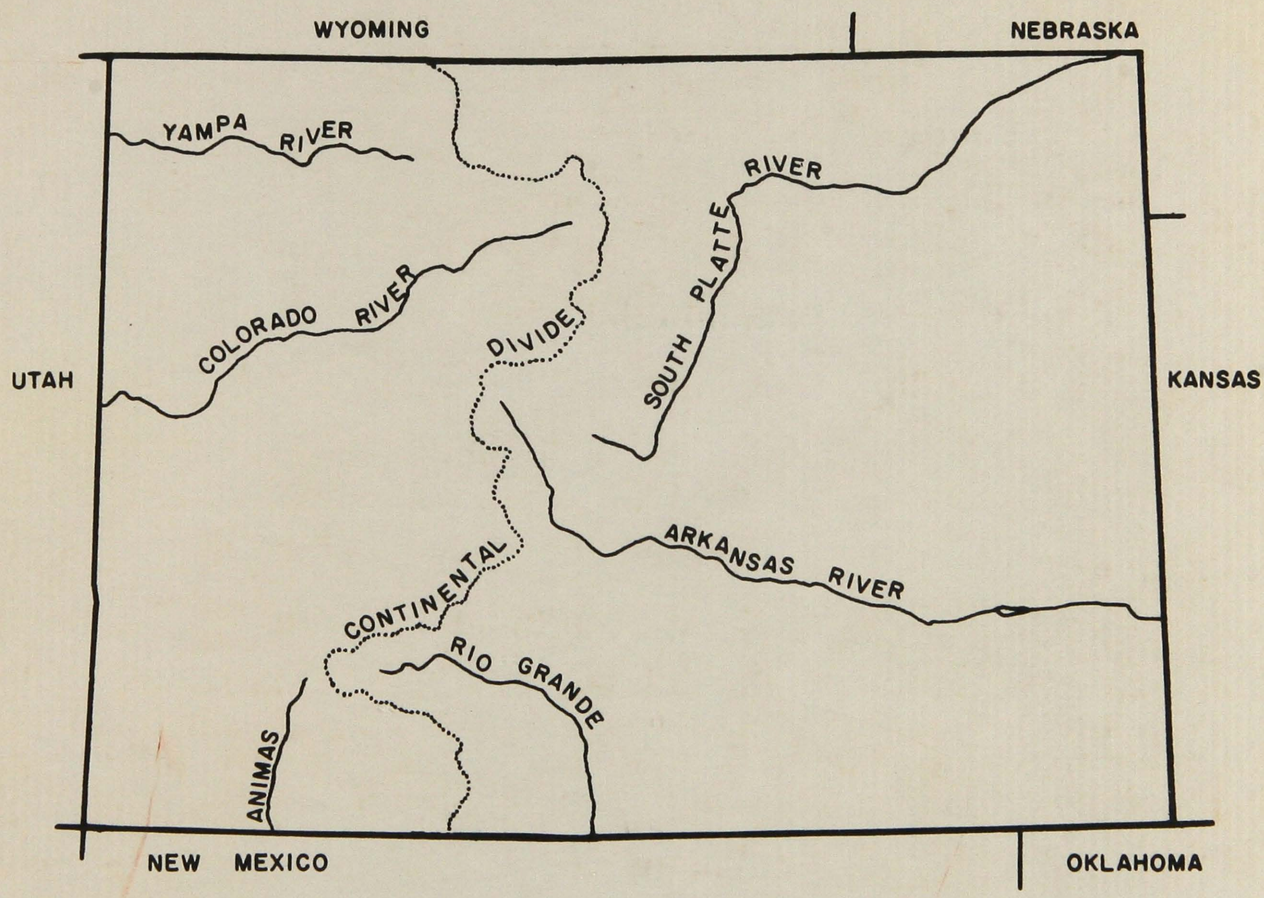
SUMMARY OF COLORADO HYDROGEOLOGY



WILLARD OWENS ASSOCIATES INC

WATER RESOURCES ENGINEERING

ENGINEERING GEOLOGY • GROUND WATER HYDROLOGY

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SUMMARY OF COLORADO HYDROGEOLOGY
WATER FOR COLORADO'S FUTURE

PREPARED FOR

COMMITTEE ON WATER
COLORADO LEGISLATIVE COUNCIL

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PROJECT NO. 73-084

GROUND WATER

COLORADO'S HIDDEN RESOURCE

Summary of
Colorado Hydrogeology

EXHIBITS

FOREWORD

This is the second edition of the text of our September 11, 1973, presentation to the Colorado Legislative Council Committee on Water. Although our oral presentation to the Committee followed the general outline of the original text, some points in the text were omitted to conserve time.

The original edition of the text was prepared in draft form in order to meet the Committee's schedule, so this second edition was prepared to add clarity, define terms and condense some sections to save the reader time in extracting pertinent information. The ideas, opinions, and recommendations are essentially the same as those presented in the first edition.

