Environmental Geology 3

Engineering Geology Report for Planning Districts 7 and 13, 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 DISTRICTS 7&13 STATE OF COLORADO

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This report was originally prepared for Planning District 7 which has since been divided into two planning districts, 7 and 13.

PREPARED FOR

THE COLORADO GEOLOGICAL SURVEY

AND

THE COLORADO DIVISION OF PLANNING

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ENVIRONMENTAL GEOLOGY NO.3

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SUMMARY

There is a possibility that valuable 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 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 agriculture and residential development. Abandoned gravel quarries have the potential to be developed into recreation sites as artificial lakes and beaches.

2. Sedimentary rocks are host for fuel and energy resources, 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 rocky 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. However, this generalization is too restrictive for Planning District 7 as the problem sediments of the Cretaceous are potentially troublesome even in areas of low topographic relief. These clay-rich rocks are subject to creep (slow downhill movement) even on gentle slopes where they are poorly drained and/or altered by construction. The potential for unstable surface conditions should be evaluated for every proposed development site.

The need for soil investigations at each proposed construction project site can be 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 most types of drainage basins located within Planning District 7. Historic records of flooding within the District may tend to minimize 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 to prevent future tragedies and economic loss.

Areas of high water table, both permanent and seasonal, are found within 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 findings of this report show 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 aquifer or surface waters. With these guidelines, planners can be assured of meeting all 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 necessary reclamation projects will have to precede development work in 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 which will ensure safe, efficient and environmentally sound land use decisions. In summary, the need for local and site-oriented geologic and engineering investigations to evaluate problems and provide solutions in specific areas and for specific proposed use of the land is stressed.

INTRODUCTION

The purpose of this report is to present the results of a comprehensive investigation of the geology and engineering geology of Planning District 7, State of Colorado. This report will present text, 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

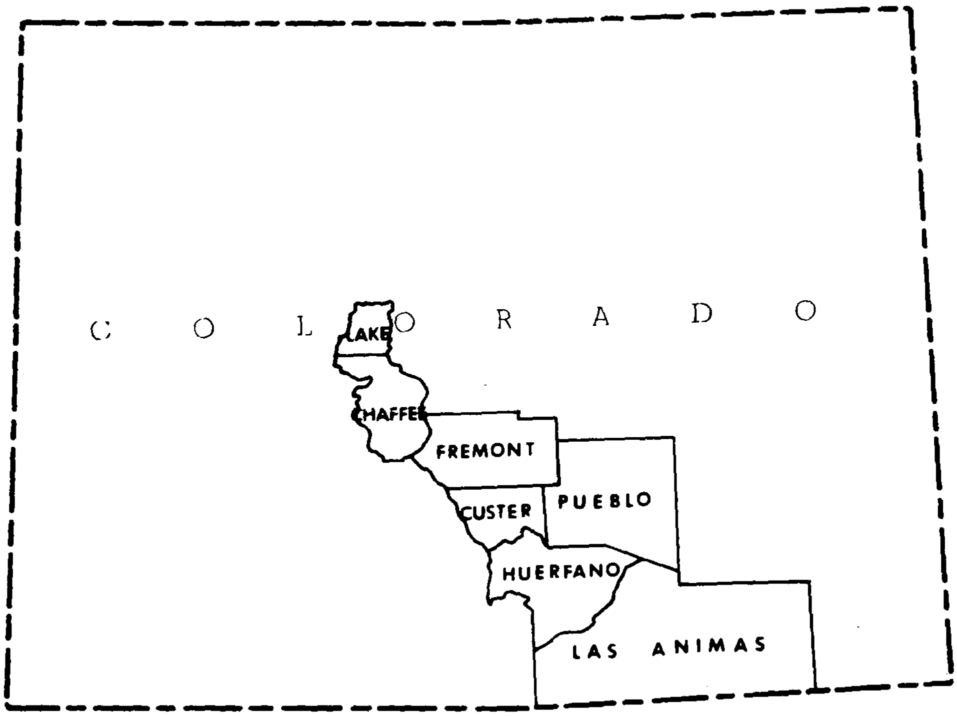
f. General geologic constraints that will affect selection and operation of solid waste disposal sites

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

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

Figure 1 defines the areal extent of the study area. Planning District 7 includes the counties of Lake, Chaffee, Fremont, Custer, Pueblo, Huerfano and Las Animas.

Figure 2 shows the major rivers and drainages in the county and identifies the location of each of the county seats. It should be noted that all the rivers in the District flow into the Arkansas River which is the only thing common to



LOCATION MAP OF PLANNING DISTRICT 7

Figure 1

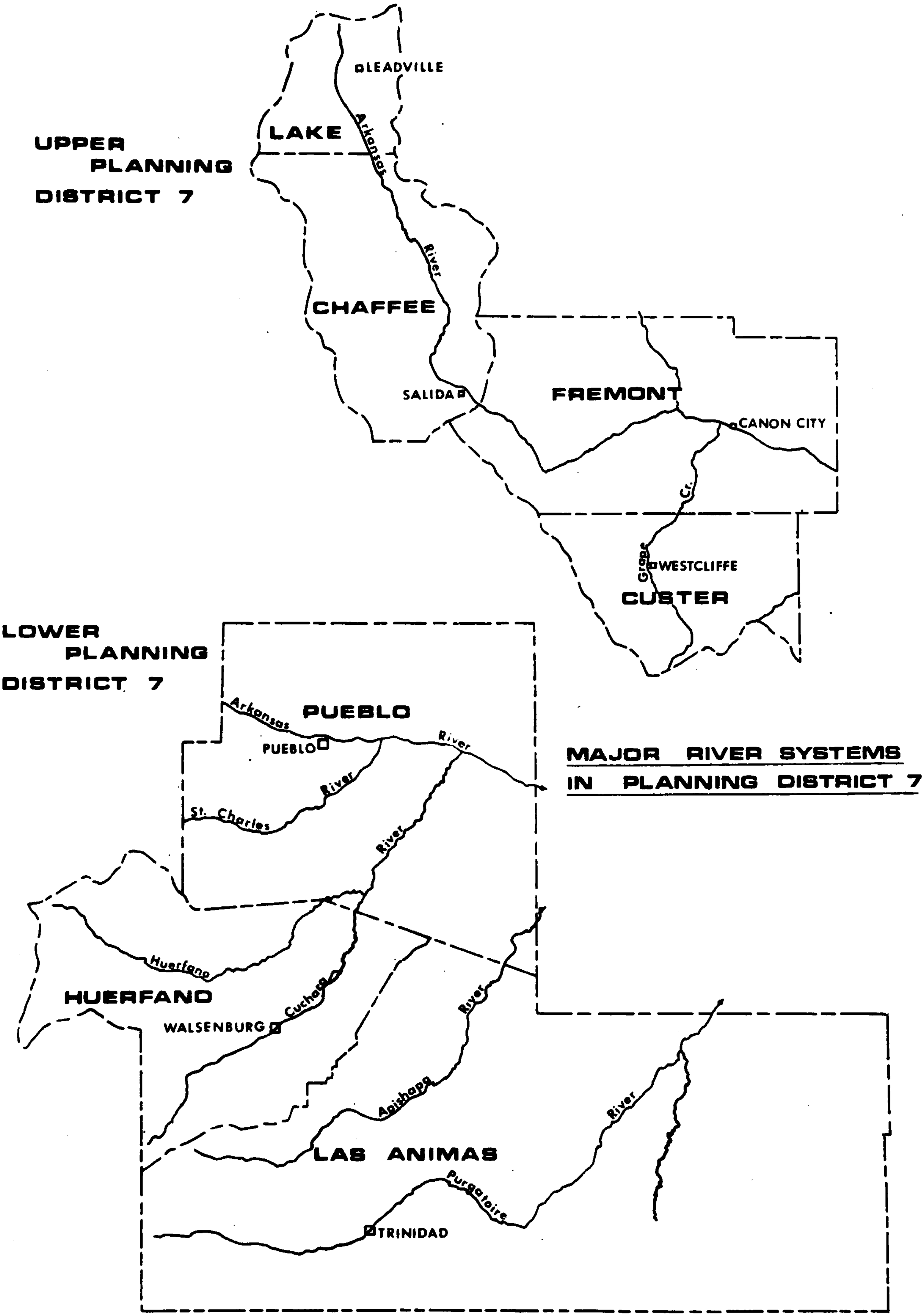

UPPER PLANNING DISTRICT 7
LAKE
LEADVILLE
Arkansas
River
CHAFFEE
SALIDA
FREMONT
CANON CITY
Cr.
Grape
WESTCLIFFE
CUSTER
LOWER PLANNING DISTRICT 7
PUEBLO
Arkansas
River
PUEBLO
St. Charles
River
River
Huerfano
HUERFANO
Cucharas
WALSENBURG
River
Apishapa
LAS ANIMAS
River
Purgatoire
TRINIDAD
MAJOR RIVER SYSTEMS IN PLANNING DISTRICT 7

Figure 2

the various counties of Planning District 7.

PHYSIOGRAPHIC FEATURES

Planning District 7 has some of the most complex and varied physiographic features of any planning district in the State (see Figure 3). In the northwest (Lake and Chaffee Counties), the Sawatch Mountain Range is separated from the Mosquito Range by the Arkansas River Valley. Farther south, along the western boundaries of Fremont, Custer and Huerfano Counties, the Sangre de Cristo Range is present. The southern extent of the Mosquito Range develops into the Wet Mountains which extend through a portion of Fremont County and essentially define the eastern boundary of Custer County. The majority of Custer County consists of the Wet Mountain Valley. Still farther south, Huerfano Park in the northwest corner of Huerfano County, and the upper extension of the Raton Basin define the western extents of Huerfano and Las Animas Counties. The Culabra Range and the Park Plateau are found on the western side of both Huerfano and Las Animas Counties. A portion of the Raton Mesa extends into the south central portion of Las Animas County. The remainder of the area, including most of Pueblo County and all of the eastern portions of Las Animas County are high plains areas common to eastern Colorado.

GENERAL GEOLOGY

Figure 4 shows schematically the geologic evolution of the State of Colorado and depicts past geologic events for Planning District 7 in the order of their occurrence. The events shown on this figure formed the present features of the area. The numbers on the right side of the column refer to the numbered graphic representations.

The geologic history of the Earth goes back approximately four billion years when the Earth consisted of nothing more than a molten mass. The geologic history of interest to this report began about two and one-half billion years ago during

