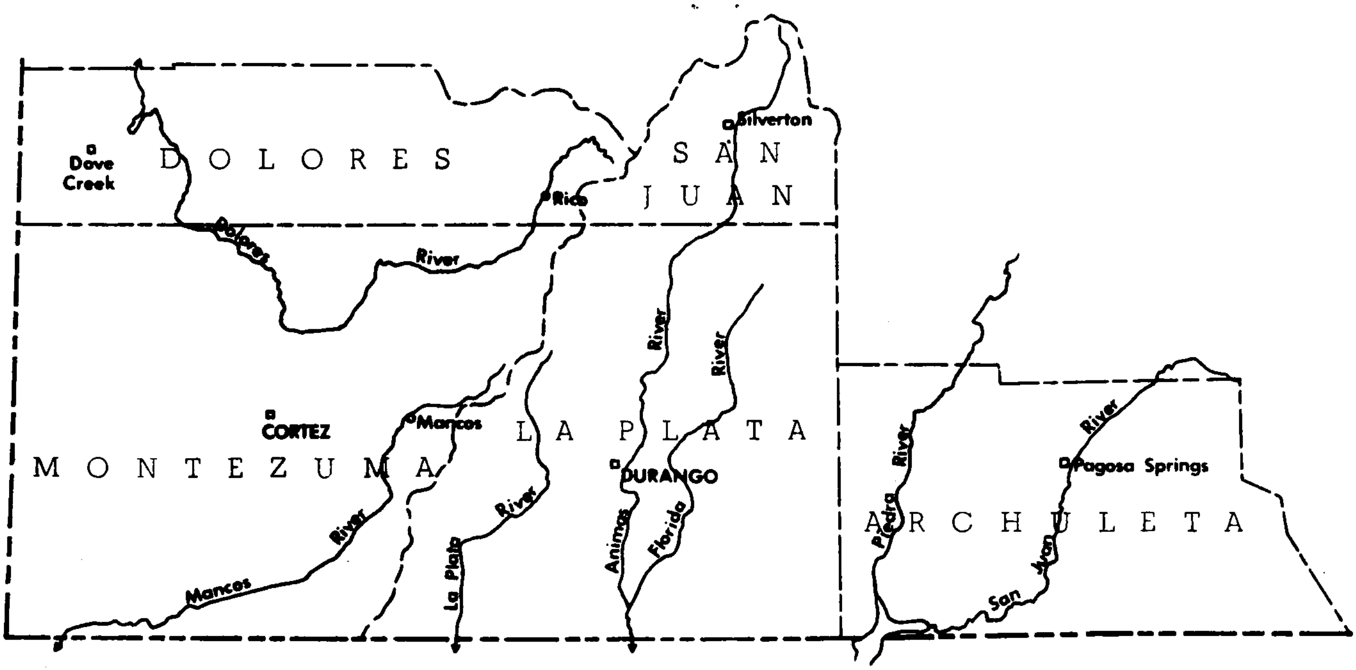
Figure 1 shows the areal extent of the study area. Planning District 9 includes the counties of Archuleta, Dolores, La Plata, Montezuma and San Juan.

Figure 2 shows the major rivers and drainage patterns in the area and identifies each county seat.



LOCATION MAP OF PLANNING DISTRICT 9

Figure 1



MAJOR RIVER SYSTEMS IN PLANNING DISTRICT 9

Figure 2

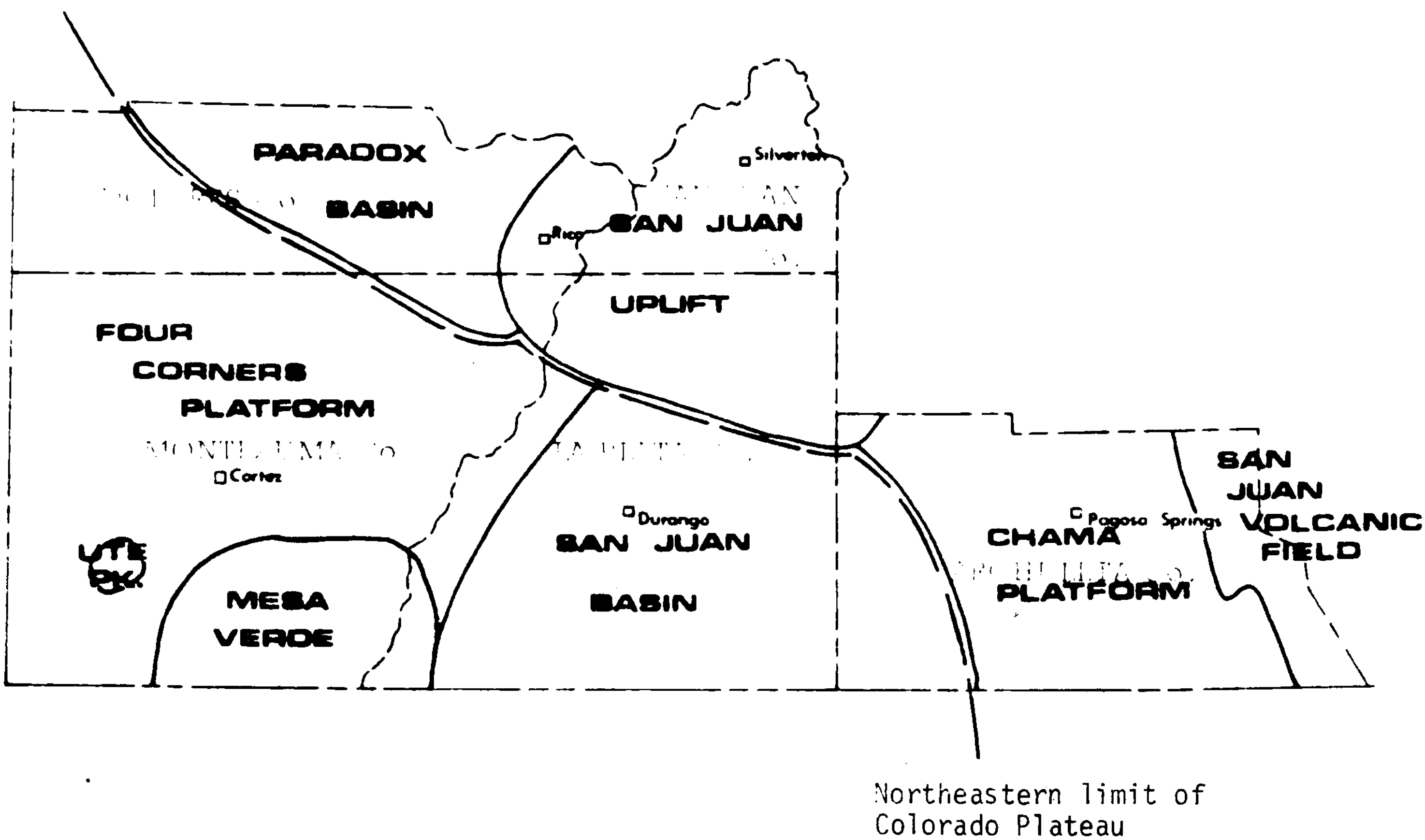
PHYSIOGRAPHIC FEATURES

The five county area which comprises Planning District 9 is situated in the southwest corner of Colorado. The Continental Divide is located near the northeast side of the District - lying within parts of the eastern sides of Archuleta and San Juan Counties. Elevations are seen to range (southwest to northeast) from 4,900 to 14,250 feet above sea level. The mean elevation is approximately 7,500 feet. The region can be described as mountainous, although the western and southern areas are part of the large physiographic province called the Colorado Plateau (Figure 3). The plateau region is dissected by drainage patterns which provide topographic continuity to the rugged nature of the alpine region. Principal rivers flow in south-southwest directions across the region with the exception of a part of the Dolores River which flows northwest through the northwest corner of the District.

GENERAL GEOLOGY

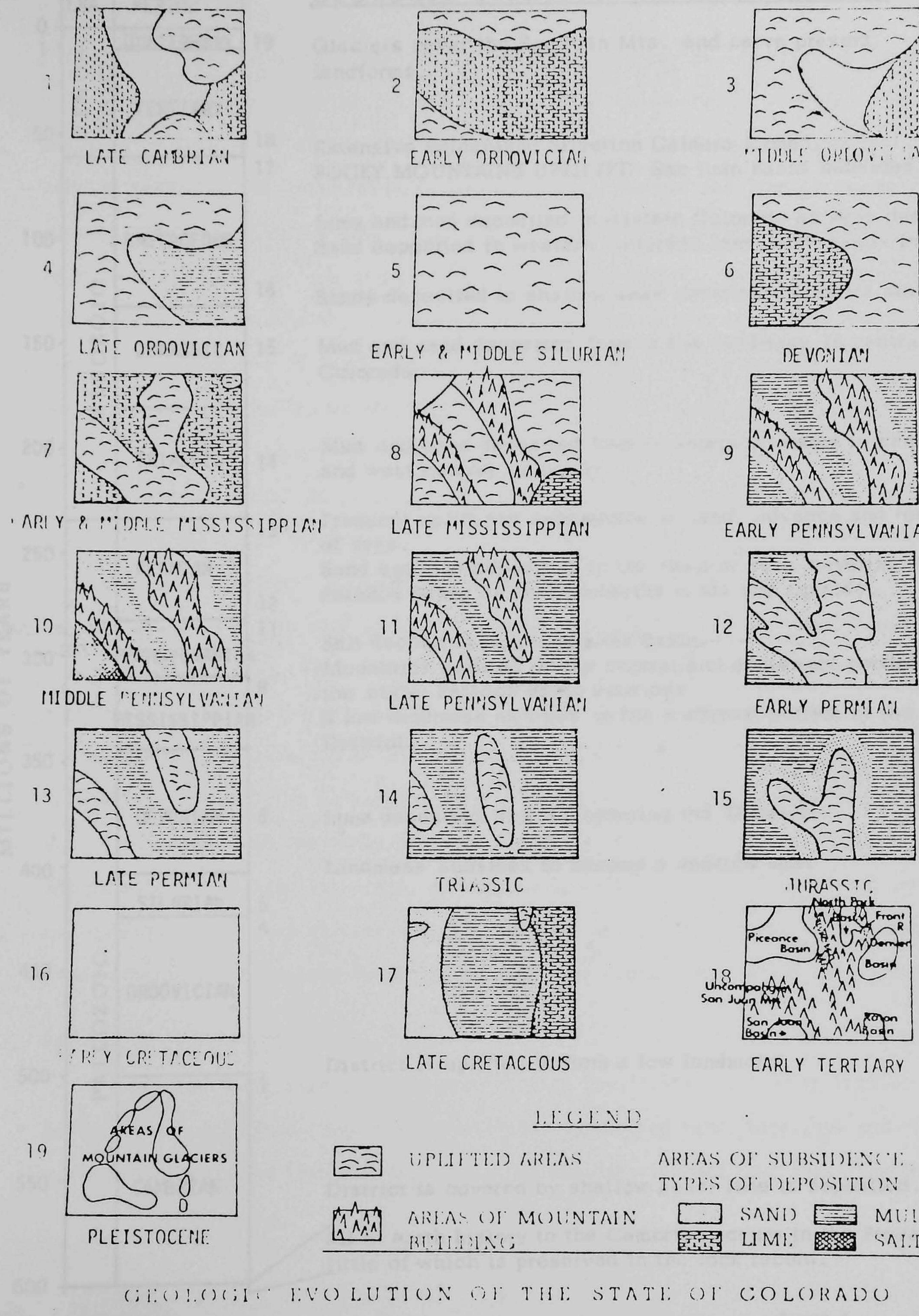
Figure 4 illustrates the geologic evolution of the State of Colorado and lists the geologic events for Planning District 9 in the order of occurrence. This synopsis shows the development of the various geologic units which eventually formed the present features of the area. A numerical cross reference is provided for the two parts of Figure 4 so that comparisons can be made between local and regional geologic events.