This report was prepared by Dorothy Beebe, Darla Boswell, Jean Buck, Michael P. Fahy, Jon R. Ford, Willard G. Owens and Donald D. Reitz of this firm.

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ACKNOWLEDGEMENTS

The personnel of Willard Owens Associates, Inc., wish to express their gratitude to those whose assistance helped to make this presentation possible. We wish to thank John C. Romero of the Colorado Division of Water Resources who contributed his knowledge of the Denver Basin by personal communication. We would also like to thank both George Lunetta, the El Paso County Hydrologist, and Jim Taylor, of the U. S. Geological Survey, Pueblo, for their cooperation in providing data as well as information concerning their own experience with the geology of the Dawson aquifer. To these people and others who provided comments and suggestions on the preparation of the report, we are most grateful.

INTRODUCTION

"Section 5. Water of streams public property.- The water of every natural stream, not heretofore appropriated, within the State of Colorado, is hereby declared to be the property of the public, and the same is dedicated to the use of the people of the state, subject to appropriation as hereinafter provided.

Section 6. Diverting unappropriated water-priority preferred uses.--The right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied. Priority of appropriation shall give the better right as between those using the water for the same purpose; but when the waters of any natural stream are not sufficient for the service of all those desiring the use of the same, those using the water for domestic purposes shall have the preference over those claiming for any other purpose, and those using the water for agricultural purposes shall have preference over those using the same for manufacturing purposes". Constitution of Colorado, Article XVI.

Water, both in the quantity available and in the way it is used, is perhaps the most critical factor in Colorado's future economy.

In approving 148-18 CRS, as amended, the Colorado Ground Water Management Act, and 148-21, the Water Right Determination and Administration Act of 1969, the Colorado Legislature demonstrated its concern about our ground water supplies. But there is still much to be done.

To provide background information on the subject, the Legislative Council Committee on Water asked Willard Owens Associates, Inc., personnel to discuss ground water and geologic problems related to water supplies at a meeting on September 11, 1973. The purpose was to provide the

Committee with ground water and geological information useful in preparing further legislation for better administration, management and utilization of the state's water resources.

Such information was presented to the Committee orally by Donald D. Reitz and Jon R. Ford, ground water hydrologists and engineering geologists. The usefulness of such data was acknowledged by Committee Chairman, Senator Fred E. Anderson in a letter to Willard G. Owens, September 12, 1973:

"...The Committee and the General Assembly as a whole appreciate the public service that you have extended to us in preparing this comprehensive report. It is this type of cooperation that makes our jobs as legislators much easier. We need the factual information you provided in order to make proper use of our water."

Willard Owens Associates, Inc., with offices in Wheat Ridge, Colorado, and Helena, Montana, provides geological and water resources consultation for individuals, companies, municipalities and state agencies in Colorado and several other states. Studies include geological investigations for land owners and developers to determine existing and potential geological problems and hazards, and to develop water supplies for new developments.

Personnel of Willard Owens Associates, Inc. belong to many professional and technical organizations including: American Institute of Professional Geologists, Association of Engineering Geologists, Rocky Mountain Association of Geologists, American Society of Civil Engineers, and Colorado Society of Engineers.

This report and its preparation have not been financed by any of the above clients or organizations. Obviously, however, better development and management of water resources will benefit both our clients and all other present and future users of water in Colorado.

This report includes descriptions of water-yielding geologic formations (aquifers), how and where ground water occurs, and descriptions of specific areas in Colorado where ground water is a primary resource. The report also offers certain recommendations on future development and management of water supplies.

We hope this presentation will supplement the Committee's understanding of Colorado's water problems, and thus result in legislation that will help utilize our water resources more effectively. Present water rights must be protected. But vast quantities of water remain in underground storage to be used for Colorado's future.

Some of the major water resources of the state are described in various detail in the body of this report.

However, we feel that the main ideas and plans of action that should concern the Legislature are described in the section of this report entitled "Practical Research and Management" which begins on page 13 and "Summary Statement" which begins on page 65.

This report is basically a general review of the hydrogeology (ground water geology) of Colorado. Hydrogeology is a relatively young field, but the number of hydrogeologists in the state increases every year. Efforts to further understand the ground water conditions are being put forth by ground water consultants, the U. S. Geological Survey, the Colorado Division of Water Resources, the Colorado Geological Survey and many others.

All sectors of the legal and technical fields of hydrogeology need to continue working together to adequately manage this valuable resource. The next major crisis could very well be a water shortage crisis.