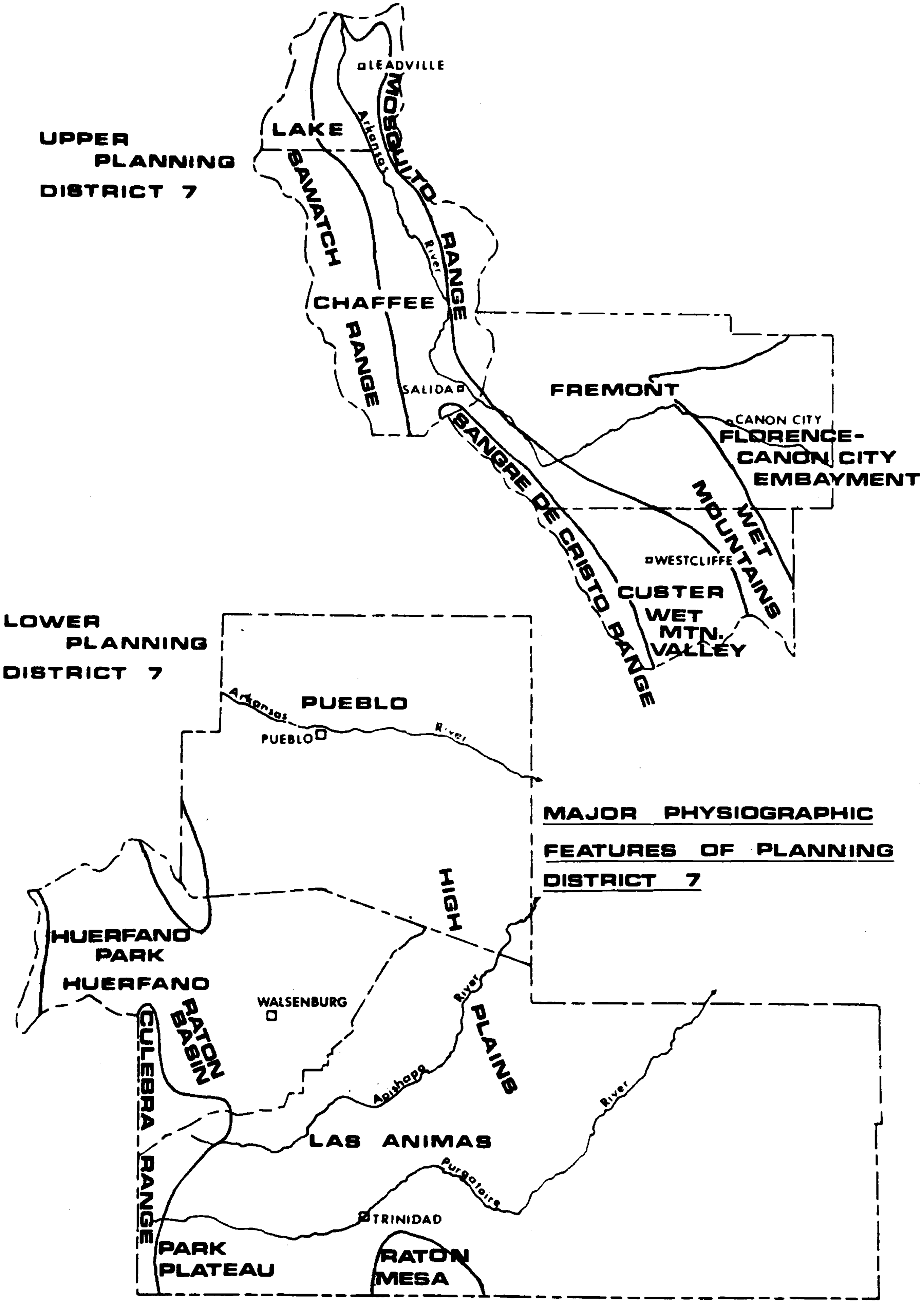
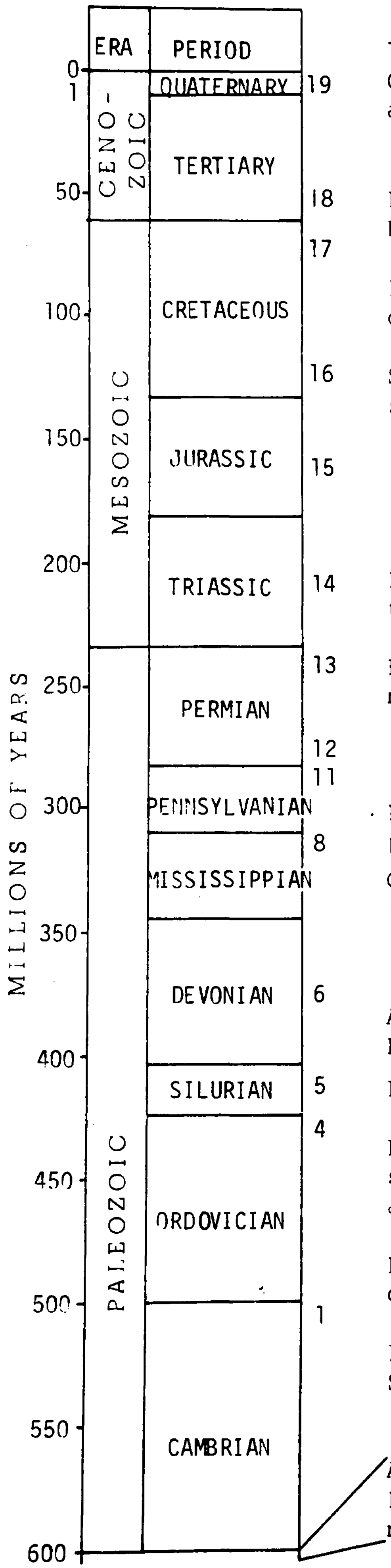

UPPER
PLANNING
DISTRICT 7
LEADVILLE
LAKE
MOSQUITO RANGE
Arkansas River
SAWATCH RANGE
CHAFFEE
SALIDA
FREMONT
CANON CITY
FLORENCE-
CANON CITY
EMBAYMENT
SANGRE DE CRISTO RANGE
WET MOUNTAINS
WESTCLIFFE
CUSTER
WET
MTN.
VALLEY
LOWER
PLANNING
DISTRICT 7
PUEBLO
Arkansas River
PUEBLO
MAJOR PHYSIOGRAPHIC
FEATURES OF PLANNING
DISTRICT 7
HIGH PLAINS
HUERFANO
PARK
HUERFANO
RATON
BASIN
WALSENBURG
River
CULEBRA RANGE
Apishapa
River
LAS ANIMAS
Purgatoire
TRINIDAD
PARK
PLATEAU
RATON
MESA

Figure 3

GEOLOGIC EVENTS IN PLANNING DIST. 7



Glaciers cover the mountains of the District and carve present landforms.

Extensive volcanism; Spanish Peaks formed. ROCKY MOUNTAINS UPLIFTED; Raton Basin subsides.

Lime and mud deposited in eastern Colorado as seas deepen.

Sands deposited in shallow seas covering the entire state.

Mud and sand deposited in the eastern portion of the state as the mountains erode and subside.

Frequent uplift and subsidence of land; advance and retreat of seas.

Mud, lime, and sand deposited in the eastern portion of the district as mountains to the west erode.

Central portion of the district is uplifted to form mountain ranges in approximately the same location as the Rockies.

A shallow sea covers the northern portion of the District; lime deposited.

Entire District emerges as a low landmass.

District slowly emerges as a low landmass as the seas recede toward the east, depositing sand and mud in the northern portion of the District.

Entire District covered by shallow seas; lime deposited.

Lower half of District uplifted to form low landmass; Sand deposited in northern half of District.

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

Figure 4

Late Precambrian time when masses of various types of sedimentary and igneous rocks were repeatedly deposited, buried, altered, uplifted and intruded with new igneous bodies. About 600 million years ago, the Cambrian Period began. During the Cambrian Period, the southern half of District 7 was uplifted, forming a low land mass while sand was being deposited in the sea which covered the northern half of the district. Approximately one hundred million years later, the Ordovician Period began with the entire district being covered by a shallow sea in which limestone was deposited. Later, during that period, the district slowly emerged from the sea as a low land mass and the seas receded toward the north. As the seas receded, they deposited sand and mud in the northern portion of the district. About 425 million years ago, the Silurian Period started. The entire district was positive (a land area of low relief) and no rocks were deposited during that time. Slightly more than 400 million years ago, at the start of the Devonian Period, the area became submerged and a shallow sea covered the northern portion of the district depositing limestone. The central portion of the district was uplifted to form mountain ranges during the latter part of the Mississippian Period and the early part of the Pennsylvanian Period. These mountains were approximately in the same location as the present Rocky Mountains. During the Mississippian, Pennsylvanian and early Permian Periods, the eastern portion of the district and probably the western portion as well, repeatedly changed from very shallow seas to terrestrial conditions resulting in delta deposits similar to those which are found where the Colorado River now flows into the Gulf of California. During this time, mud, lime and sand were deposited throughout the eastern portions of the district. Approximately 250 million years ago, during the late Permian Period, frequent uplift, alternating with subsidence of the land, continued the advance and retreats of the seas across the area. About 240 million years ago, the Triassic Period began with sand and mud being deposited in the eastern portion of the district as the mountains eroded and subsided. During the Jurassic Period, and into the

Cretaceous Period, sands were deposited in the shallow seas that covered the entire state except for the central mountain core. Approximately 135 million years ago, during the Cretaceous Period, most of the sedimentary rocks that are found in the area today were deposited. During this period, as the seas deepened, lime and mud were deposited in much of eastern Colorado. About 70 million years ago, the Tertiary Period began with extensive volcanism and mountain uplifting. During that period, the Spanish peaks were formed and the Raton Basin subsided to form a large lake. This lake may be compared (in nature) to the Great Salt Lake. It was during Tertiary time that the present Rocky Mountains were uplifted in their present position. Approximately 1 million years ago, during the Quaternary period, higher mountainous areas were covered by glacier ice which together with continuing uplift of mountain ranges determined major land forms. In recent time, erosion has created the land forms as we see them today.

As a result of the complex geologic history described, most of Planning District 7 contains a wide variety of sedimentary rocks primarily consisting of shales, limestones, sandstones and conglomerates. Most of the mountain ranges are composed of crystalline rocks of either granite or metamorphic rocks. The central portions of Lake and Chaffee Counties along the Arkansas River consist of sedimentary rocks, but both of these counties are rimmed by crystalline rock of the mountain ranges. Most of western Fremont County and portions of Custer County also consist of crystalline rocks although the Wet Mountain Valley is largely composed of a very thick sequence of sands, gravels, silts and clays that were deposited in a deep valley. It is estimated that the sands and gravels in the Wet Mountain Valley are as much as 5,000 feet thick. Geologically and physiographically, Planning District 7 can be divided into two distinct areas. In general, Pueblo, Huerfano and Las Animas Counties consist of high plains and mountain front structures. Custer, Fremont, Chaffee and Lake Counties are dominated by mountain-type geology and physiography, consisting mostly of crystalline rocks with some sedimentary rocks and deep alluvial deposits in the valleys.

HOW TO USE THIS REPORT

This report has been specifically prepared and directed toward Planners, and County and Regional officials. It has been assumed that those reading and using this report will have some understanding of geologic terms and conditions although every attempt has been made to present this report in a way that is technically sound, but described in layman's terms. As a portion of this report, a glossary is included at the end of the report which is intended to explain any term used in the report which may not be clear to the layman. At the beginning of the investigation, it became obvious to all concerned that a compilation of geologic data would not be sufficient to define the planning and development hazards in the district. Therefore, special maps have been prepared. These are located in the pockets at the end of this report. These maps do not define individual geologic units ("formations"), but define expectable engineering conditions which are prevalent with various mapping units. For example, the maps define areas which outline all the various types of alluvial material found in the District. All of these materials have similar engineering geology properties which may or may not be hazardous to planning or development. We have attempted to define the problems concerning these alluvial materials, identify their location and make recommendations as to how problems, typical of such areas, may be solved. Ideally, this report can be used for several purposes. First, the Regional and County Planners, as well as the State Planning personnel can use these maps 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, these maps 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 these maps to identify possible geologic problems that are likely to occur in the area.

When geologic reports are presented to the Planning staff, they can use these maps as a reference to determine if the person or firm writing the report has addressed the problems that are most prevalent in the area. By using these maps, the Planning staff can determine which problems are apparent and expectable in the area and which are not. For example, there is no need to worry about avalanche problems in eastern Las Animas County, nor is there any reason to worry about coal mine subsidence in western Chaffee County. The maps and text of this report will show that such conditions are not expectable in the respective areas mentioned.

It should be emphasized again that this report is not intended to be used in the place of the geologic report required in Senate Bill 35 and should not be used for this purpose. The purpose of the report is to give planners insight into what to focus the geologic requirements of Senate Bill 35 upon.

ENGINEERING GEOLOGY

I. Alluvium 

Materials characteristically consisting of unconsolidated rock particles of mixed or sorted sizes which have accumulated during Recent geologic times 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 oversteepened valley walls; and

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

Geologic engineering planning considerations 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. Such a deposit is referred to as a placer deposit.

   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. The Arkansas River gravel is mined extensively throughout the district and may become a major gravel source for the State in the future.

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

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

   b. Numerous avalanche areas are found in the western portion 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 commonly are 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 over-steepened 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 over steepened 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).

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. Some expansive clays are known along stream valleys and 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 (such as a deposit which has been isolated from the stream owing to deep erosion or uplift) there is little danger of flooding. Alluvial fans found at the intersection of the mountain base and the valley floor are subject to intense flooding despite the fact that they may appear to be well drained hills. Heavy rains will swell the streams located on these fans and can result in severe flooding.

b. Flooding may also occur in valleys blocked by landslides or large mudflows.

c. Erosion may be severe in all types of alluvial deposits owing to the unconsolidated nature of the material. This is particularly severe when the ground cover or vegetative cover 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 conditions.

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 through the solid waste and reach underlying aquifers or surface waters. In general, solid waste should never be placed in water-deposited alluvium of 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 massive land movements, flooding and high water tables and erosion.

b. Pollution potential from mine tailings exists, but varies with different types of mines and kinds of operation. 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. (Acidic water will attack and destroy certain types of concrete.) It is recommended that investigation of the chemical quality take place before construction is begun.

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, in areas of unstable surface conditions, or in alluvium having a high percolation rate such as clean sand and gravel.

b. Routes for surface transportation are generally favorable in areas of alluvium; however, 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 engineered fill, 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 accumulation 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 found throughout the district.

SU-2 Siltstone and sandstone - coarser grained rocks composed of cemented sand or silt particles found in various areas throughout the district.

SU-3 Conglomerate - (cemented gravel) a very coarse grained rock derived from previously existing rocks. The Ogallala or Nussbaum formations in eastern Las Animas and Pueblo Counties are primary examples.

SU-4 Limestone and Dolomite - crystalline calcium and magnesium carbonate rocks found mostly along the upturned edges of the mountain uplifts.