The geologic history of the Earth goes back approximately four billion years when the Earth was probably nothing more than a molten mass. The geologic history of interest to this report began about two and one-half billion years ago during the Late Precambrian Era as masses of various types of sedimentary and igneous rocks were repeatedly formed, buried, altered, uplifted and injected with new igneous bodies. About 600 million years ago, the first well-defined geologic periods began. The first was the Cambrian Period during which sand and lime accumulated in the sea which covered the District. Approximately one hundred million years later, the



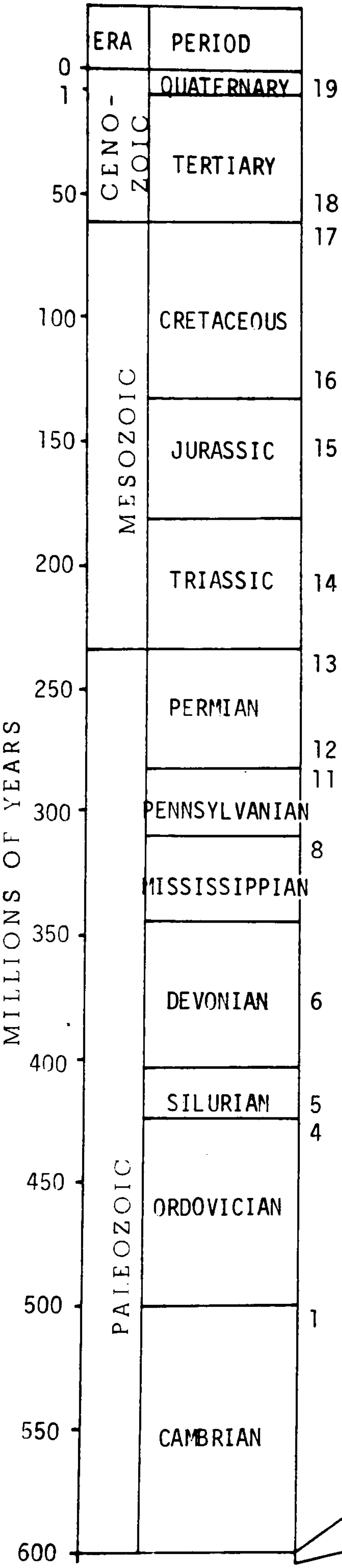
MAJOR PHYSIOGRAPHIC FEATURES OF PLANNING DISTRICT 9

Figure 3



GEOLOGIC EVOLUTION OF THE STATE OF COLORADO

GEOLOGIC EVENTS IN PLANNING DIST. 9



Glaciers cover the San Juan Mts. and carve present landforms.

Extensive volcanism: Silverton Caldera formed.
ROCKY MOUNTAINS UPLIFTED: San Juan Basin subsides.

Lime and mud deposited in eastern Colorado as seas deepen:
Sand deposited in western Colorado from landmasses in Utah.

Sands deposited in shallow seas covering the entire state.

Mud and sand deposited from a low landmass in central Colorado.

Mud and sand deposited from mountain remnants in central and west central Colorado.

Frequent uplift and subsidence of land, advance and retreat of seas.
Sand and mud deposited in the shallow seas covering the Paradox Basin as the mountains erode and subside.

Salt deposited in the Paradox Basin.
Mountains uplifted in the central and southwest portion of the state; Paradox Basin subsides.
A low landmass emerges in the northeast portion of the District.

Lime deposited in seas covering the District.

Landmass subsides to become a shallow sea.

District is uplifted to form a low landmass.

District is covered by shallow seas; lime is deposited.

All of earth history to the Cambrian occurs in the Precambrian, little of which is preserved in the rock record.

Figure 4

Ordovician Period began with the gradual uplift of the region effecting the withdrawal of the sea and terminating the deposition of sediments. The region remained positive (a land area) throughout the Silurian Period. Slightly more than 400 million years ago (Devonian Period), the area was submerged and lime sediments accumulated in the shallow sea. Later, during the Mississippian Period, a broad region was uplifted to form mountain ranges in approximately the same location as the present Rocky Mountains. During the Pennsylvanian and early Permian Periods, the southwestern part of the District was subjected to alternating times of emergence and submergence. Shallow marine sediments consisting of sand, clay and salt accumulated in the region. Between 250 and 130 million years ago, Late Permian to Early Cretaceous time, the pattern of alternating uplift and subsidence of the land continued. Sediments forming in these seas included sand and clay, but not evaporites such as salt and gypsum. Shallow seas covered the entire State during the Cretaceous Period, and most of the sedimentary rocks that are found in the area today were deposited during that time. About 70 million years ago, the Tertiary Period began with extensive volcanism and mountain building movements. During that period, the San Juan Mountains were formed and the San Juan Basin subsided to form a small sea. This sea was probably an inland sea much as the Great Salt Lake is now. It was during this time that the Rocky Mountains were uplifted to their present position. Approximately 1 million years ago, during the Quaternary Period, much of the area was covered by mountain glaciers which carved the present land forms. In Recent Time, erosion of these land forms has produced the topographic relief seen today.

HOW TO USE THIS REPORT

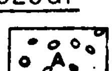
This report has been prepared specifically for Planners and other Public Officials who share the broad responsibilities for making safe, effective and environmentally sound land use decisions. It has been assumed that those reading and using this report will have some understanding of geologic terms and conditions. However, every attempt has been made to prepare this report in a manner which combines technically sound data with a layman's vocabulary. At the end of this report, a glossary is provided to define any terms used within the report which may not be clear to the reader.

It was obvious from the start that a compilation of geologic data would not be adequate to define the planning and development hazards in the District. Therefore, a special map has been prepared and is located in the pocket at the end of this report. This map does not show specific geologic formations, but shows selected broad geologic units which, in general, have similar engineering properties.

Ideally, this report can be used for several purposes. First, the Regional and County Planners, as well as the State Planning personnel can use the map to define those areas where serious geologic hazards are common. This can help the Planners to lay out County, Regional or State planning guidelines which will take into consideration the geologic constraints of a given area. Secondly, this map can be used as a means of checking preliminary filings for proposed subdivisions under Senate Bill 35. When the developer brings in a sketch plan to the County or Regional Planning office to discuss an intended subdivision, the Planning staff can use this map to identify possible geologic problems that are likely to occur in the area and determine if the person or firm writing the report has addressed the problems that are most prevalent in the area.

The significant fact is that problems exist and should be recognized during the planning stage. It is the express purpose of this report to aid the planner in the awareness of geology-related problems. The report is not intended as a substitute for geologic reports required by Senate Bill 35 and it should not be used for this purpose.

ENGINEERING GEOLOGY

I. Alluvium  Surface materials characteristically consisting of unconsolidated rock particles of mixed or sorted sizes which have accumulated during Recent geologic time are collectively referred to in this report as alluvium, regardless of the manner in which the materials accumulated. Specific types include:

A-1 Water deposited clays and silts found in stream flood plains;

A-2 Water deposited sand and gravel found in stream channels and valleys;

A-3 Water deposits of mixed particle sizes from clay to gravel found in uplifted terraces, fans and pediments;

A-4 Wind deposits such as silt (loess) or sand dunes which need not be restricted to a topographic feature;

A-5 Gravity deposits of mixed particle sizes from clay to boulders such as mud flows, talus, rock glaciers and landslides found along over-steepened valley walls; and

A-6 Glacial deposits of mixed particle sizes from clay to boulders found in alpine areas.

<u>Geologic engineering planning considerations</u> for the above mentioned types of alluvium include:

1. "Mineral resources which affect land use decisions"

   a. Metallic minerals may be found in water deposited alluvium such as Types A-1 through A-3. These mineral accumulations are called placer deposits.

   b. Construction materials such as sand and gravel may have accumulated in mineable quantities in some wind or water deposited alluvium such as Types A-2 through A-4.

   c. Energy resources such as uranium ores may be found in water or wind laid alluvial deposits as Types A-1 through A-4.

2. "Massive land movements or other unstable surface conditions"

   a. Unstable surface conditions are anticipated in areas that contain gravity formed deposits such as Type A-5.

   b. Numerous avalanche areas are found in several parts of the District and these will be discussed under special problems later in the report.

   c. During the process of glaciation, the rock materials moved by the ice are commonly piled up and left in an oversteepened condition. These glacial deposits may achieve temporary stability as natural vegetation covers the alluvium. However, if the glacial deposit is undrained (a condition which is caused by barriers to natural permeability) there is a high probability that an oversteepened slope will fail. Glacial deposits should be examined thoroughly for stability prior to any development work.

d. Mud flows can be expected in alluvial fans (Type A-3), on any oversteepened valley wall containing either gravity deposits (Type A-5) or glacial deposits (Type A-6), or in some stream channels (Types A-1 and A-2).

e. Regardless of the gentle appearance, alluvial fans are poor sites for developments. These deposits are formed by materials washed down from the mountains during heavy rains or floods. They are found at the mouths of canyons, along the edges of mountains, and are fan shaped with the apex of the fan at the canyon mouths. Alluvial fans are unconsolidated deposits of sands, gravels, clays and silts. The danger of building on an alluvial fan lies in the potential for erosion and further alluvial deposition during flooding. Streams often erode the loose material as they cut new channels through the deposits. During periods of floods, the streams rush down from the mountains, overflow their channels and deposit materials ranging from fine clays to boulders along the fan. Any construction on an alluvial fan is subject to flood and erosion.

3. "Areas of swelling or settling soils or other soil factors that will affect foundation construction"

a. Settling conditions are anticipated in areas containing loess-a wind deposited collapsible silt (Type A-4).

b. Expansive clays are known to exist along some stream valleys and on some uplifted terraces (Types A-1 through A-3).

c. Compressible sands can be anticipated along stream valleys and upland terraces where these deposits become saturated (Types A-1 through A-3).

4. "General areas of flood danger and/or erosional hazards"

a. Flooding may be anticipated in areas covered by water deposited alluvium (Types A-1 and A-2). However, where these water laid deposits do not adjoin an active stream, there is little danger of flooding.

b. Flooding may also occur in valleys blocked by landslides or large mudflows (Type A-5).

c. Erosion may be severe in all types of alluvial deposits owing to the unconsolidated nature of the material. This is most severe when the ground cover (vegetation) is stripped and the alluvial material is left exposed for extended periods of time.

5. "Areas of high water table, both permanent and seasonal"

a. High water tables are found in areas covered by water deposited alluvium (Type A-1 and A-2).

b. Gravity and glacial deposits (Types A-5 and A-6) may have localized high water tables.

6. "General geologic constraints that will affect selection and operation of solid waste disposal sites"

   a. Gravity formed deposits (Type A-5) should be avoided for solid waste disposal sites because of their unstable condition.

   b. Solid waste should never be disposed of in any type of alluvium that can have fluctuations in water table or where water can percolate down through the solid waste and reach an underlying aquifer or surface waters. In general, solid waste disposal should never be placed in water deposited alluvium in stream valleys or channels (Types A-1 and A-2).

7. "Pollution potential or other possible hazards associated with old mine tailing dumps"

   a. Mine tailings may be considered artificial alluvium and as such, are susceptible to land movements, flooding, high water tables and erosion.

   b. Pollution potential from mine tailings exist, but varies with different types of mines and kinds of operations. For example, acidic water may be produced as potable water moves through coal mine dumps containing the mineral pyrite.

   c. Any development or major planning decisions should take into consideration on-site, as well as up-stream, mine tailing dumps, their geochemical composition, their solubility and their cumulative effect on humans, animals, plants and construction materials. It is recommended that investigation of the chemical quality take place before construction is begun.

   d. Problems related to radiation hazards are not expected except in uranium mill towns and in those areas identified by the U. S. Geological Survey that have uranium and thorium deposits.

8. "Other critical factors which may become evident during the study"

   a. Sewage disposal can be accomplished in most types of alluvium, but significant problems can be encountered in alluvium having a high water table or in areas of unstable surface conditions.

   b. Routes for surface transportation are generally favorable where located on alluvium; however, prior consideration must be given by developers to slope stability, swelling or settling soils, flood dangers and areas of high water tables.

   c. Although most types of alluvium are workable for excavation or compaction, trenches in saturated alluvium are often dangerous (cave-in) and plans to protect workmen and materials should be thoroughly evaluated.