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

Geological engineering and planning considerations 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 are shown on Figures 5, 6, 7 and 8. Most of these resources have been found in the finer grained detrital rock such as shales, siltstones and sandstones (Types SU-1 and SU-2).

b. Metallic minerals are found as replacements in sedimentary rocks, primarily limestone and dolomites (Type SU-4). Increasing development of metalic ores, particularly in the major mining districts of Lake, Chaffee, Fremont and Custer Counties should be anticipated. The mining districts are shown on Figure 9.

c. As the supply of local building stone in the metropolitan areas of Colorado are exhausted, local quarrying for building stone such as limestones and sandstones (Types SU-2 and SU-4) may become common. A large deposit of limestone, known as the Leadville limestone, has been quarried extensively near Monarch since 1877 for use in the steel furnaces at Pueblo. Another extensive use of limestone is in the refining of sugar beets; this, however, requires a limestone very high in calcium.

d. Mineable refractory clays have been found in the Dakota Sandstone in various areas throughout Fremont, Custer, Pueblo, Huerfano and Las Animas Counties as defined on Figure 10.

e. Various types of limestone are quarried and processed in the manufacture of cement. The cement plant located to the east of Florence obtains raw material from the Cretaceous bedrock at the site.

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

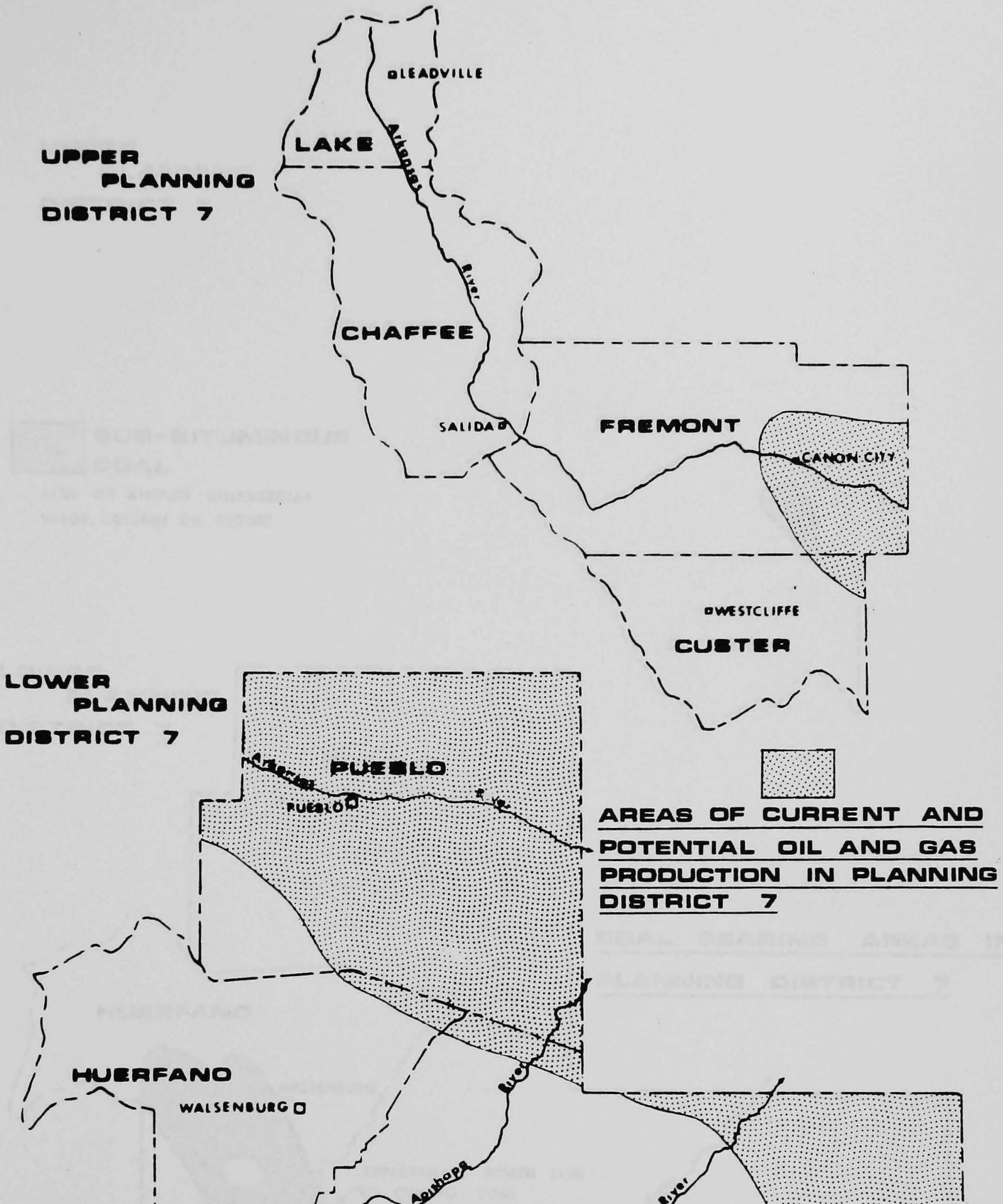
a. Unstable surface conditions are to be expected in areas where sedimentary rocks are highly deformed (folded bedding or layers), or broken (fractured and/or faulted). All types of sedimentary rocks may be deformed; however, rocks of Type SU-1 are the most prone to produce unstable conditions when deformed.

b. Subsidence of the surface in the 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"

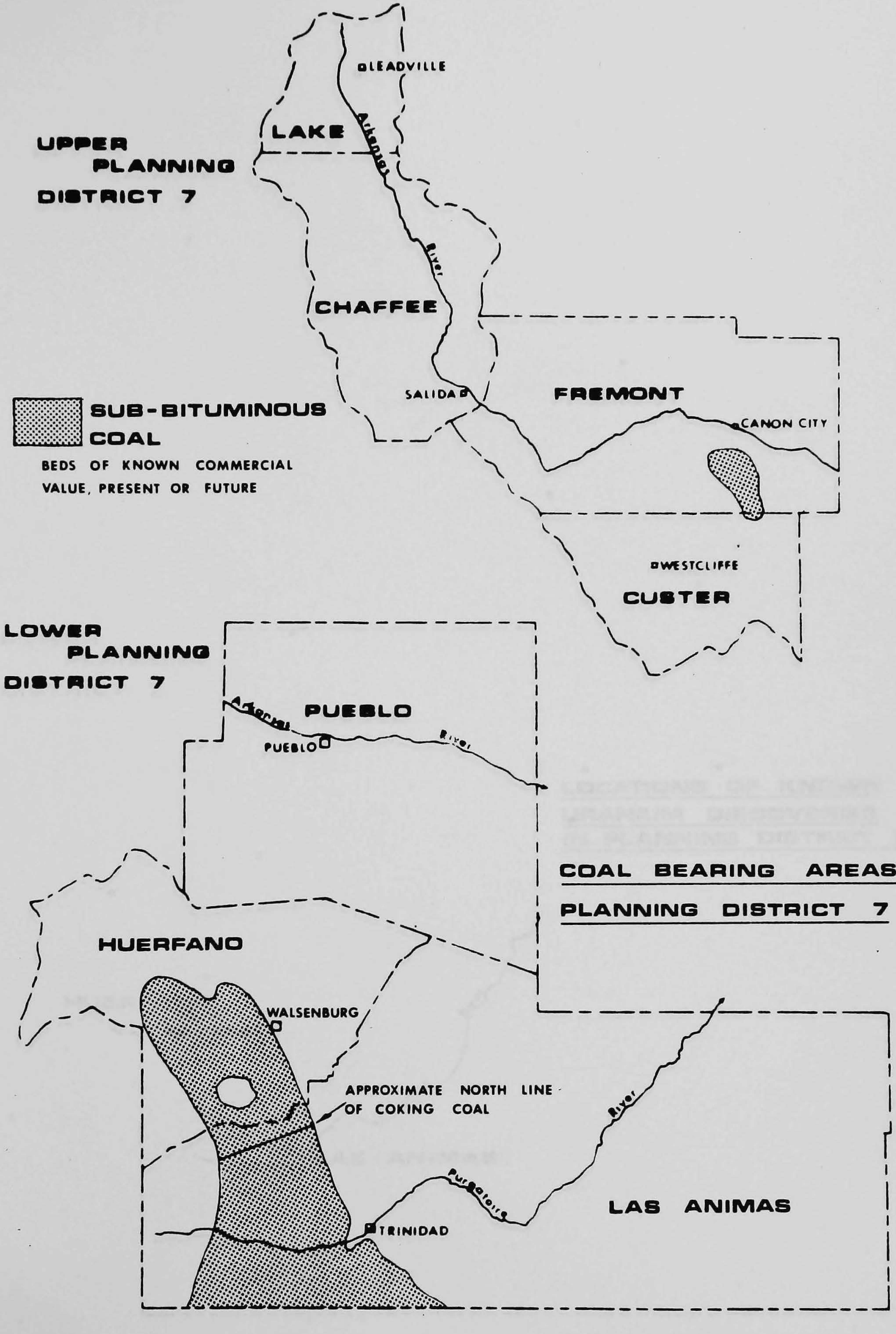
a. Swelling claystones and clayshales have generally been lumped into the sedimentary units having specific problems which will be discussed later in this report.

b. Carbonate and evaporite 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.



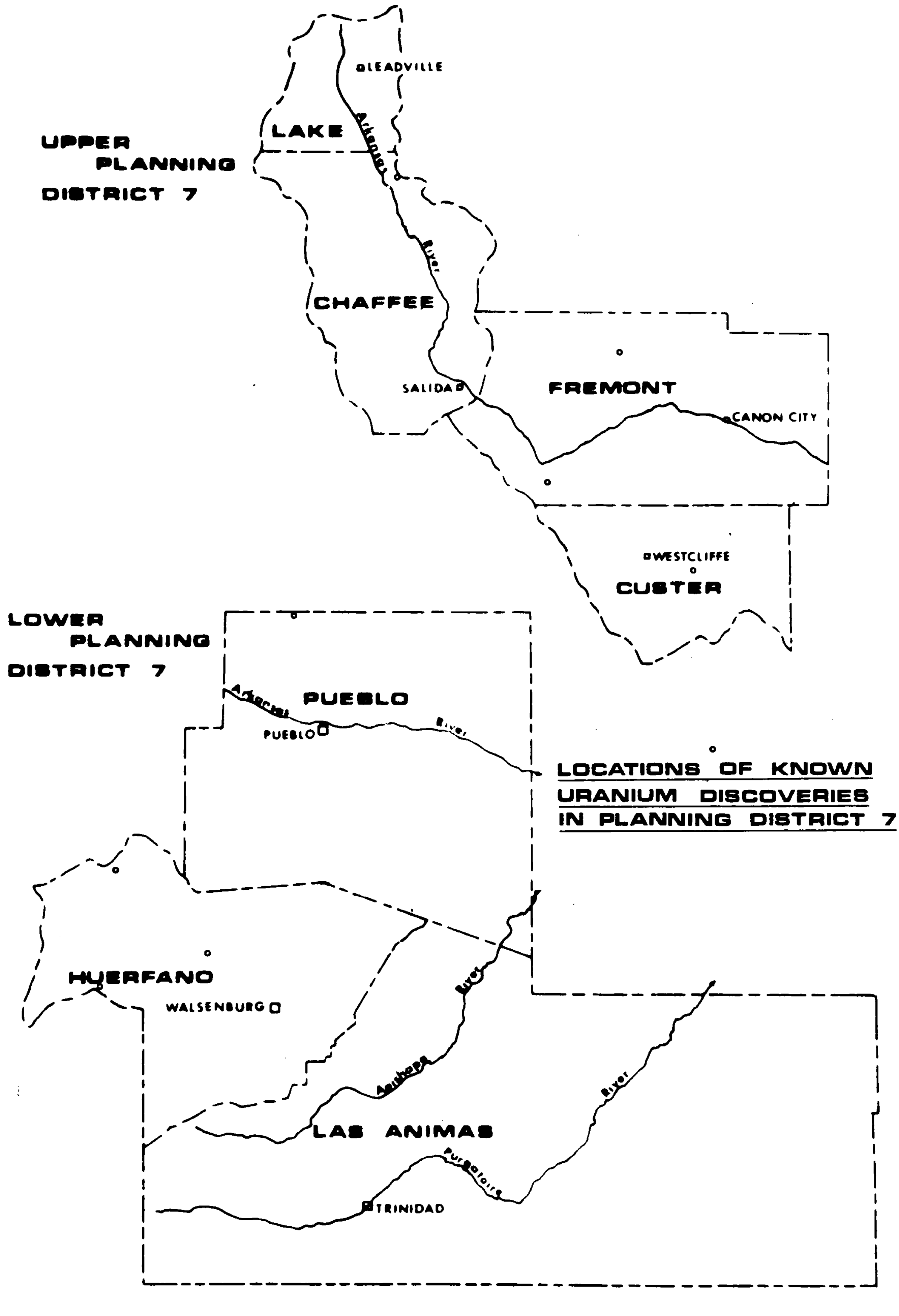
AREAS OF CURRENT AND POTENTIAL OIL AND GAS PRODUCTION IN PLANNING DISTRICT 7

Figure 5



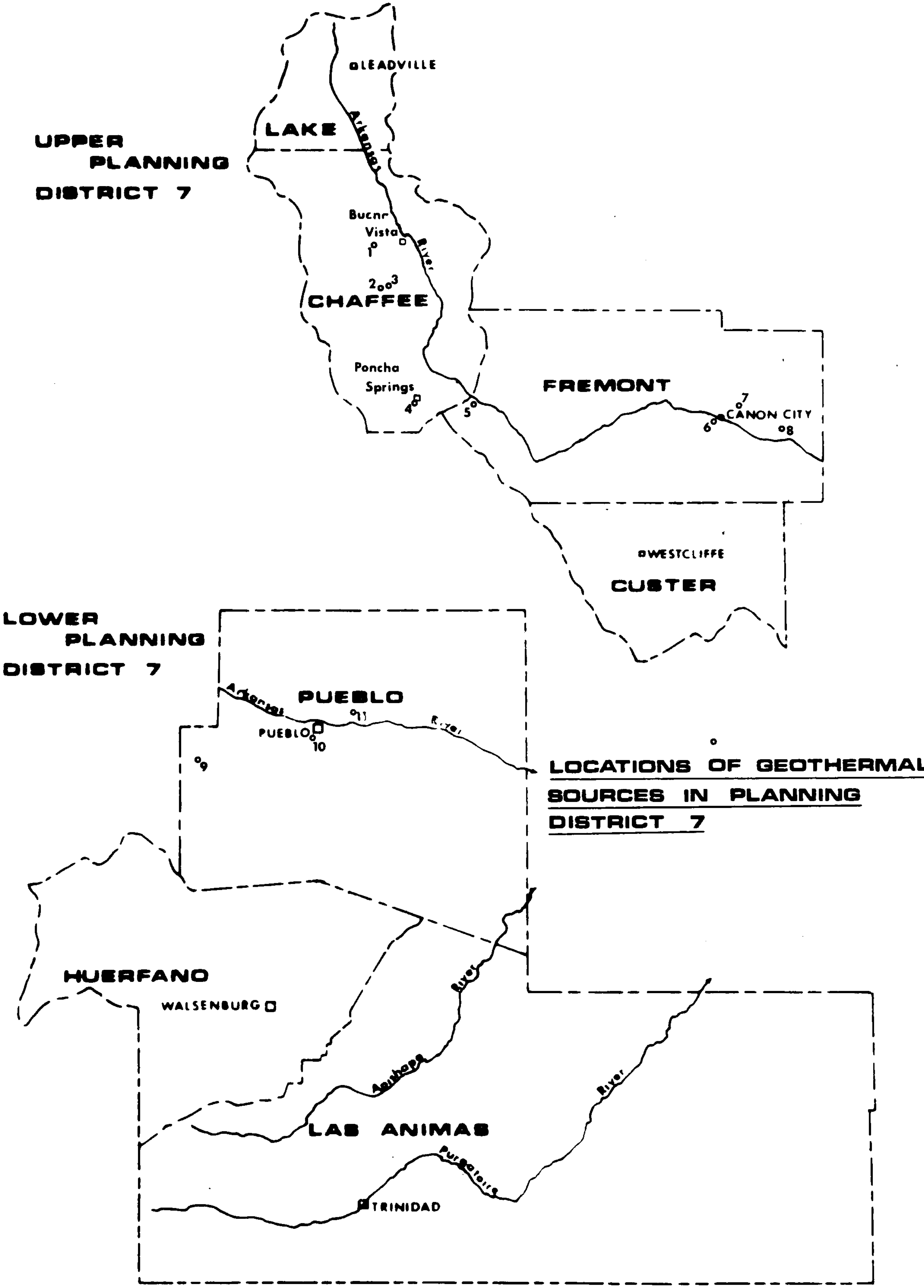
COAL BEARING AREAS IN PLANNING DISTRICT 7

Figure 6



LOCATIONS OF KNOWN URANIUM DISCOVERIES IN PLANNING DISTRICT 7

Figure 7



LOCATIONS OF GEOTHERMAL SOURCES IN PLANNING DISTRICT 7

Figure 8

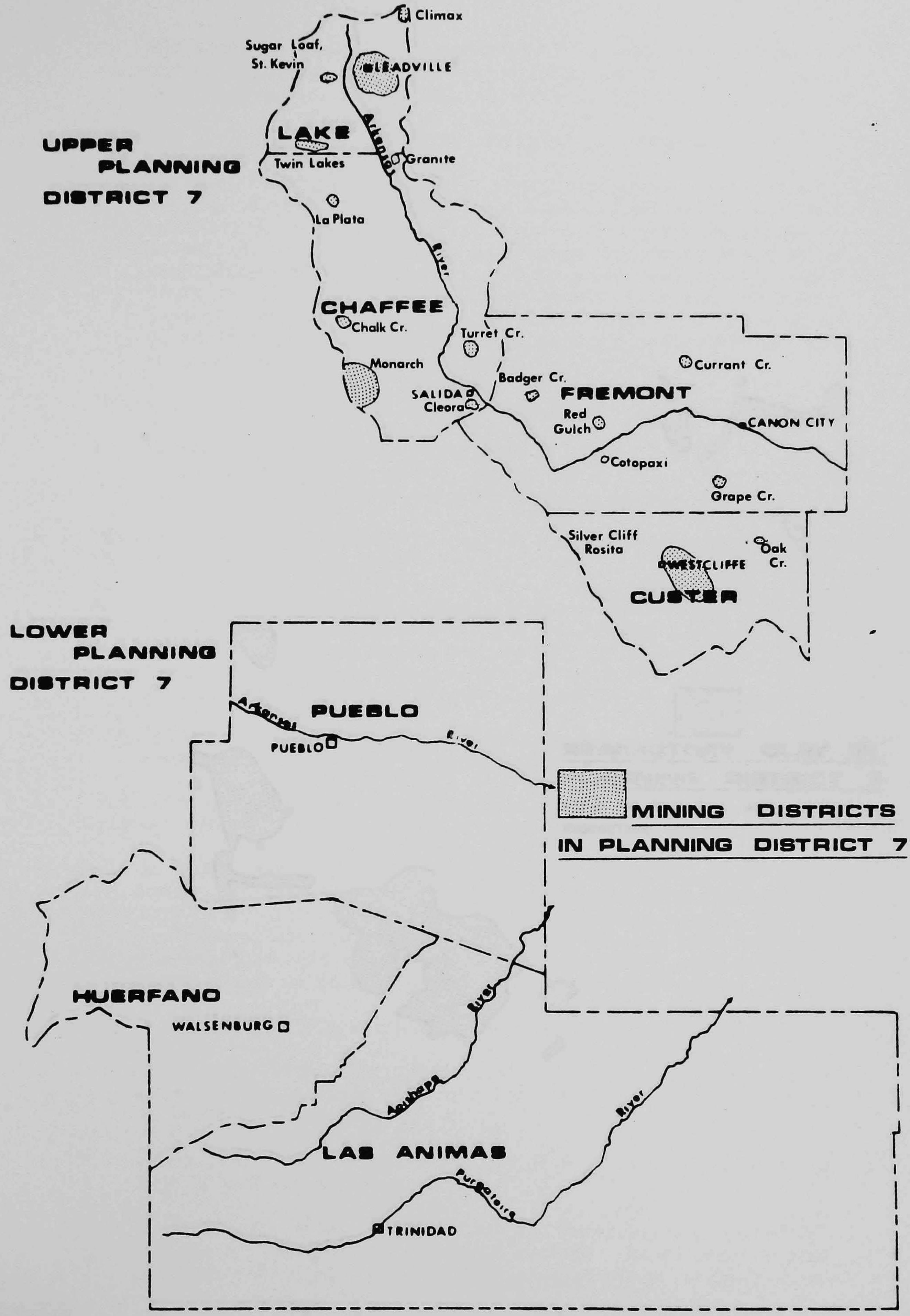

UPPER PLANNING DISTRICT 7
Climax
Sugar Loaf, St. Kevin
LEADVILLE
LAKE
Twin Lakes
Granite
La Plata
CHAFFEE
Chalk Cr.
Turret Cr.
Monarch
SALIDA
Cleora
Badger Cr.
Currant Cr.
FREMONT
Red Gulch
CANON CITY
Cotopaxi
Grape Cr.
Silver Cliff Rosita
WESTCLIFFE
Oak Cr.
CUSTER
LOWER PLANNING DISTRICT 7
Arkansas River
PUEBLO
PUEBLO
MINING DISTRICTS IN PLANNING DISTRICT 7
HUERFANO
WALSENBURG
River
LAS ANIMAS
River
Purgatoire
TRINIDAD

Figure 9

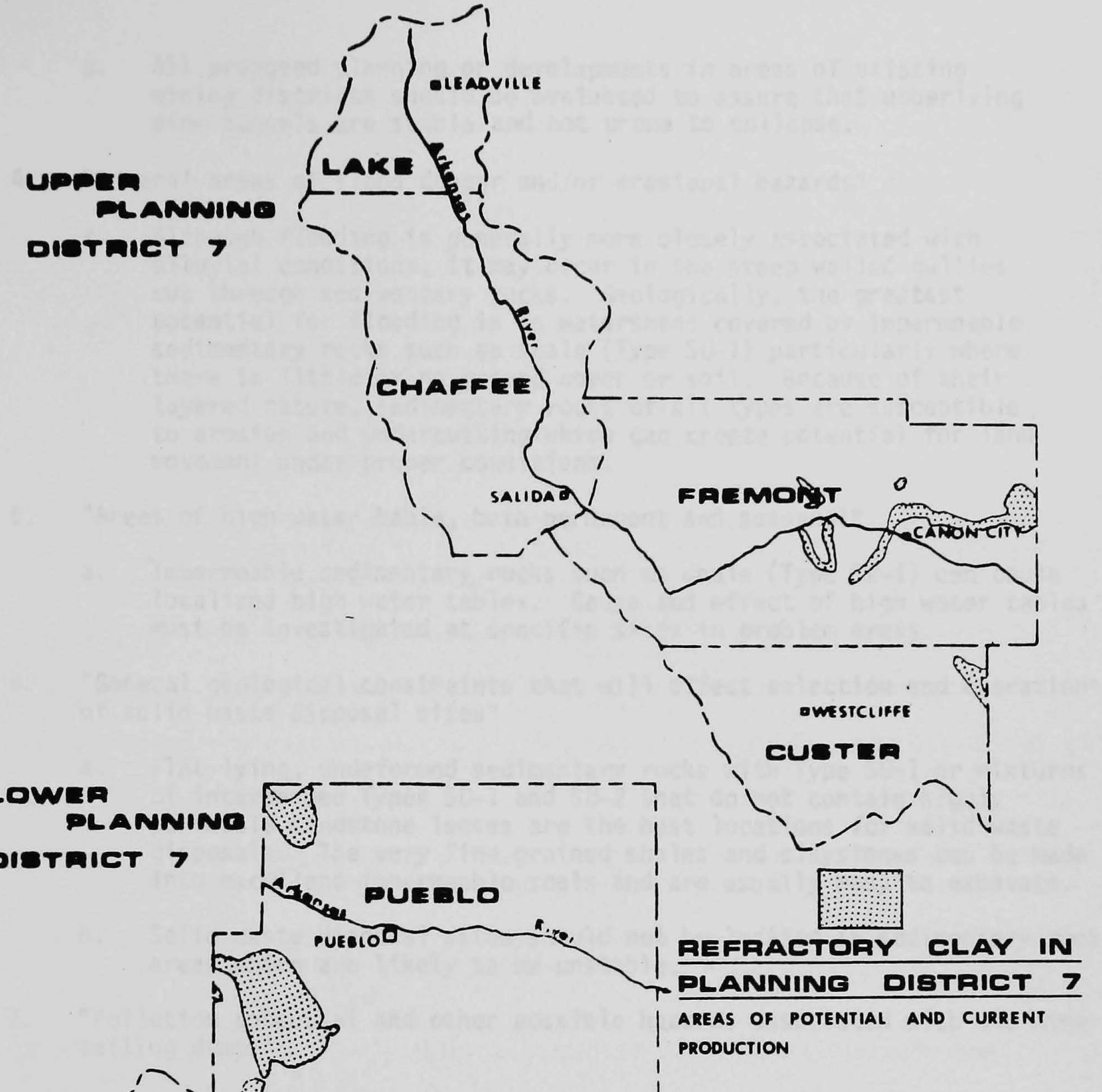

UPPER PLANNING DISTRICT 7
LEADVILLE
LAKE
Arkansas River
CHAFFEE
SALIDA
FREMONT
CANON CITY
WESTCLIFFE
CUSTER
LOWER PLANNING DISTRICT 7
PUEBLO
Arkansas River
PUEBLO
REFRACTORY CLAY IN PLANNING DISTRICT 7
AREAS OF POTENTIAL AND CURRENT PRODUCTION
HUERFANO
WALSENBURG
Apishapa River
LAS ANIMAS
Purgatoire River
TRINIDAD

Figure 10

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 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 disposals. 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 leach fields, seepage pits or other subsurface disposal systems in 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 investigations should also evaluate the effects 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. Some strip mining of coal is occurring in the Florence area. Developments and planning in this area should consider the effects of such mining operations.