II. Sedimentary Rocks (Undivided) [Su] Sedimentary rocks characteristically consist of layered accumulations of rock particles, plant or animal remains, products of chemical action or evaporation, or mixtures of these materials. They are distinguished from "alluvium" by their greater age and consolidated nature. The undivided sedimentary rocks are set apart from those sedimentary rocks which have specific engineering problems. These problem rocks are described in the following section. Specific types of undivided rocks include:

SU-1 Shale, claystone and mudstone - extremely fine grained rocks derived from previously existing rocks and found throughout the district;

SU-2 Siltstone and sandstone - coarser grained rocks found in various areas throughout the district;

SU-3 Conglomerate - a very coarse grained rock derived from previously existing rocks;

SU-4 Limestone and Dolomite - crystalline carbonate rocks found mostly in the central part of the District; and

SU-5 Undifferentiated sediments, not specifically addressed, consisting of mixed carbonates, evaporites and other types of detrital rocks found in limited quantities in many areas.

The somewhat problematic Morrison formation has been included with the "Sedimentary Rocks (Undivided)" map unit. This formation consists of multi-colored sandstone and mudstone beds of Upper Jurassic age, and is found, to a limited extent, in all five counties which comprise Planning District 9. Rocks of the Morrison formation are most common in the canyons of the west-central part of District 9. They also form a belt-like outcrop which extends east from the La Plata Mountains to the vicinity of the Piedra River.

In some places, the Morrison formation consists predominantly of mudstone which is bentonitic. These rocks will present engineering problems similar to those associated with the Lewis Shale and Mancos Shale (i.e.-unstable surface conditions, swelling clay, erosional hazards, high water table and so forth). However, in many areas, the formation consists predominantly of sandstone. These sandier outcrops will present engineering considerations which are consistent with those described below for the subject map unit.

<u>Geological engineering and planning considerations</u> for these types of sedimentary rocks include:

1. "Mineral resources which affect land use decisions"

    a. Fuel and energy resources such as gas, oil, coal, uranium and thermal springs have been developed in the sedimentary rock areas of the planning district. Continued exploration for, and the development of these resources should be anticipated. Areas where these resources are known to exist are shown on Figures 5, 6, 7 and 8. Most of these resources have been developed in the finer grained detrital rock such as shale, siltstone and sandstone (Types SU-1 and SU-2).

    b. Metallic minerals are found as replacements in sedimentary rocks, primarily limestone and dolomites (Type SU-4). New development should be anticipated. The mining districts are shown on Figure 9.

    c. Locally, some limestone (SU-4) and sandstone (SU-2) have been quarried for building stone in the past. A brief account of this is noted for San Juan County. There may be a need to develop such construction material resources in the future.

2. "Massive land movements or other unstable surface conditions"

    a. Unstable surface conditions are to be expected in areas where sedimentary rocks are highly deformed (folded bedding or layers), or broken (fractured and/or faulted). All types of sedimentary rocks may be deformed; however, rocks of Type SU-1 are the most prone to produce unstable conditions when deformed.

    b. Subsidence of the ground surface over mined-out coal seams is common in many areas. These areas must be investigated for subsidence prior to development.

3. "Areas of swelling or settling soils or other soil factors that will affect foundation construction"

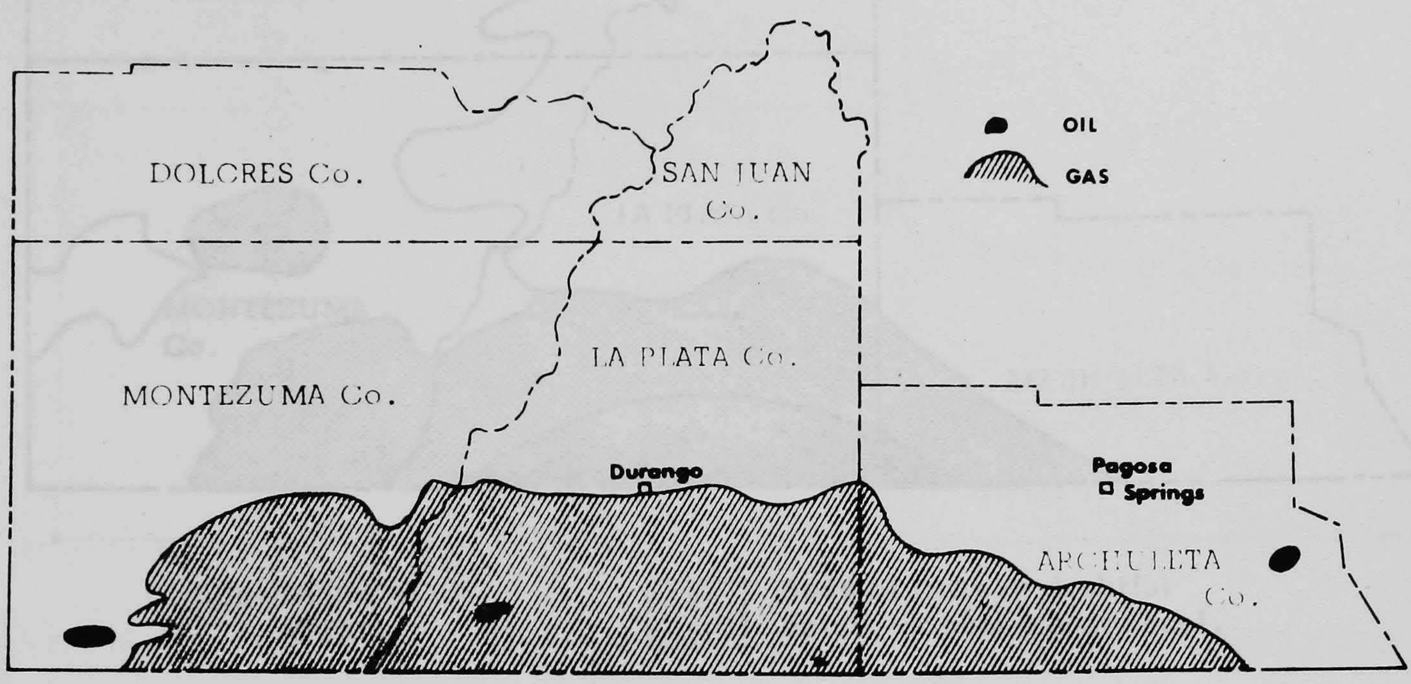
    a. Bentonite (common name for an expansive clay mineral) occurs in certain sedimentary rocks found in Planning District 9. Foundations to be constructed in Type SU-1 sedimentary rocks (or overlying soils) should receive prior investigation for expansive clays.

    b. Carbonate and evaporate rocks (Types SU-4 and SU-6) are soluble under certain conditions. There is a possibility of soil and rock collapse where such rocks are being dissolved.

    c. All proposed planning or developments in areas of existing mining districts should be evaluated to assure that underlying mine tunnels are stable and not prone to collapse.

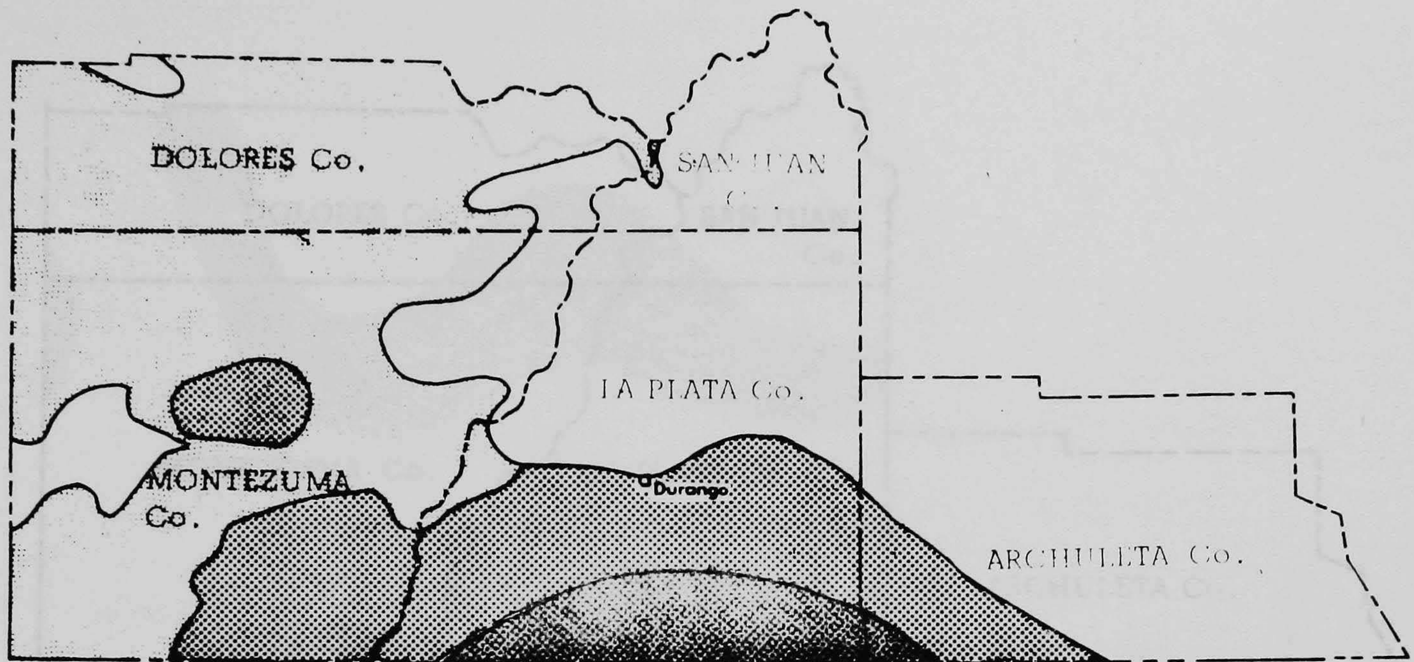
4. "General areas of flood danger and/or erosional hazards"

    a. Although flooding is generally more closely associated with alluvial



AREAS OF CURRENT AND POTENTIAL OIL AND GAS PRODUCTION IN PLANNING DISTRICT 9

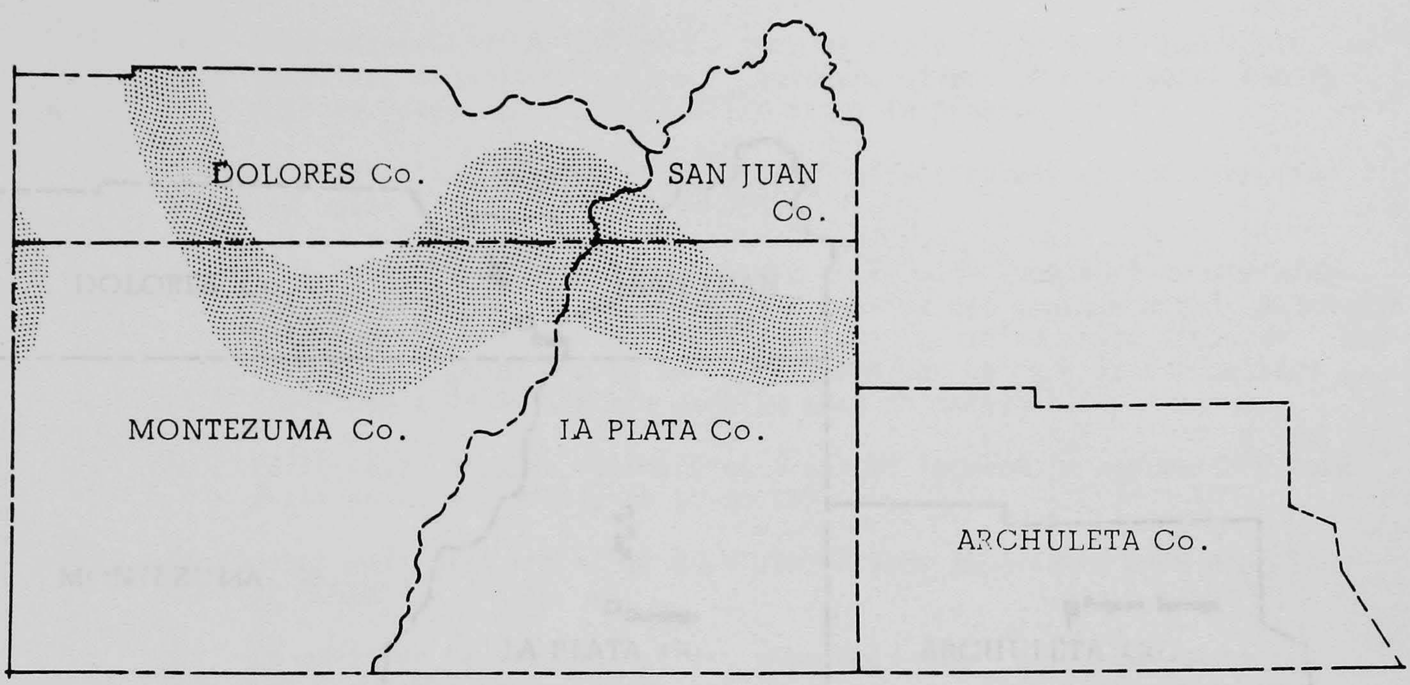
Figure 5



SUB-BITUMINOUS COAL		Beds of little or doubtful value, or poor quality coal.
SUB-BITUMINOUS COAL		Beds of known commercial value, present or future.
MEDIUM AND HIGH VOLATILE BITUMINOUS COAL		Beds of known commercial value, present or future.