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 Ss Sedimentary rocks with specific engineering geology problems have been identified on the maps. These special problems or formations primarily consist of those units deposited during Upper Cretaceous time. These units are described as follows:

SS-1 The Carlyle Shale and Graneros Shale which are essentially dark gray shales with an intervening limestone unit known as the Greenhorn;

SS-2 The Niobrara formation consists of a yellow chalk with some thin, white limestone (a light gray limestone near the base is known as the Fort Hays limestone); and

SS-3 The Pierre shale — a thick sequence of dark gray siltstones and shales.

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

1. "Massive movements or other unstable surface conditions"

a. Gravity movements of sedimentary rocks are common. These slides are caused by a combination of many factors such as slope, moisture, load and so forth. These conditions are particularly severe along steep walled mesas, canyons and valleys or where the subject sedimentary units formed 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 shale and siltstone members of these units 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 units are highly deformed or fractured.

d. Subsidence of the surface in the mined out coal seams is a possibility, and development of such areas must be preceded by a thorough investigation for subsidence.

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

   a. The clay shale members of the Pierre, Niobrara and Carlyle formations are all moderately to highly swelling when excess moisture is applied to them. All developments and structures in the areas covered by these sediments should have comprehensive soil 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.

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

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

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. Some problems do exist where limestone layers are found. The limestones are sometimes difficult to excavate and crush. In addition, fractures and solution cavities in the limestone can carry polluted water from the solid waste disposal sites to useable water sources in other areas.

   b. Solid waste disposal sites should never 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.

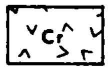
6. "Pollution potential and other possible hazards associated with old mine tailing dumps"

   a. Except for some very local conditions in Lake and Chaffee Counties, there are no mine tailing dumps in the vicinity of the subject sedimentary units.

   b. Along the outcrop edges of the subject units, particularly in Huerfano, Pueblo and Fremont Counties, some coal developments are likely. The tailings or spoil piles from such developments may create problems with acidic water, erosion, dust and suspended sediments.

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

   a. On-site leach fields or other types of subsurface disposal systems are not recommended for these types of sedimentary units. Without a substantial soil or alluvium cover, sewage disposal on sites covered by these formations will probably require specially engineered evapo-transpiration systems or other types of sewage disposal systems.

IV. Metamorphic and intrusive rocks  Metamorphic and intrusive rocks are grouped together as a single map unit because of similarity in their 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 7 include:

CR-1 Metamorphic rocks which usually appear as a light and dark banded, coarse grained rock and are found in the western two-thirds of Planning District 7; and

CR-2 Intrusive igneous rocks which come in a variety of grain sizes and colors, resulting from the rate of cooling of a molten mass and the chemical composition of the mass.

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 mining districts are shown on Figure 9.

b. Building stone (marble and granitic rocks) have been quarried to some extent in Chaffee, Fremont and Pueblo Counties. Continued development and perhaps expansion of these operations should be expected.

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 circumstances, these rocks can become very unstable. The following should be considered when working in metamorphic or igneous intrusive rocks:

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

2) Geologic deformation 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 can have distinctive planes of weakness, and slippage along these planes is common especially along steeply dipping units. Slides, for example, are more apt to occur at road cuts where these planes dip into the cut rather than away from the cut.

4) Weathering of these rocks, in combination with any of the other four 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-metamorphic terrane. This hazard is related to the dense and impermeable nature of the rocks and steep watersheds in which they occur.

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.

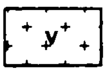
6. "Pollution potential and other possible hazards associated with old mine tailing dumps"

   a. Extensive mine tailing dumps may be unstable and subject to settling or movement.

   b. A pollution potential exists for many types of mine dumps. However, the degree of danger depends upon the proximity of the tailings to a stream or aquifer and the type of mine. An example of such a pollution potential is contamination of water by dissolved zinc from zinc mine tailings.

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

   a. Utility and road construction and rippability 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, the maintenance costs and type of excavation required.

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 essentially flow out at the surface of the Earth before solidifying. Pyroclastic rocks consist of the fragmented materials which have been ejected into the air and fell to the ground in what can be considered bedded formations. Ash is a familiar example of a pyroclastic rock. The general types of these rocks in Planning District 7 include:

V-1 Extrusive rocks (lava flows) are found to some extent in every county in Planning District 7 with the exception of Pueblo County.

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

Engineering Geology and planning considerations for the above mentioned types of rocks include:

1. "Mineral resources which affect land use decisions"

   a. In several counties in Planning District 7, pumice and perlite (Type V-1) are quarried as light-weight aggregates, abrasives and as a source for insulation.

   b. In Custer County, some Tertiary volcanic rocks are used for construction purposes.

   c. Metallic minerals may also be found in volcanic rocks. A very good example is seen in Custer County where gold, silver, lead, copper and zinc have been mined in volcanic rhyolite near Silver Cliff.

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 in relation to volcanic rocks. These conditions are:

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

      2) Geologic deformation (joints, fractures and faults).

      3) The internal nature of the rock itself; in the case of pyroclastic rocks, this would concern the strength of the bond holding the material together - some pyroclastic rocks (such as ash deposits) can crumble very easily.

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

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 from volcanic rocks should be examined for conditions that could affect foundations.

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

   a. Per intrusive and metamorphic rocks, there is a flash flood potential in volcanic rocks owning 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 development planned in areas covered with pyroclastic rocks.

   c. In some locations, lava flows form hard resistant "caprocks" over less resistant rock. These flat mesa like areas are stable on top but access roads would be difficult to build.

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. In general, extrusive volcanic rocks are not suitable for solid waste disposal sites because seals would be difficult to form and the hard rocks would be difficult to excavate in some cases to the point that blasting is necessary.

   b. Pyroclastic rocks will not be as difficult to excavate with heavy equipment, but problems may be encountered in preparing seals, such considerations can only be identified by examination of specific sites by an engineering geologist.

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 7. These factors, coupled with stability considerations, should be studied in detail prior to development work in volcanic terrain.

PROBLEM AREAS

The purpose of this part of the report is to specify certain areas in Planning District 7 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 Area I

Problem area I is located in northeastern Lake County and can be referred to as the Leadville mining district. The problems found there are both natural and artificial. The rocks are intensely folded, faulted and intruded. These highly fractured rocks can be unstable. The extreme topographic relief found in the mining district adds to the potential instability. There is a strong possibility for gravity movements, both rock and snow, in this rugged region. Construction will be difficult and costly.

Artificial hazards exist because of the extensive mining in the area. Mines underlie much of the area and cave-ins could cause surficial subsidence. The shafts, expecially open, abandoned holes, are dangerous. Mine tailing dumps present additional stability problems and may also threaten the water supply with pollution.

Problem Area II

Problem area II is the Spanish Peaks region with the associated radial dike swarms. This area is unique in that the dike swarms stand like walls above the surrounding, more erosive, sedimentary rock. Engineering problems are related to these dike swarms.

The tops of some of the dikes are popular locations for homesites because of the view, but the shallow soil cover on these dikes makes sewage disposal a difficult problem. A poorly located leach field will allow the leachates to seep down to the crystalline bedrock and then bleed down the exposed sides of the dikes. Valley locations between the dikes are more favorable building sites because of a more extensive soil and alluvial cover, but these areas may be plagued by rock falls from the dikes. The construction of surface transportation routes through the dike swarm will also be difficult.

Problem Area III

Problem area III covers disseminated areas of potential avalanches and, as such, is not specifically shown on the map. Such areas are common in alpine regions. In Planning District 7, this would include the Sangre de Cristo Range, the Wet Mountains, the Mosquito Range and the Sawatch Range.

Avalanches occur where snow has accumulatea to the extent of becoming unstable. During the buildup, a point is reached when the weight of the snow is too great and the body of snow rushes in mass down the mountain. The danger of such avalanches is obvious. Even small snow slides can be hazardous where they cross surface transportation routes.

Some avalanches occur year after year at the same location and have left a scar on the mountainside. These avalanche chutes are long paths down a mountain which are barren of most vegetation. Avalanches have worn these paths by moving trees, rocks and other material down the mountain. These chutes will enable future avalanches to be more dangerous because of the lack of obstructions.

Problem Area IV

Problem area IV encompasses those areas that were covered by glaciers in the past. (This ice age dates back approximately one million years.) These areas are similar to problem area III in that they are too widespread to be located on the enclosed map. However, glaciers have covered most high mountain ranges in Colorado with, in Planning District 7, includes the Sangre de Cristo Range, the Mosquito Range and the Sawatch Range.

The glaciers that once covered the Rocky Mountains and can still be found in places today, are known as mountain glaciers. These "rivers of ice" developed on mountain peaks and began to move down the valleys. The ice was replenished by new snow which was compacted. The moving glaciers scoured everything in their path and cut deep "U" shaped valleys in the rock. Rocks and even large boulders were carried down the mountain and were deposited at the base (toe) and along the trend of the glaciers.

The erosional remains of these glaciers are seen in Planning District 7.

These "U" shaped valleys and moraines create engineering problems today. The valleys are commonly oversteepened, presenting hazards of rock falls and slides. Moraines tend to be poorly drained and are liable to slide under load.

Problem Area V

Areas of extremely complex geology make up problem area V, and there are several of these areas located in the major mountain ranges of Planning District 7. These areas are too extensive to be delineated on the map but in general, follow the Mosquito, Sangre de Cristo, Sawatch and Wet Mountain Ranges. These areas consist predominantly of highly deformed crystalline and sedimentary rocks with some volcanics. In addition, unconsolidated surficial material is present in the form of stream deposits, glacial moraines, talus and landslide deposits.

These complexly deformed, heterogeneous (mixed) rock areas inherently contain the gamut of engineering problems described for the various rock types in this report. Foundation engineering could be costly, and in areas of shallow bedrock, leach field sites would be difficult to locate. These problems coupled with those associated with glaciation and gravity movements make the mountain areas difficult to develop.

Problem Area VI

Recently, tests conducted by the Colorado Health Department indicate that ground water in Pueblo County may be contaminated significantly by radioactive material. To date, almost 50 percent of the samples tested from private water wells have shown concentrations of radium in excess of the 3 picocurie-per-liter standard which is presently acceptable for potable water. Water availability and quality should be of prime concern for planners and developers alike.

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, Chief Geologist

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).

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

Acharya, Ashutosh, 1949, Geology of the Grape Creek area, Fremont County, Colorado: M.S. Thesis, Colorado School of Mines.

Ames, Vincent Eugene, 1957, Geology of McCarty Park and vicinity, Costillo and Huerfano Counties, Colorado: M.S. Thesis, Colorado School of Mines.

Anonymous, 1933, Map of Canon City coal field: Denver Public Library Files of Mineral Resources of Colorado.

Armstrong, Escar Weldon, 1951, Structural geology in an area in northeastern Fremont County, Colorado: M.S. Thesis, Iowa State College.

Asquith, Donald O., 1952, Geology of a portion of the Sangre de Cristo Range northwest of Cuchara Camps, Colorado: M.S. Thesis, Kansas.

Aughenbaugh, Nolan B., 1959, Geology of the Sangre de Cristo Mountains at Mosca and Morris Creeks, Colorado: M.S. Thesis, Michigan.

Beach, Richard A., 1968, Geology of the Ophir Creek area, Custer and Huerfano Counties, Colorado: Research at Colorado School of Mines.

Beck, D. L., and Stewart, Hugh A., 1912, On the geology and topography of Mount Brass and Buckskin Gulch, Mosquito Range, Colorado: B.A. Thesis, Colorado School of Mines.

Behre, Charles H., Jr., 1932, Physiographic history of the upper Arkansas and Eagle Rivers, Colorado (abst): Geological Society of America Bulletin, v.43, p.169.

_________1953, Geology and ore deposits of the west slope of the Mosquito Range (Colorado): U. S. Geological Survey Professional Paper 235, 176 p., 20 pls., 101 figs.

Behre, C. H., Jr., Goddard, E. N., and Sandberg, A. E., 1939, Preliminary geologic map of the west slope of the Mosquito Range in the vicinity of Leadville, Colorado: U. S. Geological Survey General Mineral Resource Map, scale 1:12,000.

Bell, Robert D., 1952, The geology of the Cuchara Pass area, Colorado: M.S. Thesis, University of Kansas.

Bhutta, Muhammad Afhar, 1954, Geology of Salida area, Chaffee and Fremont Counties, Colorado: D.Sc. Thesis, Colorado School of Mines.

Blanco, Stephen, 1972, Geology of the Rye-Colorado City area, Pueblo and Huerfano Counties, Colorado: Research at Colorado School of Mines.

Blum, Victor Joseph, 1944, The magnetic field and the geology of the Canon City area, Colorado: Ph.D. Thesis, St. Louis.

Boydston, Donald, Santos, Elmer S., and Hamit, Brenton M., 1954, Geology of the east central portion of the Huerfano quadrangle, Huerfano County, Colorado: M.S. Thesis, Michigan.

Brewer, Quenton L., 1931, Geology and ore deposits of a section of the Chalk Creek mining district, Chaffee County, Colorado: M.S. Thesis, Colorado School of Mines.

Brock, M. R. and Singewald, Q. D., 1968, Geologic map of the Mount Tyndall quadrangle, Custer County, Colorado: U.S. Geological Survey Geologic Quadrangle Map - 596, scale 1:24,000.

Brock, M. R. and Barker, Fred, 1972, Geologic map of the Mount Harvard quadrangle, Chaffee and Gunnison Counties, Colorado: U. S. Geological Survey Geologic Quadrangle Map 952, scale 1:62;500.

Brouder, George Thomas, 1958, The geology of Shaws Park, Fremont County, Colorado: M.S. Thesis, Oklahoma.

Bruder, Karl F. and Wheeler, Charles T. Jr., 1955, Geology of the Greaser Creek area, west-central Huerfano Park, Huerfano County, Colorado: M.S. Thesis, University of Michigan.

Butler, B. S. and Vanderwilt, J. W., 1931, The Climax molybdenite deposit of Colorado: Colorado Scientific Society Procedures, v. 12, n. 10.

Butler, Charles R., 1949, Geology of the northern part of the Sangre de Cristo Mountains, Colorado (abst.): Geological Society of America Bulletin, v.60, pp.1959-1960.

Butler, James Robert, 1954, Geology of an area north of Cotopaxi, Fremont County, Colorado: M.S. Thesis, Colorado.

Burford, Arthur E., 1960, Geology of the Medano Peak area, Sangre de Cristo Mountains, Colorado: Ph.D. Thesis, Michigan.

Capps, S. R., Jr., 1909, Pleistocene geology of the Leadville quadrange, Colorado: U. S. Geological Survey Bulletin 386, 99 p.

Christman, R. A., et al., 1953, Thorium investigation 1950-1952, Wet Mountains, Colorado: U. S. Geological Survey Circular 290.

Christman, R. A., Brock, M. R., Pearson, R. C., Singewold, Q. D., 1959 (1960), Geology and thorium deposits of the Wet Mountains, Colorado, -- a progress report: U. S. Geological Survey Bulletin 1072-H, pp. 491-535.

Chronic, John and Chronic, Holka, 1972, Prairie, peak and plateau - a guide to the geology of Colorado: Colorado Geological Survey Bulletin 32, 126 p.

Clackyin, Albert R. and Ray, Chalmer, Jr., 1945, Structure of the Red Creek area, Fremont County, Colorado: Geological Society of American Bulletin, v.57, pp.819-827.

Collins, Donald N., 1959, A study in sediment transportation by the Arkansas River in Colorado and Kansas: M.S. Thesis, Kansas.

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

Colorado Mineral Resources Board, 1947, Mineral resources of Colorado.

__________ 1960, Mineral resources of Colorado, first sequel.

Copeland, Jerry H., 1959, Geology of the upper Middle Creek area, Huerfano County, Colorado: M.S. Thesis, Colorado School of Mines.

Corey, Ronald L. and Ryan, Richard C., 1960, Geology of the Slide Mountain area, Huerfano and Costilla Counties, M.S. Thesis, Michigan.

Darton, N. H., 1906,Geology and underground waters of the Arkansas valley in eastern Colorado: U. S. Geological Survey Professional Paper 52, 90 p.

DeLong, James Edward, Jr., 1966, Geology of the Chalk Mountain area, Climax, Colorado: M.S. Thesis, Michigan.

Demaison, G., 1955, Geology of Twin Mountain area, northwest of Canon City, Fremont County, Colorado: M.S. Thesis, Colorado School of Mines.

Denison, David Floyd, 1963, Geology of an area north of Bartlet Mountain, Climax district, Colorado: M.S. Thesis, Michigan.

DeVoto, Richard H., 1961, Geology of southwestern Park and Chaffee Counties, Colorado: D.Sc. Thesis, Colorado School of Mines.

__________ 1972, Pennsylvanian and Permian rocks, sedimentation, tectonism, and geologic history of central Colorado: Research at Colorado School of Mines.

Dings, M. G., Robinson, C. S., and Brock, M. S., 1952, Geologic map of Garfield quadrangle, Colorado: U. S. Geologic Survey Open File Report PN 13342.

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

Emmons, S. F., 1898, Tenmile district special, Colorado: U. S. Geological Survey Geologic Folio 48, 4 maps, 6 p.

Emmons, S. F. and Irving, J. D., 1907, The downtown district of Leadville, Colorado: U. S. Geological Survey Bulletin 320, 75p.

Emmons, S. F., Irving, J. D., and Laughlin, G. F., 1927, Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geological Survey Professional Paper 148, 368 p.

Evans, Stewart T., and Trudell, Lawrence G., 1958, Geology of the South Veta Creek area, Huerfano quadrangle, Huerfano County, Colorado: M.S. Thesis, Michigan.

Fisher, C. A., 1906, Nepesta, Colorado: U. S. Geological Survey Folio 135, 6p., 3 maps.

Fouret, James H., 1955, Geology of the central Culebra Range region, Costilla, Huerfano and Las Animas Counties, Colorado: M.S. Thesis, Colorado School of Mines.

Franks, Paul C., 1956, Geology of the Beulah area, M. S. Thesis, Kansas.

Gallo, Benedict J., 1962, The stratigraphy and paleontology of the (Cretaceous) Dakota group and the Benton shale (Colorado group in part) south and east of the Wet Mountains from Bodito, Huerfano County to Rye, Pueblo County, Colorado: M.S. Thesis, Michigan.

Ganguli, Ajit Kumar, 1950, Geology of the area southwest of Florence, Fremont Counties, Colorado: M.S. Thesis, Colorado School of Mines.

Gerhard, Lee C., 1961, Geology of the lower Phantom Canyon area, Fremont County, Colorado: M. S. Thesis, Kansas.

Gilbert, G. K., 1897, Pueblo, Colorado: U. S. Geological Survey Geologic Folio 36, 5 maps, 9 p.

Guyton, J. Stephen, Hutton, John R., and Sokolsky, George E., 1960, Geology of the Devils Hole area, Custer and Huerfano Counties, Colorado: M.S. Thesis, Michigan.

Haas, James J., Kaarsberg, John F., and Stephens, John J., 1956, Geology of the Poison Canyon area, Huerfano County, Colorado: M. S. Thesis, Michigan.

Harbour, R. L. and Dixon, G. H., 1956, Geology of the Trinidad-Aguilar area, Las Animas and Huerfano Counties, Colorado: U. S. Geological Survey Oil and Gas Map 174, scale 1:31,680.

_________ 1959, Coal resources of Trinidad-Aguilar area, Las Animas and Huerfano Counties, Colorado: U. S. Geological Survey Bulletin 1072-G, pp. 445-489.

Hardley, William F. and Salotti, Charles A., 1955, Geology of the upper Mais Creek area, Wet Mountains, Colorado: M.S. Thesis, Michigan.

Haynes, Edward H., 1952, The geology of a portion of the east slope of the Sangre de Cristo Range, Huerfano County, Colorado: M.S. Thesis, Kansas.

Henley, Charles H., 1936, Geology of an area near Walsenberg, Colorado with reference to oil and gas possibilities: Denver Public Library Files on Mineral Resources of Colorado.

Herman, Theodore C., 1962, Geology of the Placer Creek area, Huerfano and Costilla Counties, Colorado: M.S. Thesis, Michigan.

Herrera, Amilcar Oscar, 1951, Geology of the area southwest of Florence, Fremont County, Colorado: M.S. Thesis, Colorado School of Mines.

Hiestand, T. C., et al., 1954, Two Guidebooks, Denver to Colorado Springs and Denver to Canon City: Rocky Mountain Association of Geologists.

Hills, R. C., 1900, Walsenberg, Colorado: U. S. Geological Survey Geologic Folio 68, 6 maps, 6p.

_________ 1901, Spanish Peaks, Colorado: U. S. Geological Survey Geologic Folio 71, 6 maps, 7p.

Holmes, Douglas A., and Lootins, Douglas J., 1959, Geology of the Silver Mountain area, Huerfano County, Colorado: M.S. Thesis, Michigan.

Honea, Russell M., 1955, Volcanic geology of the Ruby Mountain area, Northrop, Colorado: M.S. Thesis, Colorado.

Hulstrand, Richard F., Tinker, C. N. and Wendt, R. L., 1955, Geology of the Turkey Creek-Williams Creek area, Huerfano County, Colorado: M.S. Thesis, Michigan.

Johnson, J. Harlan, 1929, Contributions to the geology of the Sangre de Cristo Mountains of Colorado: Colorado Scientific Society Procedures, v. 12, pp. 3 - 21.

Johnson, R. B., 1958, Patterns of radial dike swarms associated with West Spanish Peak and Dike Mountain, south central Colorado (abst): Geological Society of America Bulletin, v. 69, n.12, part 2, p.1731.

__________ 1958, Geology and coal resources of the Walsenberg area, Huerfano County, Colorado: U. S. Geological Survey Bulletin 1042-0, pp. 557-583.

__________ 1959 (1960), Geology of the Huerfano Park area, Huerfano and Custer Counties, Colorado: U. S. Geological Survey Bulletin 1071-D, pp. 87 - 119.

__________ 1961, Coal resources of the Trinidad coal field in Huerfano and Las Animas Counties, Colorado: U. S. Geological Survey Bulletin 1112-E, pp.129-180.

__________ 1968, Geology of the igneous rocks of the Spanish Peaks region, Colorado: U. S. Geological Survey Professional Paper 594-G, pp.G1-G47.

Johnson, R. B. and Stephens, J. G., 1954, Coal resources of the La Veta area, Huerfano County, Colorado: U. S. Geological Survey Coal Investigations Map 20, scale 1:31,680.

__________ 1954, Geology of the La Veta area, Huerfano County, Colorado: U. S. Geological Survey Oil and Gas Map 146, scale 1:31,680.

__________ 1955, Geologic map of the Walsenburg area, Huerfano County, Colorado: U. S. Geological Survey Oil and Gas Map 161, scale 1:48,000.

Johnson, R. B., Wood, G. H., Jr., and Harbour, R. L., 1958, Preliminary geologic map of the northern part of the Raton Mesa region and Huerfano Park in parts of Las Animas, Huerfano and Custer Counties, Colorado: U. S. Geological Survey Oil and Gas Map 183, scale 1:63,360.

Johnston, Paul L., 1959, The geology of the Red Gulch area, Fremont County, Colorado: M. S. Thesis, Kansas.

Jonson, David G., 1955, The geology of the Resurrection Mine area, Lake County, Colorado.

Kane, Henry Edward, 1965, The Quaternary geology and geomorphology of the southeastern portion of the Canon City embayment, Colorado: Doctoral Thesis, U.C.L.A.

Kim, Ok Joon, 1951, Geology of the Wetmore-Beulah area, Custer and Pueblo Counties, Colorado: M.S. Thesis, Colorado School of Mines.

Knoph, Adolph, 1936, Igneous geology of the Spanish Peaks region, Colorado: Geological Society of America Bulletin, v.47, pp.1727-1784.

Koch, Robert Winfeld, 1963, A structural study of the Venable Peak region of the Sangre de Cristo Range, Colorado: M. S. Thesis, Colorado School of Mines.

Koschmann, A. H. 1948, Tenmile mining district: U. S. Geological Survey Open File Report.

Koschmann, A. H. and Wells, F. G., 1946, Preliminary report on the Kokomo mining district, Colorado: Colorado Scientific Society Proc., v.15, n.2, pp. 51-112.

Kouther, Jamul, 1968, The geology of Mount Ouray area, Bonanza quadrangle, Chaffee County, Colorado: Research at Colorado School of Mines.