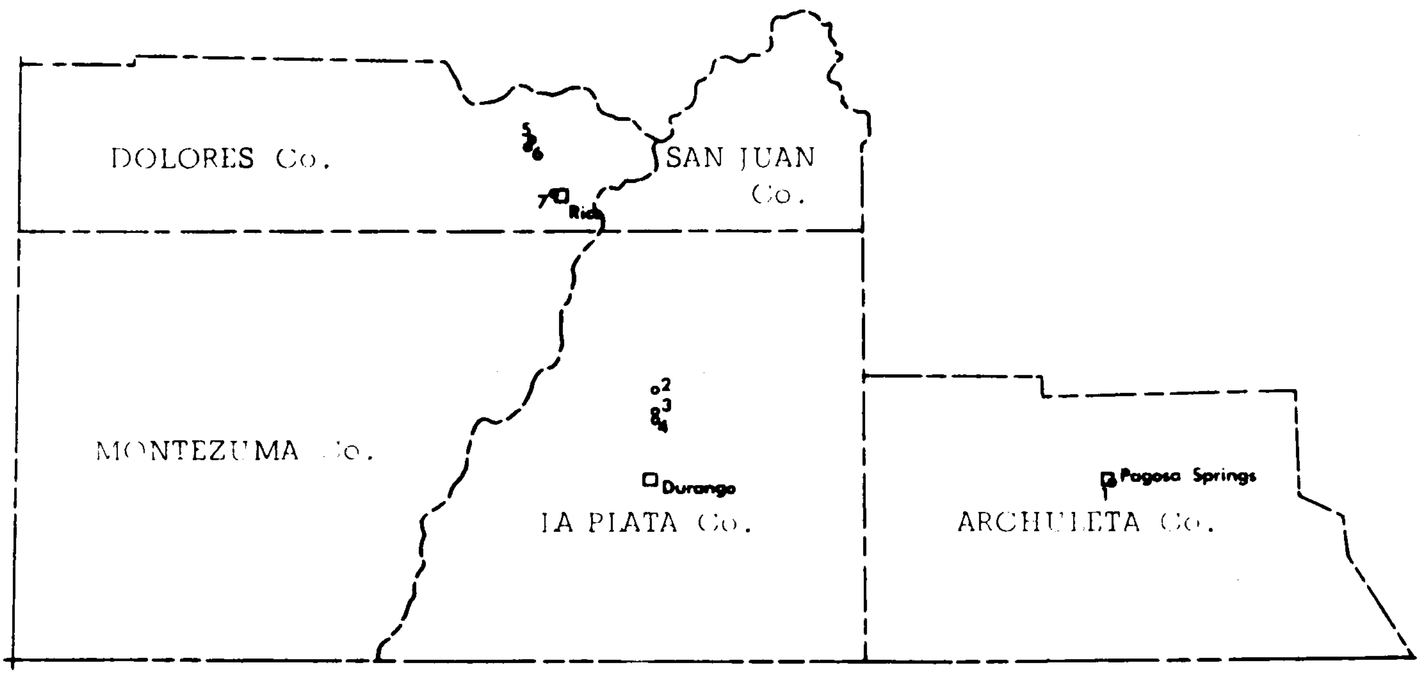
COAL BEARING AREAS IN PLANNING DISTRICT 9

Figure 6



AREAS OF POTENTIAL URANIUM DEPOSITS IN PLANNING DISTRICT 9

Figure 7



• LOCATIONS OF GEOTHERMAL SPRINGS IN PLANNING DISTRICT 9

Figure 8

conditions, it may occur in the steep walled gullies cut through sedimentary rocks. Geologically, the greatest potential for flooding is in watersheds covered by impermeable sedimentary rocks such as shale (Type SU-1) particularly where there is little or no ground cover or soil. Because of their layered nature, sedimentary rocks of all types are susceptible to erosion and undercutting which can create potential for land movement under proper conditions.

5. "Areas of high water table, both permanent and seasonal"

   a. Impermeable sedimentary rocks such as shale (Type SU-1) can cause localized high water tables. Cause and effect of high water tables must be investigated at specific sites in problem areas.

6. "General geological constraints that will affect selection and operation of solid waste disposal sites"

   a. Flat lying, undeformed sedimentary rocks with Type SU-1 or mixtures of interbedded Types SU-1 and SU-2 that do not contain highly permeable sandstone lenses are the best locations for solid waste disposal. The very fine grained shales and claystones can be made into excellent impermeable seals and are usually easy to excavate.

   b. Solid waste disposal sites should not be located in sedimentary rock areas which are likely to be unstable.

7. "Pollution potential and other possible hazards associated with old mine tailing dumps"

   a. In addition to the discussion presented under "Alluvium" above, water running through mine tailing dumps and into sedimentary rock units that will eventually serve as water sources for individual homes, developments or municipalities can be a problem. A complete geologic investigation of areas around mine tailing dumps should be made prior to planning or development.

8. "Other critical factors which may become evident during the study"

   a. State regulations have specific limits on the distances between leachfields, seepage pits or other subsurface disposal systems and the bedrock surface.

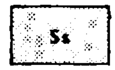
   b. In no case should a subsurface disposal system be placed in any type of sedimentary bedrock.

   c. Surface transportation facilities are generally unaffected by sedimentary rocks defined in this section. Local construction problems should be individually evaluated prior to construction.

   d. Some of the sedimentary rocks in this area are very hard, such as the limestones and sandstones (Types SU-2 and SU-4). These very hard rock units can pose specific construction problems to installation of any underground utilities. Planning and development in such areas should consider the rippability (ease of excavation) of such materials and whether or not blasting will be necessary. Such investigation should also evaluate the affects of blasting on nearby structures or developments.

e. Artificial problems, such as coal mine subsidence should be considered where applicable. Plans for reclamation of open pit mines should be presented to County and Regional officials.

f. Radiation hazards may be found in uranium mill towns and in those areas identified by the U. S. Geological Survey as prospects for uranium and thorium deposits.

III. Sedimentary rocks with specific problems 

Sedimentary rocks with specific engineering geology problems have been identified on the map. These special problem formations primarily consist of rock units deposited during the Cretaceous Period. These units are described as follows:

SS-1 The Mancos Shale - a dark grey sandy shale with some limestone layers; and

SS-2 The Lewis Shale - a dark grey or greenish grey shale, much like the Mancos. The Lewis Shale has some sandy layers and some limestone layers.

Geological engineering and planning consideration for the above mentioned sedimentary rocks include:

1. "Massive land movements or other unstable surface conditions"

a. The subject sedimentary rock units, where exposed or overlain by younger sediments or volcanics, are susceptible to massive land movements. These conditions are particularly severe along steep walls of mesas, canyons and valleys, or where the subject sedimentary units form dip slopes. Development and planning considerations must take into account unstable surface conditions and specific restrictions should be placed on the proximity of development structures to hazardous areas.

b. The Mancos and Lewis Shales are easily eroded when they are exposed to weathering. This can result in slumping along roadcuts and stream valleys.

c. Unstable surface conditions are also to be expected in areas where these sedimentary rocks are highly deformed or fractured.

2. "Areas of swelling or settling soil or other soil factors that will affect foundation construction"

a. The Mancos and Lewis shales have some swelling potential when excess moisture is applied to them. All developments in the areas covered by these rocks should have comprehensive soil engineering investigations to define the location and extent of the various swelling soils and to make recommendations on construction procedures and techniques to overcome such problems.

3. "General areas of flood danger and/or erosional hazards"

   a. Stream or river valleys, particularly steep walled gullies, which cut through the exposures of these sedimentary units have moderate to high potential for flooding and erosion. Such hazards must be evaluated prior to construction and necessary safeguards provided.

   b. On gentle slopes which have little or no soil cover, and are underlain by the subject sedimentary rocks, sheet flooding should be anticipated.

   c. Because of the layered nature of these rocks, erosion and undercutting is severe along steep walled gullies and valleys. This undercutting creates a potential hazard for rock movement (landslides).

4. "Areas of high water table both permanent and seasonal"

   a. A high water table should be anticipated in low lying areas underlain by the subject sedimentary units.

5. "General geologic constraints that will affect selection and operation of solid waste disposal sites"

   a. The subject sedimentary units generally make excellent solid waste disposal sites because they are relatively impermeable. These sites are best located in relatively flat lying beds in an area of low relief.

   b. Stability factors should be taken into account at any solid waste disposal site. They should not be located in any place where there is a question or evidence of land movement of any sort. A properly operating, non-polluting landfill could become a pollution hazard with only a small amount of land movement.

6. "Other critical factors which may become evident during the study"

   a. On-site leach fields are not recommended for these types of sedimentary rocks. Without a substantial soil or alluvial cover, sewage disposal in these areas will probably require specially engineered evapo-transpiration systems or other types of sewage disposal systems.

   b. Surface transportation routes across Mancos-Lewis exposures will be necessary but maintenance will be costly. These routes must be laid out carefully to avoid stability hazards.

   c. Excavation and/or compaction considerations should be evaluated on a per site basis.

IV. Metamorphic and intrusive rocks  Metamorphic and intrusive rocks are grouped together as a single map unit because of their similar engineering properties. A metamorphic rock is the resultant of a transformation of another rock, brought about by great pressures, high temperatures and/or chemical changes. However, igneous rocks form by solidification from an essentially molten state. Intrusive igneous rocks are those which have penetrated other rocks but have solidified before reaching the surface of the Earth. The general types of these crystalline rocks, found in Planning District 9 include:

CR-1 Metamorphic rocks which are found in the central part of the Planning District. These consist predominantly of coarse grained minerals which are segregated by types giving a light and dark banded appearance to the rocks.

CR-2 Intrusive igneous rocks, found at various locations throughout the Planning District, show a wide range of colors and grain sizes. These variations were controlled primarily by the chemical composition of the molten materials and the rate at which they cooled.

Geological engineering and planning considerations for the above mentioned types of rocks include:

1. "Mineral resources which affect land use decisions"

   a. Ore bodies containing metallic minerals have been mined within the geologically complex igneous-metamorphic rock areas. Continued exploration and development should be anticipated for these minerals. The existing mining districts are shown on Figure 9.

   b. Building stone (granitic rock) has been quarried to a limited extent in San Juan County. It is possible that these resources may be developed more extensively in the future.

2. "Massive land movements or other unstable surface conditions"

   a. The types of metamorphic and intrusive igneous rocks found in the Planning District are relatively dense and stable, but under certain conditions these rocks can become very unstable. The following should be considered when working in metamorphic or igneous terrane.

      1) In alpine and glaciated areas, oversteepened valley walls are common and gravity movements can be anticipated. Any slope greater than 30% should be evaluated specifically for stability.