Lasca, Norman P. and Volckmann, Richard P., 1961, Geology of the Music Pass area in the Sangre de Cristo Range, Colorado: M.S. Thesis, Michigan.

Lee, W. T., 1922, Raton-Brilliant-Koehler, New Mexico-Colorado: U. S. Geological Survey Geologic Folio 214, 10 maps, 17 p.

Levings, W. S., 1951, Late Cenozoic erosional history of the Raton Mesa region: Colorado School of Mines Quarterly, v.46, n.3, 111 p.

Lindgren, Waldemar and Ransome, F. L., 1906, Geology and gold deposits of the Cripple Creek district, Colorado: U. S. Geological Survey Professional Paper 54, 516 p.

Litsey, L. R., 1954, Geology of the Hayden Pass-Orient area, Sangre de Cristo Mountains, Colorado: Ph.D. Thesis, University of Colorado, 158 p.

__________ 1958, Stratigraphy and structure in the northern Sangre de Cristo Mountains, Colorado: Geological Society of America Bulletin, v. 69, n.9, pp.1143-78.

Logan, John Merle, 1962, A structural study of the northern margin of the Wet Mountains, Fremont County, Colorado: M.S. Thesis, Oklahoma.

Loughlin, G. F., 1926, Guides to ore in the Leadville district, Colorado: U.S. Geological Survey Bulletin 779, 37 p.

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

McCullough, Douglas L., 1959, Geology of the Parkdale area, Fremont County, Colorado: M.S. Thesis, Kansas.

McGinnis, Charles James, ed., 1956, Guidebook to the geology of the Raton Basin, Colorado: Rocky Mountain Association of Geologists, 8th annual field conference.

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

__________ 1966, Ground water in Huerfano County, Colorado: U. S. Geological Survey Water Supply Paper 1805, 91 p.

Malek - Aslani, Morad K., 1950, The geology of southern Perry Park, Douglas County, Colorado: M.S. Thesis, Colorado School of Mines.

__________ 1952, Geology of the Beulah area, Pueblo County, Colorado: D.Sc. Thesis, Colorado School of Mines.

Mann, C. John, 1957, Geology of Chandler Syncline, Fremont County, Colorado: M.S. Thesis, Kansas.

Martin, Charles Arthur, Jr., 1954, Geology of the South Hardscrabble Creek area, Colorado: M.S. Thesis, Kansas.

Meeves, Henry C., (no date), Lead, manganese, silver, zinc, Leadville district reserves: Abstracts of North American Geology.

Miller, Joseph H., 1951, Geology of the area southwest of Canon City, Fremont County, Colorado: M.S. Thesis, Colorado School of Mines.

Munger, Robert D., 1959, Geology of the Spread Eagle Peak area, Sangre de Cristo Mountains, Colorado: M.S. Thesis, Colorado.

Ode, H., 1953, Analysis of the dike pattern of the Spanish Peak area (abst.): Geological Society of America Bulletin v.64, p. 1459.

Peterson, Lorenz A., 1941, Geology of a portion of Fremont County, Colorado, M.S. Thesis, State University of Iowa.

Pierce, A. P., 1952, Geology of east La Veta Pass, Huerfano County, Colorado: M.S. Thesis, Colorado School of Mines.

Pinkley, George R., 1931, A summary of geological conditions covering southwestern Las Animas County, Colorado: Denver Public Library Files on Mineral Resources of Colorado.

Powell, William J., 1952, Ground water in the vicinity of Trinidad, Colorado: Colorado Water Conservation Board, Ground water Series Circular 3.

Prommel, H. W. C., 1927, Geology and structure of the Badito-Alamo region, Huerfano County, Colorado: Denver Public Library Files on Mineral Resources of Colorado.

Quinlivan, William D., 1959, Geology of the Herring Park area, northeast of Salida, Colorado: M.S. Thesis, Colorado.

Rahman, Yousef H., 1954, Geology of the Wellsville-Calcite area, Chaffee and Fremont Counties, Colorado: Ph.D. Thesis, Colorado School of Mines.

Read, Robert O., 1956, Geology of the Williams Creek area, Huerfano quadrangle, Huerfano County, Colorado: M.S. Thesis, Michigan.

Rold, John Wesley, 1950, Geology of Wellsville area, north flank of Sangre de Cristo Mountains, Colorado: Compass, v.27, pp. 159-178.

Ruby, E.E., 1952, The geology of a portion of the foothills belt of the southwest side of the Canon City Embayment, Fremont County, Colorado: M.S. Thesis, Colorado School of Mines.

Russell, Robert T., 1939, The geology of the Poncna Fluorspar District, Chaffee County, Colorado: M.S. Thesis, Northwestern.

__________ 1950, The geology of the Poncha Fluorspar District, Chaffee County, Colorado: Ph.D. Thesis, University of Cincinnati.

__________ 1954, Uranium Occurrences in South Central Colorado: Guidebook, October 13 - 15, 1954, field conference: Rocky Mountain Association of Geologists, p.9.

Sackett, Duane H., 1961, Geology of the Golden Park area, Fremont County, Colorado: M.S. Thesis, Kansas.

Satin, Lowell Robert, 1955, Geology of the Bradford area of Huerfano Park, Huerfano County, Colorado: M.S. Thesis, Michigan.

Schwarzbach, Theodore Jeremiah, 1961, Geology of the Beulah area, Pueblo County, Colorado: M.A. Thesis, Texas.

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

Serviss, Fred L. F., 1922, Trinidad Coal Field of Colorado: M.S. Thesis, Colorado School of Mines.

Siapno, William D., 1953, Geology of Part of Northern Sangre de Cristo Mountains, Colorado: M. S. Thesis, University of Colorado.

Siems, Peter L., 1948, Volcanic and economic geology of the Rosita Hills and Silver Cliff districts, Custer County, Colorado: Research at Colorado School of Mines.

Singewold, Q. D., 1955 (1956), Sugarloaf and St. Kevin mining districts, Lake County, Colorado: U. S. Geological Survey Bulletin 1027-E, pp. 251 - 299.

Singewold, Q. D., and others, 1955, Geologic and radiometric maps of the McKinley Mountain area, Wet Mountains, Colorado: U. S. Geological Survey Mineral Investigations Field Studies Map 37, scale 1:7,200.

Sinha, B. N., 1951, Geology of the region around Parkdale, Fremont County, Colorado: D.Sc. Thesis, Colorado School of Mines

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

Skipp, Betty A., 1956, Geology of the Dead Horse Creek area, northeast of Salida, Colorado: M.A. Thesis, Colorado.

Smith, Russell, 1961, The geology of the Redwing area, Huerfano County, Colorado: Ph.D. Thesis, Michigan.

Startk, J. T. and Barnes, F. F., 1935, Geology of the Sawatch Range, Colorado: Colorado Scientific Society Proc. v. 13, n.8, pp. 467-479.

Stiller, David DeLong, 1963, Geology of the Crystal Falls area, Custer County, Colorado: M.S. Thesis, Michigan.

Stoever, Edward C., Jr., 1959, Geology of the Pass Creek area, Huerfano and Costilla Counties, Colorado: Ph.D. Thesis, Michigan.

Stout, John Lee, 1959, Geology of the Siloam area, Pueblo County, Colorado: M.S. Thesis, Colorado School of Mines.

Sunderman, Jack, 1956, Geology of the Carbonate Mountain area, Sangre de Cristo Range, Colorado: M. S. Thesis, Michigan.

Thayer, James, 1959, Geology of the Steer Creek area northeast of Salida, Colorado: M.S. Thesis, Colorado.

Thompson, Craig Dickenson, 1956, Geology of Bassam Park, Chaffee County, Colorado: M.S. Thesis, Colorado University.

Thompson, John H., 1943, The molybdenum industry at Climax, Colorado: M.S. Thesis, Colorado.

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

Tweto, Ogden, 1956, Geologic map of the Tennessee Pass area, Eagle and Lake Counties, Colorado: U. S. Geological Survey Mineral Investigations Field Studies Map 34, Scale 1:14,400.

U. S. Geological Survey Special Topographic Map, 1927-1939, Tenmile mining district, Colorado (south half): U. S. Geological Survey Special Topographic Map, scale 1:12,000.

__________ 1927-1940, Tenmile mining district: U. S. Geological Survey Special Topographic Map, scale 1:12,000.

__________ 1930, Sugarloaf-St. Kevin mining districts, Colorado: U. S. Geological Survey Special Topographic Map, scale 1:24,000.

Van Arsdale, 1952, Geology of the area east of Rye, Pueblo County,Colorado: M.S. Thesis, Colorado School of Mines.

Vanderwilt, J. W., et al., 1948, Guide to the geology of central Colorado, section on Denver, Glenwood Springs, Rifle, Leadville, South Park: Colorado School of Mines Quarterly, v.43, n.2, pp.73-176.

Vanderwilt, J. W. and King, R. V., 1946, Geology of the Climax ore body: Min. and Met. Mag., v.27, n.274.

Van Diver, Bradford B., 1958, Geology of the Calumet Mining District, Chaffee County, Colorado: M.S. Thesis, Colorado.

Vargas, Francisco H., 1961, Geology of the Cotopaxi inlier on the northern trend of the Sangre de Cristo Range, Fremont County, Colorado: M.S. Thesis, Colorado School of Mines.

Vian, Richard Wright, 1965, Geology of the Devil's Hole area, Fremont County, Colorado: Doctoral Thesis, Michigan.

Volckmann, Richad Peter, 1965, Geology of the Crestone Peak area, Sangre de Cristo Range, Colorado: Doctoral Thesis, Michigan.

Waage, Karl M., 1946, Fire clay deposits of eastern Fremont, western Pueblo and adjacent counties, Colorado: Ph.D. Thesis, Princeton.

_________ 1953, Refractory clay deposits of south central Colorado: U. S. Geological Survey Bulletin 993, 104 p.

Walter, Lawrence E., Jr., 1959, Geology of the Marigold area, Fremont and Teller Counties, Colorado: M.S. Thesis, Kansas.

Webster, G. D., 1959, Geology of the Canon City-Twin Mountain area, Fremont County, Colorado: M.S. Thesis, Kansas.

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

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., Johnson, R. B., and others, 1951, Geology and coal resources of the Stonewall-Tercio area, Las Animas County, Colorado: U. S. Geological Survey Coal Investigations Map 4, scale 1:31,680.

Wood, G. H., Jr., Johnson, R. B., and Dixon, G. H., 1954, Geology and coal resources of the Gulnare, Cuchara Pass and Stonewall area, Huerfano and Las Animas Counties, Colorado: U. S. Geological Survey Open File Report Press Notice 64691.

_________ 1956, Geology and coal resources of the Gulnare, Cuchara Pass and Stonewall area, Huerfano and Las Animas Counties, Colorado: U. S. Geological Survey Coal Investigations Map 26, scale 1:31,680.

_________ 1957, Geology and coal resources of the Starkville-Weston areas, Las Animas County, Colorado: U. S. Geological Survey Bulletin 1051, 68 p.

Wynne, Milo E., 1962, Geology of a portion of Fremont County, Colorado: M. S. Thesis, Kansas.

MAP BIBLIOGRAPHY

Boos, C. Maynard, and Boop, Margaret Fuller, 1957, Tectonics of the eastern flank and foothills of the Front Range, Colorado: American Assoc. Petroleum Geologists Bulletin, v. 41, n. 12, pp. 2603-2676.

Burbank, W. S. and Pierson, C. T., 1953, Preliminary results of radiometric reconnaissance of parts of the northwestern San Juan Mountains, Colorado: U. S. Geological Survey Circular 236, 11 pp.

De Voto, Richard H., Peel, Frederick A. and Pierce, Walter H., 1971, Pennsylvanian and Permian stratigraphy, tectonism and history, northern Sangre de Cristo Range, Colorado: Guidebook of the San Luis Basin, Colorado, New Mexico Geological Society, pp. 141-163.

Dings, M. G., and Robinson, C. S., 1957, Geology and ore deposits of the Garfield quadrangle, Colorado: U. S. Geological Survey Professional Paper 289, 110 pp.

Emmons, F. S., Irving, J. D. and Loughlin, G. F., 1927, Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geological Survey Professional Paper 148, 368 pp.

Feth, J. H., 1961, A new map of western conterminous United States showing the maximum known or inferred extent of Pleistocene Lakes: U. S. Geological Survey Research 1961, Short Papers on the Geologic and Hydrologic Sciences Articles 1-146, pp. B110 - B112.

Fisher, C. A., 1906, Nepesta, Colorado, U. S. Geological Survey Geologic Folio 135, 6 pp., 3 maps.

Gabelman, John W., 1952, Structure and origin of northern Sangre de Cristo Range, Colorado: American Assoc. Petroleum Geologists Bulletin, v. 36, n. 8, pp. 1574 - 1612.