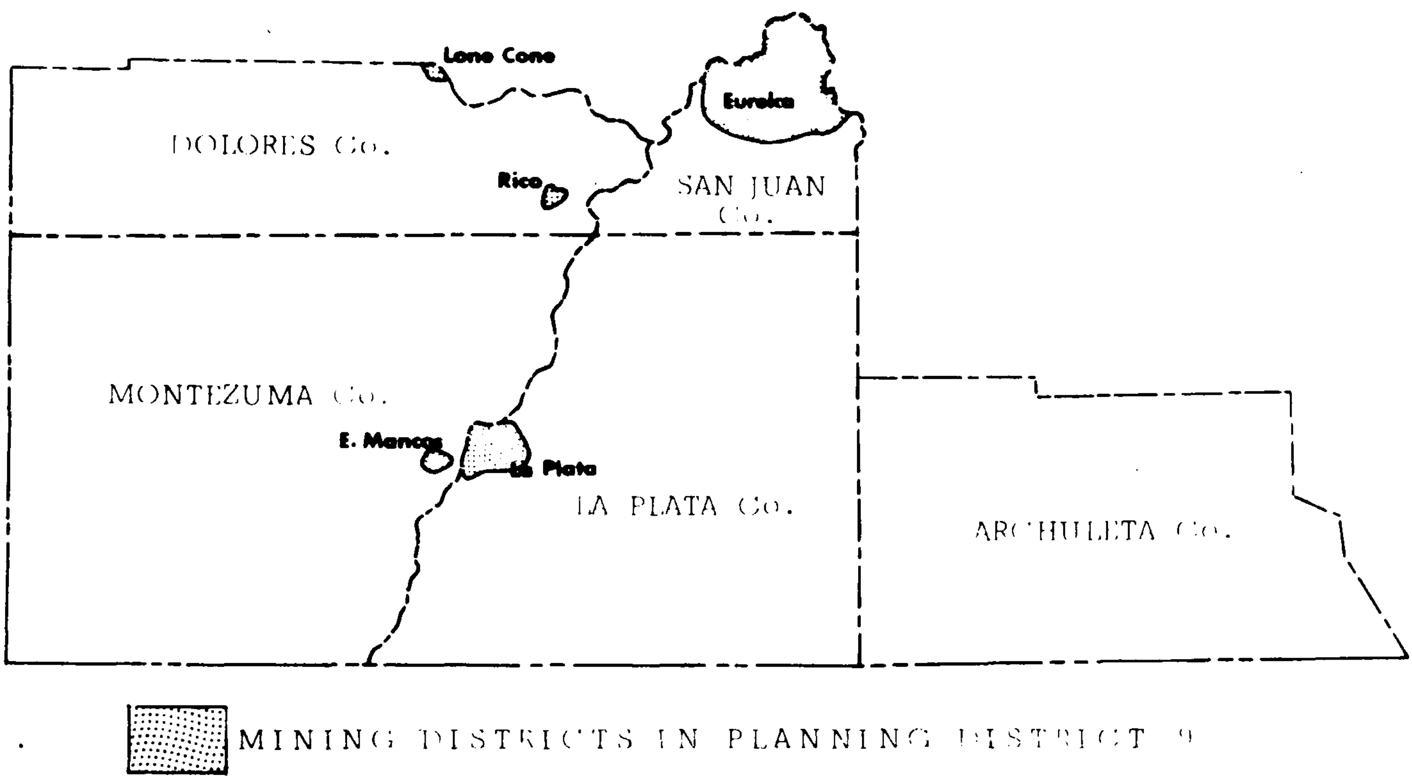

Lone Cone
Eureka
DOLORES Co.
Rico
SAN JUAN Co.
MONTEZUMA Co.
E. Mancos
La Plata
LA PLATA Co.
ARCHULETA Co.
MINING DISTRICTS IN PLANNING DISTRICT 9

Figure 9

2) Geologic structures such as joints, fractures and faults will contribute to the instability of these rocks.

3) The internal structure of the rocks can be a detriment to the stability of the rock. Metamorphic rocks, in particular, have distinctive planes of weakness, and slippage along these planes is common especially along steeply dipping ones. For example, slides are more apt to occur at roadcuts where the planes dip into the cut rather than away from the cut.

4) Weathering of these rocks, in combination with any of the other three factors, will further weaken the stability of the rock.

b. It is recommended that prior to construction engineering geology studies be conducted to determine slope stability.

3. "General areas of flood danger and/or erosional hazards"

a. The potential for flash floods should be anticipated in igneous or metamorphic terrane. This hazard is related to the dense and impermeable nature of the rocks and steep watersheds.

b. Erosion of the bedrock itself should not be a problem. However, erosion of the weathered or glacial cover can be serious.

4. "Areas of high water table, both permanent and seasonal"

a. High water tables can be found in igneous and metamorphic areas where drainage has been blocked by either glacial deposits or gravity deposits (landslides, mud flows and talus).

b. Most commonly fractured and jointed rocks have no defineable water table except that which may build up in the soil or weathered zone above the rock mass.

5. "General geologic constraints that will affect selection and operation of solid waste disposal sites"

a. Metamorphic and igneous rocks are, in general, not suitable for solid waste disposal sites. Such rocks would be difficult to excavate and seals would be difficult to form.

b. In large areas of these rocks, a more suitable site for solid waste disposal may be found by locating drained alluvial deposits overlying these rocks. If this is the case, however, the alluvium should be of a clayey nature, above the water table and free of flood danger.

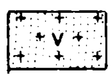
6. "Pollution potential and other possible hazards associated with old mine tailing dumps"

a. Extensive mine tailing dumps may be unstable and subject to settling or movement. If improperly placed, erosion will redistribute the tailings downstream.

b. A pollution potential exists for many types of mine dumps. However, the degree of danger depends on the proximity of the tailings to a stream or aquifer and the type of mine, such as the potential for contamination from zinc-mine tailings.

7. "Other critical factors which may become evident during the course of the study"

   a. Sewage disposal, transportation routes, and material workability considerations for these rocks can all be considered costly undertakings. Such projects must take into account the stability factors, the pollution potential, the possibility of avalanches (covered in section on special problems), the possibility of flooding and the maintenance costs.

V. Volcanic rocks  Volcanic rocks consist of two principal types - extrusive (lava flows) and pyroclastic (ash falls). The extrusive rocks originate in a molten state and flow out at the surface of the Earth before solidifying. Pyroclastic rocks contain the fragmented materials which were ejected into the air and fell to the ground in what can be considered bedded formations. Volcanic ash is a familiar example of a pyroclastic rock. The general types of these rocks in Planning District 9 include:

V-1 Extrusive (igneous) rocks found in San Juan and Archuleta Counties; and

V-2 Pyroclastic rock, the grain size of which can vary from very fine (ash) to very coarse (breccia), found in areas associated with the extrusive rocks mentioned above.

<u>Geological engineering and planning considerations</u> for the above mentioned types of rocks include:

1. "Mineral resources which affect land use decisions"

   a. Neither energy nor construction resource considerations are anticipated for areas covered by volcanic rocks.

   b. Precious metals have been extracted from the volcanic areas in San Juan and Archuleta Counties, mainly gold, silver, copper, lead and zinc.

2. "Massive land movements or other unstable surface conditions"

   a. The same conditions noted earlier relating to the stability of igneous intrusive and metamorphic rocks can apply to volcanic rocks. These conditions are:

1) Oversteepened valley walls (slopes greater than 30%);

2) Geologic structures (joints, fractures and faults);

3) The internal nature of the rocks (in the case of pyroclastic rocks, this would concern the strength of the bond holding the material together - some pyroclastic rocks can crumble very easily or weather to clays which can cause landslides); and

4) Weathering, by itself or in combination with one of the above, can create instability and the potential for a landslide.

b. The San Juan Tuff, a pyroclastic formation, is prone to slide especially where it overlies the Mancos Shale. This formation outcrops in San Juan County.

3. "Areas of swelling or settling soils, or other soil factors that will affect foundation construction"

a. Volcanic (pyroclastic) ash is a principal source of bentonite, an expansive clay mineral, and soils developed over volcanic rocks should be examined for conditions that could affect foundations.

4. "General areas of flood danger and/or erosional hazards"

a. Similar to intrusive and metamorphic rocks, there is a flash flood potential in volcanic rocks owing to their dense nature, which prevents infiltration of surface water.

b. Erosion will be slow for extrusive rocks, but highly variable for pyroclastic rocks. Erosional hazards should be examined for developments planned in areas covered with pyroclastic rocks.

5. "Areas of high water table, both permanent and seasonal"

a. Pyroclastic rocks will tend to be more like sedimentary rocks - i.e., they will probably be porous and have some degree of permeability. However, localized high water tables may be encountered, and cause and effect must be examined in these problem areas.

b. In areas where drainage has been blocked, high water tables can be expected.

6. "General geologic constraints that will affect selection and operation of solid waste disposal sites"

a. Extrusive volcanic rocks are not suitable, in general, for solid waste disposal sites because seals would be difficult to form and the hard rocks would be difficult to excavate.

b. Tuffaceous (pyroclastic) rocks will not be as difficult to work with heavy equipment, but problems may be encountered in preparing seals, such considerations can only be identified by examination of specific sites by engineering geologists.

7. "Other critical factors which may become evident during the course of the study"

    a. Geologic factors for sewage disposal, transportation routes and material workability vary greatly for the volcanic rocks found in Planning District 9. These factors, coupled with stability considerations, should be studied in detail prior to development work in volcanic terrane.

PROBLEM AREAS

The purpose of this part of the report is to specify certain areas in Planning District 9 as "problem areas". These serve as an example of the inter-relationship and possible complexities of the engineering problems described in this report. The outlines shown on the principal map for some of these areas are generalized and are not intended to imply uniform conditions throughout. The geologic complexities will vary from one area to another; for example, at one place, investigations may show the area to be highly faulted, and at another location, there may be outcrops of several different rock types within a small area. It is hoped that in describing some of the areas of complex geology, the planner will realize the importance of considering the possible effects one geologic unit will have upon the other.

Problem Areas IA and IB

Two problem areas, sililar in nature, are listed together here as IA and IB. Problem Area IA is Sleeping Ute Mountain in western Montezuma County, and IB is the area of the La Plata Mountains on the Montezuma-La Plata County border. Both areas are characterized by igneous intrusions into sedimentary rocks, including the Mancos Shale. In addition, much Recent alluvium is found within each boundary, and this comprises the fourth geologic unit within each small area. Problems in these two areas result from topography and the inter-relationship of these four rock units.

Rough topography can create an avalanche potential. Talus deposits resulting from the erosion of the intrusive and sedimentary rocks will be unstable for construction, and would be a hazard to construction immediately around such deposits. Areas of landslides or glacial deposits will give rise to the same problems. Steeply dipping sedimentary beds are prone to slide and these areas are hazardous for developments. The Mancos Shale, also outcropping in each area, is landslide prone. The Mancos Shale and alluvial cover both have some swelling capacity which should further discourage building. The rocks in these areas may be highly fractured which would add to or intensify the above mentioned unstable conditions.

Problem Area II

Problem Area II, located in eastern Dolores County, is unique in having both natural and artificial hazards. Rugged topography and high elevations produce an avalanche potential. Steeply dipping sedimentary beds can be unstable as well as alluvial deposits such as talus, glacial moraines and older landslide deposits. Flash floods can be a problem especially in areas where a river or stream is confined to a narrow valley. High water tables resulting from a shallow alluvial cover over bedrock should further restrict development here. Weathering of the bedrock, especially in areas of glacial oversteepening, will be hazardous and cause rock falls and slope instability. Artificial hazards are found in the old mine tailing dumps and abandoned, open mine shafts. Many times these shafts may be hidden by snow or vegetation and create a trap. Old mines at any location can be dangerous and should be sought out before development takes place.

Problem Areas IIIA and IIIB

Problem Areas IIIA and IIIB in San Juan County have similar problems although they are located in different types of rocks. The rocks in both areas are highly faulted and broken and are located at high elevations in rugged topography. Problem Area IIIA is located in volcanic rocks which can be very unstable if the lava flows are fairly thin and are located over incompetent rock. Both areas, however, share the problems of avalanches, rock falls and instability associated with areas of rough topography as described for the previous two areas. In addition, the highly broken nature of the rock can create an unstable situation in what is normally considered to be competent rock. There is little possibility of further movement along the faults, but movement along the faults in the geologic past has crushed and broken the igneous, metamorphic and volcanic rocks to the extent that they can be unstable.

Problem Area IV

Problem Area IV, located in eastern Archuleta County, is unique in the character of the geology and the resulting problems. All five map units are present within this small area. There are, for example, extensive outcrops of the easily eroded Mancos and Lewis shales which are, in places, overlain by volcanic lava flows. This combination of rock types has resulted in extensive landslides at some time in the geologic past, probably late Tertiary or early Quaternary. These older landslides have undergone some settling and consolidation and a limited amount of construction should not cause stability problems. However, extensive development may create problems. Anywhere the Mancos or Lewis shale is exposed, there will be landslide or erosion problems, and these problems can be expected in this area.