Gilbert, G. K., 1897, Pueblo, Colorado: U. S. Geological Survey Geologic Folio 36, 9 pp., 5 maps.

Johnson, R. B., 1969, Geologic map of the Trinidad quadrangle, south central Colorado: U. S. Geological Survey Miscellaneous Geologic Investigations Map I-558, scale 1:12,000.

Kansas Geological Society, 1930, Guidebook, Fourth Annual Field Conference: Kansas Geological Society.

Knepper, Daniel H., Jr., and Marrs, Ronald W., 1971, Geological development of the Bonanza - San Luis Valley - Sangre de Cristo Range area, south central Colorado: Guidebook of the San Luis Basin, Colorado; New Mexico Geological Society, pp. 249 - 264.

Lovering, T. S., and Goddard, E. N., 1950 (1951), Geology and ore deposits of the Front Range, Colorado: U. S. Geological Survey Professional Paper 223, 319 pp.

Lowell, Gary R., 1971, Cenozoic geology of the Arkansas Hills region of the southern Mosquito Range, central Colorado: Guidebook of the San Luis Basin, Colorado; New Mexico Geological Society, pp. 209 - 217.

Scott, G. R., 1968 (1969), Geologic and structure contour map of the La Junta quadrangle, Colorado and Kansas: U. S. Geological Survey Miscellaneous Geologic Investigations Map I-560, scale 1:250,000.

Stark and Barnes, 1935, Geology of the Sawatch Range: Colorado Scientific Society Procedures, v. 13, pp. 467-479.

U. S. Geological Survey (W. C. Mendenhall, Director) in cooperation with the Colorado State Geological Survey Board and the Colorado Metal Mining Fund, 1930, Geologic Map of Colorado.

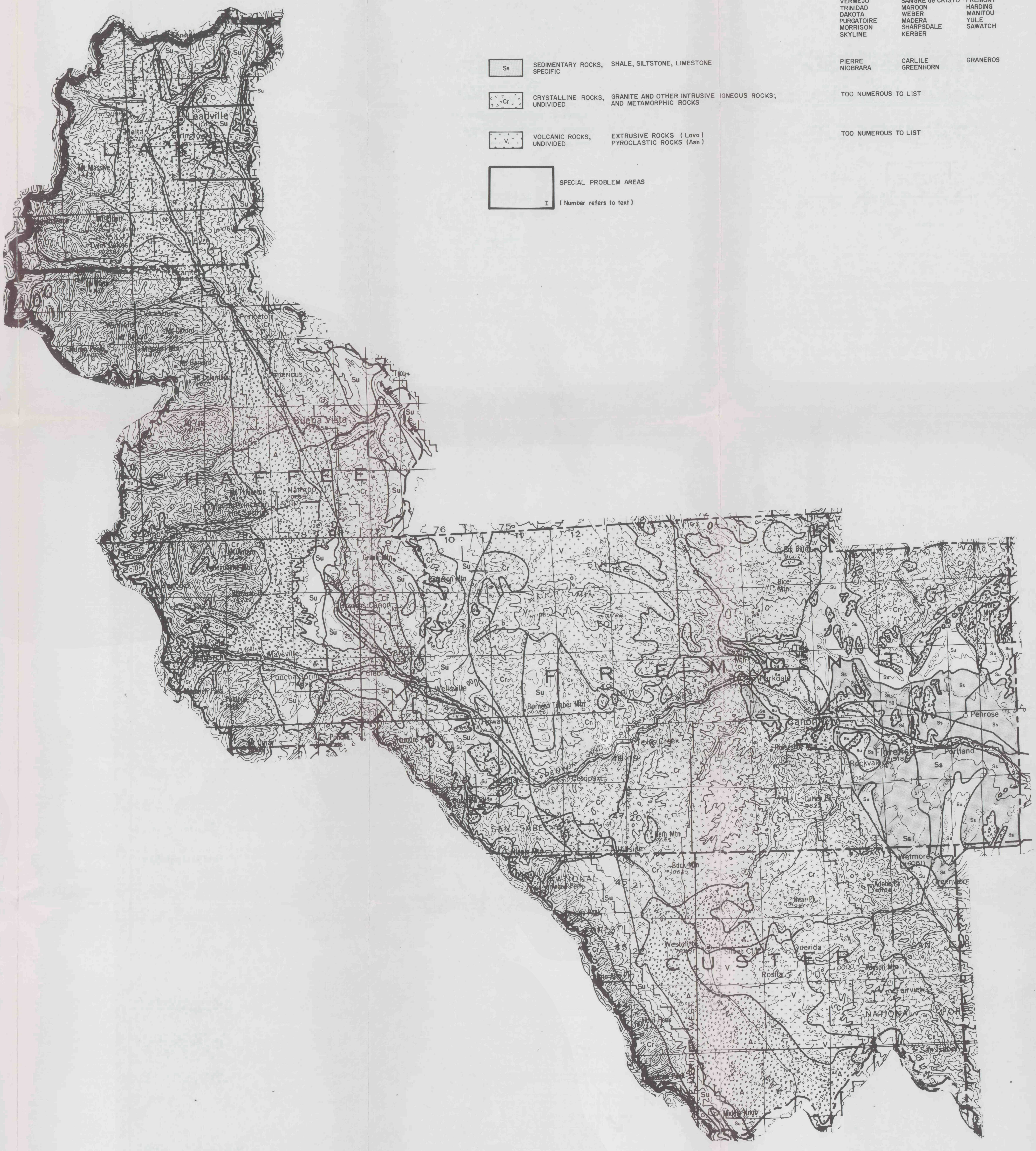
Van Alstine, Ralph E. and Lewis, G. Edward, 1960, Pliocene sediments near Salida, Chaffee County, Colorado: U. S. Geological Survey Research 1960 - Short Papers in the Geological Sciences, p. B245.

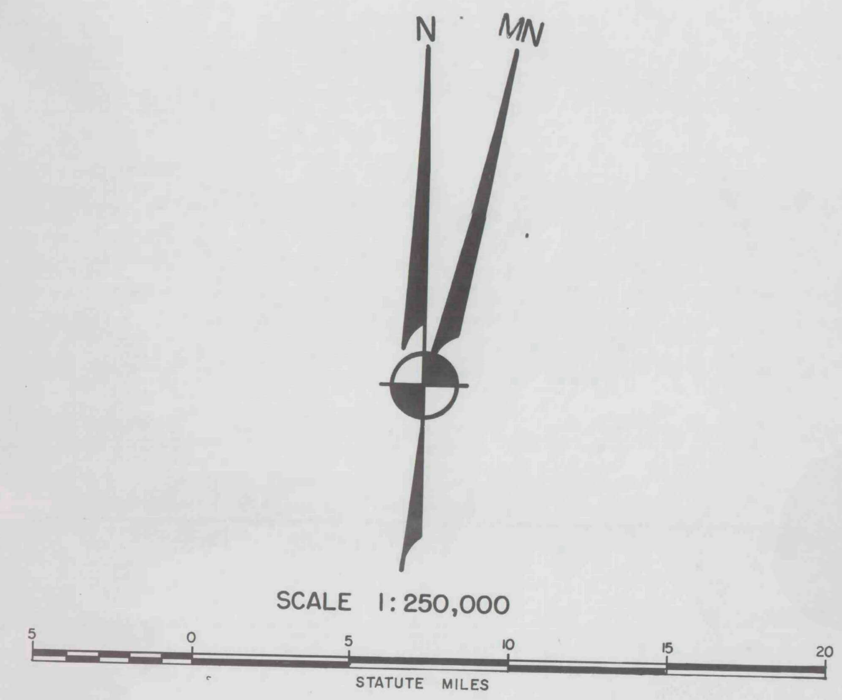
Van Alstine, Ralph E., 1969, Geology and mineral deposits of the Poncha Springs northeast quadrangle, Chaffee County, Colorado: U. S. Geological Survey Professional Paper 626, 52 pp.

__________, 1971, Allochthonous Paleozoic blocks in the Tertiary San Luis-Upper Arkansas graben, San Luis Valley: Guidebook of the San Luis Basin, Colorado: New Mexico Geological Society, pp. 169-179.

EG 3, Pl. 1

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, CONSOLIDATION UNDER LOADS, SOLID WASTE DISPOSAL, HIGH WATER TABLES
Su	SEDIMENTARY ROCKS, UNDIVIDED	SHALE, CLAYSTONE, MUDSTONE, SILTSTONE, SANDSTONE, CONGLOMERATE, LIMESTONE, DOLOMITE	DRY UNION, BROWNS CANYON, RATON, VERMEJO, TRINIDAD, DAKOTA, PURGATOIRE, MORRISON, SKYLINE, LYKINS, LYONS, FOUNTAIN, SANGRE de CRISTO, MAROON, WEBER, MADERA, SHARPSDALE, KERBER, LEADVILLE, WILLIAMS CANYON, CHAFFEE, FREMONT, HARDING, MANITOU, YULE, SAWATCH	CENOZOIC, MESOZOIC, PALEOZOIC	SUBSIDENCE IN MINE AREAS, SOLID WASTE DISPOSAL, POLLUTION OF AQUIFERS
Ss	SEDIMENTARY ROCKS, SPECIFIC	SHALE, SILTSTONE, LIMESTONE	PIERRE, NIOBRARA, CARLILE, GREENHORN, GRANEROS	MESOZOIC (CRETACEOUS)	LAND MOVEMENTS, EROSION, SWELLING SOILS, FLOODING
Cr	CRYSTALLINE ROCKS, UNDIVIDED	GRANITE AND OTHER INTRUSIVE IGNEOUS ROCKS; AND METAMORPHIC ROCKS	TOO NUMEROUS TO LIST	CENOZOIC, MESOZOIC, PRECAMBRIAN	FLOODING, SOLID WASTE DISPOSAL, EXCAVATION PROBLEMS
V	VOLCANIC ROCKS, UNDIVIDED	EXTRUSIVE ROCKS (Lava) PYROCLASTIC ROCKS (Ash)	TOO NUMEROUS TO LIST	CENOZOIC	INSTABILITY, SOLID WASTE DISPOSAL, EXCAVATION PROBLEMS
I	SPECIAL PROBLEM AREAS (Number refers to text)				





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ENGINEERING GEOLOGY MAP
COLORADO PLANNING DISTRICT 7
LAKE, CHAFFEE, FREMONT AND CUSTER COUNTIES

JOB No. 218100632 | DATE May 31, 1973

DRAFTING BY R.B | CHECKED BY Florquist

PREPARED FOR

COLORADO GEOLOGICAL SURVEY
AND
COLORADO DIVISION OF PLANNING

PLATE 1

EG 3 Pl. 2

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, CONSOLIDATION UNDER LOADS, SOLID WASTE DISPOSAL, HIGH WATER TABLES
Su	SEDIMENTARY ROCKS, UNDIVIDED	SHALE, CLAYSTONE, MUDSTONE, SILTSTONE, SANDSTONE, CONGLOMERATE, LIMESTONE, DOLOMITE	NUSSBAUM, DEVILS HOLE, FARISITA, HUERFANO, CUCHARA, POISON CANYON, RATON, VERMEJO, TRINIDAD, DAKOTA, PURGATOIRE, MORRISON, ENTRADA, LYKINS, JOHNSON GAP, SANGRE de CRISTO, MINTURN, FOUNTAIN	CENOZOIC MESOZOIC PALEOZOIC	SUBSIDENCE IN MINE AREAS, SOLID WASTE DISPOSAL, POLLUTION OF AQUIFERS
Ss	SEDIMENTARY ROCKS, SPECIFIC	SHALE, SILTSTONE, LIMESTONE	PIERRE, NIOBRARA, CARLILE, GREENHORN, GRANEROS	MESOZOIC (CRETACEOUS)	LAND MOVEMENTS, EROSION, SWELLING SOILS, FLOODING
Cr	CRYSTALLINE ROCKS, UNDIVIDED	GRANITE AND OTHER INTRUSIVE IGNEOUS ROCKS; AND METAMORPHIC ROCKS	TOO NUMEROUS TO LIST	CENOZOIC MESOZOIC PRECAMBRIAN	FLOODING, SOLID WASTE DISPOSAL, EXCAVATION PROBLEMS
V	VOLCANIC ROCKS, UNDIVIDED	EXTRUSIVE ROCKS (Lava) PYROCLASTIC ROCKS (Ash)	TOO NUMEROUS TO LIST	CENOZOIC	INSTABILITY, SOLID WASTE DISPOSAL, EXCAVATION PROBLEMS

SPECIAL PROBLEM AREAS

II (Number refers to text)

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ENGINEERING GEOLOGY MAP
COLORADO PLANNING DISTRICT 7
HUERFANO, LAS ANIMAS AND PUEBLO 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 2