The reader is reminded that the preceding text and illustrations are guidelines for the layman who is vitally concerned with, but not experienced in, engineering geology. The information presented cannot be substituted for the professional site investigations which must be an integral part of urban and rural rejuvination and growth, and must encompass the spectrum from industrial to recreational projects.

The reader is urged to study these guidelines and become familiar with the geologic factors that rightly affect land use and planning decisions. Such efforts will work toward the better use and protection of our environment.

F. M. FOX & ASSOCIATES, INC.

Bruce A. Florquist

Bruce A. Florquist, Chief Geologist

Robert B. Sennett

Robert B. Sennett, Sr. Project Engineer

GLOSSARY

Acidic water - water in which excessive acid-forming constituents have been dissolved. Example: water passing through rock formations containing sulfide picks up these materials and becomes acidic. This water, as a result, is capable of deteriorating certain types of concrete and polluting water supplies.

Alluvium - clay, silt, sand, gravel or mixtures of these rock particles which have accumulated during Recent geologic time and are characteristically unconsolidated. All such materials are referred to collectively in this report as alluvium regardless of the manner in which the materials accumulated (water, wind, gravity or glacial deposits).

Altered rock - a rock that has undergone physical and/or chemical changes. Metamorphic rocks are examples of altered rocks.

Aquifer - a porous rock formation that bears ground water which can be recovered through wells.

Avalanche (rock) - see Gravity deposits, page iii.

Avalanche (snow) - a sudden fall of snow from a high elevation to a lower one. Avalanches commonly follow avalanche "chutes" (long, steep paths down a mountain side, barren of trees or other growth).

Bedded formation - a rock unit which shows successive beds, layers or strata, owing to the manner in which it was formed (such as the layers seen in sedimentary rocks).

Bedrock - any solid rock exposed at the surface of the earth or overlain by unconsolidated material (A.G.I*.).

Bentonite - a montmorillonite-type clay formed by the decomposition of volcanic ash. Bentonite swells when wetted which can cause foundation problems.

Cambrian - the geologic period which began about 600 million years ago at the close of the Precambrian period. The Cambrian period lasted about 100 million years and is part of the Paleozoic era.

Carbonates - sedimentary rocks consisting mainly of calcareous material (compounds with the radical CO_3).

Cenozoic - the most recent geologic era which began some 60 million years ago and includes the present. The Cenozoic era saw the extinction of dinosaurs, the ice age and the coming of man.

Clay - an earthy, extremely fine grained material (particle diameter less than .005 mm). Clay becomes plastic when wet and hard upon drying.

Claystone - a sedimentary rock comprised mainly of clay sized material which has been consolidated by compaction or cementation.

Compaction - a decrease in volume of soil or rock particles caused by the action of external forces applied to the material.

*American Geological Institute Glossary of Geology

Conglomerate - a sedimentary rock consisting of large, rounded particles, such as gravel and sand, cemented together.

Consolidation - the process by which loose and/or soft material becomes hard.

Cretaceous - a geologic period lasting about 72 million years, during the Mesozoic era.

Crystalline rock - a general term for igneous and metamorphic rock in contrast to sedimentary rocks (A.G.I.)

Cutbank - the bank of a stream on the outside edge of a curve which is constantly being cut by the motion of the stream. Vertical or overhanging banks may result from this stream action.

Delta - an alluvial deposit found at the mouth of a river. The delta is formed by a river carrying clay, silt and some sand where the velocity decreases as the river enters a larger body of water.

Dense - a term describing the texture of a very fine grained rock. The grain size in such a rock is generally less than .05 to .1 mm in diameter and cannot be seen by the naked eye.

Deposition - the natural accumulation of material deposited by water, wind, glacial or gravity action.

Detrital - sedimentary deposits consisting of particles derived from other rocks. (This is in opposition to a chemical rock - such as salt.)

Devonian - a geologic period lasting about 60 million years in the Paleozoic era.

Dip - the angle at which a bedded rock formation is tilted from the horizontal.

Dip slope - a slope on the surface of the land that has approximately the same angle as the underlying formation.

Dolomite - a calcareous sedimentary rock, similiar in appearance to limestone. (See carbonates.)

Dunes - wind blown deposits of loose sand and silt which may be massive or may resemble wave like forms with the gentle slope facing the wind direction and the steep slope away from the wind. Dunes may be actively moving or may become stabilized.

Embayment - an indentation of a shoreline forming a bay.

Engineering geology - the application of the geological sciences to engineering practice for the purpose of assuring that the geologic factors affecting the location, design, construction, operation and maintenance of engineering works are recognized and adequately provided for (A.G.I.).

Era - a division of geologic time of the highest order, made up of one or more periods.

Erosion - the wearing away of rock or soil and the movement of these rock particles. Wind, water, ice and gravity movements cause erosion.

Evaporate - a sedimentary rock consisting mainly of materials, formerly in solution, deposited by the evaporation of water. Example: rock salt is formed by the evaporation of sea water, leaving the dissolved salts behind.

Evapo-transpiration - a system for disposing of fluids by either evaporation or transpiration from vegetation or a combination of both.

Extrusive - a term applying to igneous rocks which formed by the cooling and solidification of lavas flowing out on the surface of the earth. All volcanic rocks are extrusive.

Fan, alluvial - a fan shaped alluvial deposit formed by a stream descending from a steep slope to a more gentle slope and depositing material on the more gentle slope. On an alluvial fan, the apex points upstream to the steeper slope and the fan portion spreads out on the gentle slope.

Fault - a fracture or zone of fractures along which there has been movement parallel to the plane of breakage.

Flood plain - a level area to each side of a river or stream covered by materials deposited by the stream during stages of flooding.

Fractures - breaks in a solid rock along which there has been little or no movement. Fractures commonly form in association with faulting and folding.

Geochemistry - the science of the chemistry of the earth. Geochemical refers to the chemical composition of a rock and the chemical origin of that rock.

Geology - a science that deals with the history of the earth, especially as recorded in the rocks (A.G.I.).

Glacial deposits - unconsolidated material deposited as a result of glacial activity. Particle sizes vary from boulders which the glaciers "plucked" from a valley floor to very fine "rock flour" resulting from constant grinding. The most common glacial deposit is the moraine.

Glacier (mountain)- a river of ice moving in a mountain valley. Glaciers form by the compaction and remelting of snow which builds up and begins to slowly move down a mountain to the valley. Glaciers were widespread in the Rocky Mountains during the Quaternary period.

Granite - an intrusive igneous rock (as opposed to extrusive or volcanic rock) consisting mainly of certain amounts of feldspar, quartz, mica and a small amount of other minerals.

Gravity deposits - alluvial deposits formed by materials moving or falling from an unstable position to a more stable one. Common types of gravity deposits include landslides, mudflows and rockfalls.

Igneous - a rock formed by the cooling and solidification of a molten mass. This may occur within the earth or on the surface.

Impervious - a term used to describe any dense material through which fluids cannot pass.

Intrusive - an igneous rock formed by the cooling of a molten mass beneath the surface of the earth.

Joints - another term for a fracture in a solid rock along which little or no movement has taken place.

Jurassic - a geologic period lasting about 46 million years during the Mesozoic era.

Land movements (massive) - landslides.

Lava - molten rock flowing on the surface of the Earth until it cools and solidifies. All lavas are classified as extrusives.

Leachfield - a subsurface, porous field into which liquid wastes are drained and purified by percolation.

Limestone - a sedimentary rock comprised mainly of calcium carbonate ($CaCO_3$) formed in water by the gradual settling of calcium carbonate particles. Limestone is usually a hard, resistant rock.

Loess - a wind blown silt deposit that is usually nonstratified and unconsolidated. Loess erodes to steep vertical faces but appears to have a rolling or hilly topography on the upper surface.

Marble - a metamorphosed limestone or other calcareous rock; marble is usually a very hard, resistant rock, often with distinctive color patterns which makes it a popular building stone.

Mesa - a flat topped mountain, surrounded wholly or partially by steep cliffs. A mesa can result when a hard, resistant rock overlies a weak, erosive rock.

Moraine - a glacial deposit of loose rock material pushed or dragged down a valley by a glacier.

Mesozoic - a geologic era lasting approximately 170 million years. The Mesozoic era saw the flourishing of dinosaurs. It was at the close of this era and the beginning of the Cenozoic that the dinosaurs became extinct.

Metamorphic - a rock formed from another rock that has undergone changes due to increased temperatures and pressures or changes in the chemical environment while buried beneath the surface of the earth.

Mississippian - a geologic period lasting about 35 million years in the Paleozoic era.

Mudstone - a general geologic term applied to any extremely fine grained sedimentary rock. Clayey siltstone or silty claystone can be loosely termed as mudstone.

Nonstratified - a term applied to formations that have no distinct bedding.

Ordovician - a geologic period lasting about 75 million years in the Paleozoic era.

Outcrop - the exposure of bedrock at the surface of the Earth.

Paleozoic - a geologic era lasting about 370 million years. The Paleozoic era saw the widespread evolution of life, the first land plants and the first land animals.

Pediment - a sloping plain at the intersection of a valley floor and a mountain. Pediments are bedrock with a thin veneer of alluvium in places.

Pennsylvanian - a geologic period that lasted about 30 million years in the Paleozoic era.

Percolation - movement of water through soil and rock by means of pore spaces between grains, cracks in the rock and along bedding planes. Percolation is limited to small openings and does not include movement of water through such openings as caves.

Period - a classification of time in the geologic time scale - the length of each period is different; however, there is continuity of events within a period over a widespread portion of the earth.

Permeability - the ability of a material to transmit water, oil or other fluids due to the pore spaces within the rock and the degree to which these spaces are connected.

Permian - a geologic period lasting about 50 million years; this is the last period in the Paleozoic era.

Perlite - a volcanic glass similiar to obsidian but having a higher water content. Characteristically, perlites have concentric cracks formed by contraction upon cooling.

Physiographic - a description of the surface and land-form features of a region.

Piedmont - an area located at the foot of a mountain range where materials eroded and washed out of the mountain are deposited.

Planes of weakness - a two dimensional area between two objects that is subject to failure or movement because of weak or nonexistent bonds. Example - a sedimentary rock showing bedding will probably break along these planes rather than across them because they are relative planes of weakness.

Precambrian - all rocks formed before Cambrian time (more than 600 million years old). The Precambrian is divided into two eras, the Early and Late Precambrian (A.G.I.).

Pumice - a very light, cellular lava which is usually white or light grey in color. Pumice has been described as a sort of volcanic froth and is so light it will float on water.

Pyroclastic - a general geologic term for ash and other materials explosively ejected from a volcano through the air.

Quaternary - the most recent geologic period stretching from about one million years ago to the present.

Recent - a subdivision of the Quaternary period which began at the close of the Ice Age (about 10,000 years ago) and extends to the present.

Recharge area - an area of permeable rock and soil which allows the downward movement of surface water and the replenishment of ground water.

Replacement - chemically and physically new material formed in the place occupied by the original matter by simultaneous solution and deposition. This occurs at the molecular level. Example - petrified wood is a replacement in which the mineral, silica, has taken the place of the wood leaving the structure intact.

Rippability - ease of excavation.

Sandstone - a rock comprised mainly of sand-size particles that have been compacted or cemented.

Sanitary landfill - a system of solid waste disposal in which waste is placed in a closed environment and covered daily. A properly constructed sanitary landfill will decompose and not pollute the environment.

Sedimentary - a geologic term describing rocks formed by the accumulation or deposition of particles. These are commonly laid down by water, such as rivers, lakes and seas, but can also be deposited by winds (i.e., dunes).

Seepage pits - a method of liquid waste disposal in which the waste is deposited in a pit and is purified as it percolates down through the soil.

Shale - a rock comprised mainly of clay size particles which have been compacted or cemented. Shale is usually well stratified and in some cases, is weak and crumbly.

Silt - a sediment particle with a diameter between 0.005 mm. and 0.05 mm. (a size between sand and clay). Silt is unconsolidated and is a common type of river alluvium.

Siltstone - a rock comprised mainly of silt-size particles which have been compacted or cemented.

Silurian - a geologic period that lasted about 20 million years during the Paleozoic era.

Slippage - gradual, slight movements along a plane of weakness.

Solubility - a measure of the concentration potential for a material dissolved in a liquid at equilibrium when there is undissolved material also in contact with the liquid; the greatest amount of a material that can be dissolved in a fluid at a specific temperature and pressure.

Stratification - the bedded or layered appearance of sedimentary rocks which results from the depositional origin. However, not all sedimentary rocks show well-defined stratification.

Subside - a sinking or down warping of the earth's crust. This occurs over a wide portion of the crust and is very gradual. During geologic history, seas commonly filled the depressions formed by subsidence. The term "subside" can also be used to describe a smaller feature - such as the subsidence of land over an underground mine where the overburden is collapsing into the mine cavity.

Swelling soils - soils containing clay minerals which have the ability to absorb water into their structures and expand in size. The water can be released through drying, allowing the soil to return to the original size. In general, swelling clays are derived from volcanic ash.

Tailing dump - piles of loose debris and ore of a quality too poor to be used, usually found near a mine. When located on a slope these tailings can be very unstable.

Talus - a pile of broken rock fragments found at the foot of a steep cliff or escarpment which results from the weathering and breaking down of the cliff.

Terrace - a step like feature located on a slope; the terrace itself is flat or gently sloping and bounded above and below by steeper slopes. Terraces are generally considered to consist of alluvium and flank each side of a river valley.

Tertiary - a period lasting about 62 million years in the Cenozoic era.

Thermal springs - springs whose temperatures are warmer than the average surface temperature. The source of the heat is molten magma located below the surface of the Earth.

Topography - the relief of the surface of an area and the expression of this relief on a map using one line to represent one elevation.

Triassic - a period lasting about 49 million years, the first period of the Mesozoic era.

Tuffaceous - a tuff like material; tuff being a rock comprised of tiny (generally less than 4 mm in diameter) volcanic particles.

Unconsolidated - a term used for materials that are loose; rock particles that are not cemented or compacted are considered unconsolidated.

Undercutting - removal by erosion (generally wind, stream or wave action) of the lower portion of a steep escarpment, resulting in a steeper face or even a overhanging cliff.

Uplift - elevation of a part of the Earth's surface relative to some other area (A.G.I.). In geologic history uplift has taken place slowly, generally lasting millions of years.

Volcanic rock - the class of igneous rocks derived from volcanoes. Volcanic rocks are basically of two types -- 1)rocks that were formed by flowing lava, and 2)rocks that were formed by materials ejected through the air, such as ash.

Water sheds - a general term referring to the drainage basin of a stream or river.

Water table - the upper boundary of water saturated formations or soils. Where the water table intersects the ground surface, a surface body of water is found (i.e., marsh).

BIBLIOGRAPHY

Atwood, W. W., 1916, Eocene glacial deposits of southwestern Colorado: U. S. Geological Survey Professional Paper 95-B, pp.13-26.

__________ 1918, Relation of landslide and glacial deposits to reservoir sites in the San Juan Mountains, Colorado: U. S. Geological Survey Bulletin 685, 38 p.

Atwood, Walter Wallace and Mather, K. F., 1916, Geographic history of the San Juan Mountains since the close of the Mesozoic Era: National Academy of Science Proc., v.2, pp. 177-181.

__________ 1932, Physiography and Quaternary geology of the San Juan Mountains, Colorado: U. S. Geological Survey Professional Paper 166, 176 p.

Barker, Fred, 1969, Gold investigations in Precambrian clastic and pelitic rocks, southwestern Colorado and northern New Mexico: U. S. Geological Survey Bulletin 1272-F, 22 p.

Barnes, Harley, 1953, Geology of the Ignacio area, Ignacio and Pagosa Springs quadrangles, La Plata and Archuleta Counties, Colorado: U. S. Geological Survey Oil and Gas Map -138.

Barnes, Harley, Balty, E. H., Jr., and Hays, P. T., 1954, Geology and fuel resources of the Red Mesa area, La Plata and Montezuma Counties, Colorado: U. S. Geological Survey Oil and Gas Map 149, scale 1:62,500.

Bastin, E. S., 1923, Silver enrichment in the San Juan Mountains, Colorado: U. S. Geological Survey Bulletin 735-D, pp. 65-129.

Blood, Alexander, 1969, Geology, history and economics of the Sunnyside Mine, Eureka mining district, San Juan County, Colorado: Research at Colorado School of Mines.

Bromfield, C. S., 1967, Geology of the Mount Wilson quadrangle, western San Juan Mountains, Colorado: U. S. Geological Society Bulletin 1227, 100 p.

Bromfield, C. S., and Conray, A. R., 1963, Preliminary geologic map of the Mount Wilson quadrangle, San Miguel County (and Dolores County), Colorado: U. S. Geological Survey Mineral Investigations Field Studies Map 273, scale 1:24,000.

Burbank, W. S., and Luedke, R. G., 1964, Geology of the Ironton quadrangle, Colorado: U. S. Geological Survey Geologic Quadrangle Map 291, scale 1:24,000.

__________ 1966, Geologic map of the Telluride quadrangle, southwestern Colorado: U. S. Geological Survey Geologic Quadrangle 504, scale 1:24,000.

Bush, A. L. and Bromfield, C. S., 1966, Geologic map of the Dolores Peak quadrangle, Dolores and San Miguel Counties, Colorado: U. S. Geological Survey Geologic Quadrangle 536, scale 1:24,000.

Chamberlain, Rollin T., 1919, The Building of the Colorado Rockies: Journal of Geology, v.27, pp. 145-164, 225-251.

Chronic, John and Holka, 1972, Prarie, Peak and Plateau: Colorado Geological Survey Bulletin 32, 126 p.

Collier, A. J., 1919, Coal south of Mancos, Montezuma County, Colorado: U. S. Geological Survey Bulletin 691-K, pp. 293-310.

Collins, George E., 1931, Localization of ore bodies at Rico and Red Mountain, Colorado, as conditioned by geologic structure and history: Colorado Scientific Society Proc. v.12, pp.407-424.

Colorado Bureau of Mines, 1971, A summary of mineral industry in Colorado: Colorado Bureau of Mines: Division of Minerals, Department of Natural Resources.

Colorado Mineral Resources Board, 1947, Mineral resources of Colorado: Colorado Mineral Resources Board, 547 p.

__________ 1960, Mineral resources of Colorado, first sequel, Colorado Mineral Resources Board, 764 p.

Cook, Douglas Ralph, 1952, The geology of the Pride of the West vein system, San Juan County, Colorado: D.Sc. Thesis, Colorado School of Mines.

Cross, Whitman, Spencer, A. C. and Purington, C. W., 1899 (1901), La Plata, Colorado: U. S. Geological Survey Folio 60, 14 p., 4 maps.

Cross, Whitman and Spencer, A. C., 1900, Geology of the Rico Mountains, Colorado: U. S. Geological Survey Annual Report 21, II, a., pp. 7-165.

Cross, Whitman, Howe, Ernest and Ransome, F. L., 1905, Silverton, Colorado: U. S. Geological Survey Folio 120, 34 p., 4 maps.

Cross, Whitman, Ransome, F. L., 1905, Rico, Colorado: U.S. Geological Survey Folio 130, 20 p., 5 maps.

Cross, Whitman, Howe, Ernest, Irving, J. D., and Emmens, W. H., 1905, Needle Mountains, Colorado: U. S. Geological Survey Folio 131, 14 p., 4 maps.

Cross, Whitman, Hole, A. D., 1910, Engineer Mountain, Colorado: U. S. Geological Survey Folio 171, 14 p., 6 maps (field edition, 1910, 144 p.).

Cross, Whitman and Larsen, E. S., Jr., 1935, A brief review of the geology of the San Juan region of southwestern Colorado: U. S. Geological Survey Bulletin 843, 138 p.

Dickinson, R. G., 1965, Landslide origin of the type Cerro Till, southwestern Colorado: U. S. Geological Survey Professional Paper 525-C, pp. C147-C151.

Donnell, John R., 1960, Geological road logs of Colorado: Rocky Mountain Association of Geologists, 98 p.

Eberly, Lyle Dean, 1953, The geology of the Baldy Mountain area, La Plata County, Colorado: M.S. Thesis, Illinois.

Eckel, E. B. with sections by Williams, J. S., Galbraith, F. W., and others, 1949 (1950), Geology and ore deposits of the La Plata district, Colorado: U. S. Geological Survey Professional Paper 219, 179 p.

Ekren, E. B. and Houser, F. N., 1957, Sentinel Peak, N.W. quadrangle, Montezuma County, Colorado: U. S. Geological Survey Mineral Investigations Field Studies Map 132, scale 1:24,000.

__________1959, Cortez S.W. quadrangle, Montezuma County, Colorado: U. S. Geological Survey Mineral Investigations Field Studies Map 217.

__________1959, Preliminary geologic map of the Moqui S.E. quadrangle, Montezuma County, Colorado: U. S. Geological Survey Mineral Investigations Field Studies Map 221, scale 1:24,000.

__________1959, Preliminary geologic map of the Sentinel Peak N.E. quadrangle, Montezuma County, Colorado: U. S. Geological Survey Mineral Investigations Field Studies Map 224, scale 1:24,000.

__________1965, Geology and petrology of the Ute Mountains area, Colorado: U. S. Geological Survey Professional Paper 481, 74 p.

Emmons, W. H., 1906, Gold and silver ore deposits of Bear Creek, near Silverton, Colorado: U. S. Geological Survey Bulletin 285-A, pp. 25-27.

Finley, E. A., 1951, Geology of Dove Creek area, Dolores and Montezuma Counties, Colorado: U. S. Geological Survey Oil Map 120.

Fisher, R. P., Luedke, R. G. (USGS) and Sheridan, M. J. and Raabe, R. G., (U.S.Bur. of Mines), 1968 (1969), Mineral resources of the Uncompahgre primitive area, Colorado: U. S. Geological Survey Bulletin 1261-C, pp. C1-C91.

Gardner, J. H., 1909, Coal fields of Colorado, New Mexico, Utah, Oregon and Virginia: The coal field between Durango, Colorado and Monero, New Mexico: U. S. Geological Survey Bulletin 341-C, pp. 352-363.

Hackmann, R. J., 1959, Yellow Jacket, Montezuma and Dolores Counties, Colorado: U. S. Geological Survey Miscellaneous Geologic Investigations Map 281, scale 1:62,500.

Hadley, David Watson, 1953, Correlation and distribution of Pleistocene gravel deposits in the La Plata and Animas River valleys, La Plata County, Colorado: B.S. Thesis, University of Illinois.

Hagen, John C., 1951, The geology of the Green Mountain Mine, San Juan County, Colorado: M.S. Thesis, Colorado School of Mines.

Haynes, D. D., Vogel, J. D. and Wyant, D. G., 1972, Geology, structure and uranium deposits of the Cortez quadrangle, Colorado and Utah: U. S. Geological Survey Miscellaneous Geologic Investigations Map 629, scale 1:250,000.

Hills, R. C., 1883, Extinct glaciers of the San Juan Mountains, Colorado: Colorado Scientific Society Proc., v.1, pp. 39-46.

Houser, F. N. and Ekren, E. B., 1959, Moqui S.W. quadrangle, Montezuma County, Colorado (preliminary geologic map): U. S. Geological Survey Mineral Investigation Field Studies Map 216, scale 1:24,000.

Howe, Ernest, 1909, Landslides in the San Juan Montains, Colorado (including a consideration of their causes and their classification), U. S. Geological Survey Professional Paper 67, 58 p.

Howe, Ernest and Cross, Whitman, 1906, Glacial phenomena of the San Juan Mountains, Colorado: Geological Society of America Bulletin, v.17, pp. 251-274.

Irwin, J. H., 1966 (1967), Geology and availability of ground water on the Ute Mountain Indian Reservation, Colorado and New Mexico: U. S. Geological Survey Water Supply Paper 1576-G, pp. G1-G109.

Jobin, D. A., 1962, Relation of the transmissive character of the sedimentary rocks of the Colorado Plateau to the distribution of uranium deposits: U. S. Geological Survey Bulletin 1124, 151 p.

Kelley, V. C., 1946, Geology ore deposits and mines of the Mineral Point, Poughkeepsie and upper Uncompahgre districts, Ouray, San Juan and Hinsdale Counties, Colorado: Colorado Scientific Society Proc., v. 14, n. 7, pp. 287-311.

Kilgore, Lee W., 1955, Geology of the Durango area, La Plata County, Colorado: Four Corners Geological Society 1st. Field Conference, Parts of Paradox, Black Mesa and San Juan Basin Guidebook, pp. 118-124.

Larsen, Esper S., Jr., 1949, The relation between the earth's movements and volcanism in the San Juan Mountains of Colorado: American Geophysical Union Trans., v. 30, pp. 862-866.

Larsen, E. S., Jr. and Cross, Whitman, 1956, Geology and petrology of the San Juan region, southwestern Colorado: U. S. Geological Survey Professional Paper 258, 303 p.

Lonsdale, John Tipton, 1921, Geology and ore deposits of Bedrock Gulch, La Plata County, Colorado: M.S. Thesis, State University of Iowa.

Lovering, Thomas Seward, 1932, Geology of Colorado: International Geological Cong. 16th Session (United States) Guidebook 18, Excursion C-1 (Colorado) pp. 8-26.

McLaughlin, Thad Gerald, 1956, Groundwater in Colorado and the status of investigations: Colorado Water Conservation Board, Ground Water Series, Circular 4.

Mario, Serna-Isaya, 1972, Geology and geochemistry of Calico Peak, Dolores County, Colorado: Research at Colorado School of Mines.

Miesch, A. T., 1963, Distribution of elements in Colorado Plateau uranium deposits - a preliminary report: U. S. Geological Survey Bulletin 1147-E, pp. E1 - E57.

New Mexico Geological Society, 1950, Guidebook of the San Juan Basin, New Mexico and Colorado: New Mexico Geological Society, 1st Field Conference.

Pratt, W. P., McKnight, E. T., and De Hon, R. A., 1969, Geologic map of the Rico quadrangle, Dolores and Montezuma Counties, Colorado: U. S. Geological Survey Geologic Quadrangle Map 797, scale 1:24,000 (1 inch equals 2,000 feet).

Read, C. B., Wood, G. H., Wanek, A. A., and Mackee, Pedro Verastegui, 1949, Stratigraphy and geologic structure in the Piedra River Canyon, Archuleta County, Colorado: U. S. Geological Survey Oil and Gas Map 81, scale 1 inch to 1 mile (1:63,360).

Richmond, G. M., 1965, Quaternary stratigraphy of the Durango area, San Juan Mountains, Colorado: U. S. Geological Survey Professional Paper 525-C, pp. C137-C143.

Schroder, F. C., 1906, Coal and peat: The Durango-Gallup coal field of Colorado and New Mexico: U. S. Geological Survey Bulletin 285-F, pp. 24-258.

Schultz, L. G., 1963, Clay minerals in the Triassic rocks of the Colorado Plateau: U. S. Geological Survey Bulletin 1147-C, pp. C1-C71.

Schwary, Frederick P., 1963, Geology and ore deposits of Minnie Gulch, San Juan County, Colorado: Research at Colorado School of Mines.

Seaman, David M., 1934, Minerals and mineral deposits of the San Juan Region, Colorado: M.S. Thesis, Colorado.

Shaler, M. K., and Gardner, J. H., 1907, Clays and clay products, clay deposits of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geological Survey Bulletin 315-I, pp. 296-302.

Shoemaker, Eugene M. and Newman, William L., 1953, Ute Mountains, a laccolithic feature in southwestern Colorado (abst.): Geological Society of America Bulletin, v.64, p. 1555.

Sinclair, William, 1963, Geology of the upper East Fork of the San Juan River area, Mineral and Archuleta Counties (Colorado): M.S. Thesis, Colorado School of Mines.

Sites, Jack A., 1954, The coal in Colorado: University of New Mexico Report.

Snyder, Robert Dean, 1952, Geology of the east-central rectangle of the Red Mesa quadrangle, La Plata County, Colorado: M.S. Thesis, Illinois.

Steven, T. A., and Ratle, J. C., 1960, Geology and ore deposits of the Summitville district, San Juan Mountains, Colorado: U. S. Geological Survey Professional Paper 343, 70 p.

Steven, T. A. and Schmitt, L. J., Jr., (U.S.G.S.) and Sheridan, M.J. and Williams, F. E. (U. S. Bur. of Mines), 1969, Mineral resources of the San Juan primitive area, Colorado; with a section on iron reserves in the Irving formations by Gair, J. E. and Klemic, Harvey: U. S. Geological Survey Bulletin 1201-F, pp. F1-F187.

Stoddard, Robert Russell, 1957, Geology of a portion of south central Archuleta County, Colorado: M.S. Thesis, Colorado School of Mines.

Taff, J. A. 1907, Coal fields of Colorado and Utah; the Durango coal district, Colorado: U. S. Geological Survey Bulletin 316-E, pp. 321-337.

Thurman, Franklin A., 1954, A geologic history of Colorado: Rocky Mountain Association of Geologist Symposium, Oil and Gas Fields, Colorado, pp.25-34.

U. S. Geological Survey, 1936, Summitville mining area, Colorado: U. S. Geological Survey Special Topographic Map, scale 1:12,000.

__________1955, Aneth-1, San Juan County, Utah and Montezuma County, Colorado: U. S. Geological Survey Miscellaneous Geologic Investigations Map 90.

__________1955, Aneth-8, San Juan County, Utah and Montezuma Counties, Colorado: U. S. Geological Survey Miscellaneous Geologic Investigations Map 97.

Vanderwilt, John W., 1934, A recent rockslide near Durango, in La Plata County, Colorado: Journal of Geology, v. 42, pp. 163 - 173.

Varnes, D. J., 1963, Geology and ore deposits of the south Silverton mining area, San Juan County, Colorado: U. S. Geological Survey Professional Paper 378A, pp. A1-A56.

Varnes, H. D., 1949, Landslide problems of southwestern Colorado: U. S. Geological Survey Circular 31, 13 p.

Voris, Richard Hensler, 1952, Geology of a southwest portion of the Ignacio quadrangle, La Plata County Colorado: M.S. Thesis, Illinois.

Wanek, A. A., 1954, Geologic map of the Mesa Verde area, Montezuma County, Colorado: U. S. Geologic Survey Oil and Gas Map 152, scale 1:63,360.

__________1959 (1960), Geology and fuel resources of the Mesa Verde area, Montezuma and La Plata Counties, Colorado: U. S. Geological Survey Bulletin 1072-M, pp. 667-721.

Waring, Gerald Ashley and Knechtel, Mavell McMichael, 1936, Water supplies from wells in southeastern Colorado: U. S. Geological Survey Press Memo 155345.

Weimer, Robert J. and Haun, John D., 1960, Guide to the geology of Colorado: Geological Society of America, Rocky Mountain Association of Geologists, Colorado Society, 310 p.

Williams, Wilbur S., 1965, Geology of the eastern half of the Engineer Mountain quadrangle San Juan and La Plata Counties, Colorado: M. S. Thesis, Colorado.

Winchester, D. E., et al., 1936, Annual catalog of unpublished engineering and geological reports on mineral resources of Colorado: Colorado State Planning Commission.

Wood, G. H., Kelly, V. C., and MacAlpin, A. J., 1948, Geology of the southern part of Archuleta County, Colorado: U. S. Geological Survey Oil and Gas Map 81, scale,1 inch to 1 mile (1:63,360).

Woolsey, L. H., 1907, Gold and silver: Lake Fork extension of the Silverton mining area, Colorado: U. S. Geological Survey Bulletin 315-A, pp. 26-30.

Zapp, A. D., 1949, Geology and coal resources of the Durango area, La Plata and Montezuma Counties, Colorado: U. S. Geological Survey Oil and Gas Map 109, scale 1 inch to 1/2 mile (1:31,680).

M A P B I B L I O G R A H P Y

Barnes, Harley, 1953, Geology of the Ignacio area, Ignacio and Pagosa Springs quadrangles, La Plata and Archuleta Counties, Colorado: U. S. Geological Survey Oil and Gas Investigations Map 138, scale 1:63,360.

Haynes, D. D., Vogel, J. D., and Wyant, D. G., 1972, Geology, structure and uranium deposits of the Cortes quadrangle, Colorado and Utah: U. S. Geological Survey Miscellaneous Geologic Investigations Map I-629, scale 1:250,000.

Kelley, V. C. and MacAlphin, A. J., 1948, Geology of the southern part of Archuleta County, Colorado: U. S. Geological Survey Oil and Gas Investigations Map 81, scale 1:63,360.

Larsen, E. S., Jr., and Cross, Whitman, 1956, Geology and petrology of the San Juan region, southwestern Colorado: U. S. Geological Survey Professional Paper 258, 303 pp.

Read, C. B., Wood, G. H., Wanek, A. A. and Verastegui, Pedro, 1949, Stratigraphy and geologic structure in the Piedra River Canyon, Archuleta County, Colorado: U. S. Geological Survey Oil and Gas Investigations Map 96, scale 1:48,000.

Zapp, A. D., 1949, Geology and coal resources of the Durango area, La Plata and Montezuma Counties, Colorado: U. S. Geological Survey Oil and Gas Investigations Map 109, scale 1:31,680.

SYMBOL	NAME OF MAP UNIT	TYPE OF MATERIAL	FORMATIONS	AGE	PLANNING CONSIDERATIONS
A	ALLUVIUM	UNCONSOLIDATED SURFICIAL DEPOSITS: CLAY, SILT, SAND, AND GRAVEL (for this report "ALLUVIUM" includes: water, wind, gravity, and glacial deposits)	DEPOSITS HAVE NOT BEEN NAMED	QUATERNARY	FLOODING, INSTABILITY, CONSOLIDATION UNDER LOAD, SOLID WASTE DISPOSAL
Su	SEDIMENTARY ROCKS, UNDIVIDED	SHALE, CLAYSTONE, MUDSTONE, SILTSTONE, SANDSTONE, CONGLOMERATE, LIMESTONE, DOLOMITE	TELLURIDE, SAN JOSE, NACIMIENTO, WASATCH, TORREJON, ANIMAS, Mc DERMOTT, KIRTLAND, FRUITLAND, PICTURED CLIFFS, MESAVERDE, DAKOTA, BURRO CANYON, MORRISON, JUNCTION CREEK, WANAKAH, ENTRADA, DOLORES, CUTLER, RICO, HERMOSA, MOLAS, LEADVILLE, OURAY, ELBERT, IGNACIO	CENOZOIC MESOZOIC PALEOZOIC	NATURAL RESOURCES, SWELLING SOILS, EROSION
Ss	SEDIMENTARY ROCKS, SPECIFIC	SHALE, DARK GREY, WITH SWELLING CLAY, PARTLY SANDY	MANCOS SHALE LEWIS SHALE	MESOZOIC (CRETACEOUS)	LAND MOVEMENTS, EROSION, SWELLING SOILS, FLOODING, SEWAGE DISPOSAL
Cr	CRYSTALLINE ROCKS, UNDIVIDED	GRANITE AND OTHER INTRUSIVE IGNEOUS ROCKS; AND METAMORPHIC ROCKS	TOO NUMEROUS TO LIST	CENOZOIC MESOZOIC PRECAMBRIAN	INSTABILITY, FLOODING, HIGH WATER TABLES, SOLID WASTE DISPOSAL
V	VOLCANIC ROCKS, UNDIVIDED	EXTRUSIVE ROCKS (Lava) PYROCLASTIC ROCKS (Ash)	TOO NUMEROUS TO LIST	CENOZOIC	INSTABILITY, SWELLING SOILS, FLOODING, SOLID WASTE DISPOSAL

III A — SPECIAL PROBLEM AREAS (Number refers to text)

F.M. FOX & ASSOC. INC. CONSULTING ENGINEERS & GEOLOGISTS
SOIL, FOUNDATION & GEOLOGICAL INVESTIGATIONS

4765 INDEPENDENCE STREET WHEAT RIDGE, COLORADO 80033 TEL. (303) 424-5578

ENGINEERING GEOLOGY MAP
COLORADO PLANNING DISTRICT 9
DOLORES, SAN JUAN, MONTEZUMA, LA PLATA & ARCHULETA COUNTIES

JOB No. 218100632	DATE May 31, 1973
DRAFTING BY RB	CHECKED BY FLORQUIST

PREPARED FOR

COLORADO GEOLOGICAL SURVEY
AND
COLORADO DIVISION OF PLANNING

PLATE I