HISTORICAL BACKGROUND

The Colorado Doctrine of Prior Appropriation was adopted in the state in the early irrigation days. The Colorado Doctrine, as set forth in the state constitution and judicial decisions, states that: (1) Water in its natural course is the property of the public, and is not subject to private ownership; (2) A vested right (decree) to use the water may be acquired by appropriation and application to beneficial use; (3) The person first in time to use the water has first in right; and (4) Beneficial use is the basis of the right. The constitution provides an order of preferential use which is: (1) domestic, (2) irrigation, and (3) industrial. However, a preferred use does not necessarily obtain a senior priority. The only practical effect of this is to give a preferred use the right to condemn a subordinate use, with fair compensation.

These same principles partly apply to the state's ground water resources. As would be expected, most ground water rights are junior to surface rights. However, the courts have provisions for applying senior surface priorities to wells as long as the necessary compensations are made. Section 148-18-36 of the Colorado Ground Water Management act requires the state engineer to determine whether there is unappropriated water available for any new water diversion and whether the proposed diversion would materially affect the water rights of others. This, the concept of "tributary" water, and the development of new water supplies within the State, as discussed later in this report, is based on the doctrine of prior appropriation.

Of great significance is that a vast portion of ground water is sufficiently remote from the surface water system that it is designated as non-tributary water and can be appropriated without adversely affecting surface water flow. "Tributary" ground water is defined as:
" 'Underground Water' as applied in this act for the purpose of defining the waters of a natural stream, means that water in the unconsolidated alluvial aquifer of sand, gravel and other sedimentary materials, and all other waters hydraulically connected thereto which can influence the rate or direction of movement of the water in that alluvial aquifer or natural stream. Such 'underground water' is considered different from 'designated ground water' as defined in 148-18-2(3)." 148-21-3(4).

GENERAL HYDROGEOLOGY OF COLORADO

The main objective of this presentation is to describe both what is known and what is yet to be understood through adequate investigations. To begin to understand ground water and its occurrence, it is necessary to recognize the basic subdivisions of the complex geology of Colorado.

This presentation describes the various types of water-yielding formations (aquifers) in the state, using some formations as examples. Three basic types of aquifers are discussed. These are (1) Sedimentary formations such as sandstone, (2) Unconsolidated sand and gravel, and (3) Fractured granitic rock.

Although the surface water in the State of Colorado is categorized into Irrigation Divisions based on surface water drainage for surface water administration purposes, the geological formations which underlie that surface water usually are not located in accordance with the Irrigation Division boundaries. Therefore, the following discussion of geology and water-yielding formations ignores the surface water Division boundaries.

Sedimentary Formations

As an example of the sedimentary rocks, the Dakota Group, which includes water-bearing sandstones, underlies essentially 1/2 of the entire State of Colorado. The black areas on the modified State Geologic Map, Exhibit I, show where rocks of the Dakota group are at the surface. The cross-hatched areas of Exhibit I delineate the areas where the Dakota sandstone is shallow enough to be considered a potential source of ground water supplies.

Because the Dakota group is so widespread, it is geologically complicated. In some areas it is an excellent aquifer while in others it yields saline water and hydrocarbons. Nearly all of the lighter areas on Exhibit I are underlain by the Dakota sandstones which exist at depths up to 8000 feet beneath the land surface.

Other sedimentary aquifers in the state include the Dawson, Denver, Arapahoe, Laramie, Fox Hills, Hygiene, Lyons, Green River, Ogallala, and Browns Park formations, and others.

Unconsolidated Sand and Gravel

Stream and river alluvium is the primary source of agricultural well water. Wells in the alluvium of the state's major streams are now regulated by various agencies, but are all subject to the Doctrine of Prior Appropriation. Areas not in designated basins or management districts are administered by the Colorado Division of Water Resources.

Designated ground water basins in the state are located on Exhibit I. The Kiowa-Bijou basin was studied by personnel of Colorado State University; Lost Creek and Camp Creek basins were studied by Willard G. Owens for the

Colorado Ground Water Commission and the town of Akron, respectively; Upper Black Squirrel Creek basin was studied by the Colorado Division of Water Resources; Upper Big Sandy Creek basin was studied by Willard Owens Associates.

Although the boundaries of those basins are based on surface water drainage areas, the deeper Denver basin bedrock sedimentary aquifers beneath the Lost Creek, Kiowa Bijou, Upper Kiowa Bijou, Upper Big Sandy and Upper Black Squirrel Creek basins are not limited to the boundaries of those basins. See Exhibit I. High Plains basins are discussed on pp. 21 to 26.

The unconsolidated sand and gravel of the many stream valleys in the state contain the major portion of the water in the stream systems. New uses of the ground water in transient storage in such deposits in some parts of the state are presently limited because of the strict adherence to the Doctrine of Prior Appropriation.

Fractured Granitic Rock

Most of the mountainous portion of Colorado is underlain by granite and other igneous and metamorphic rock, Exhibit I.

Because these rock types have no effective porosity or permeability, the only way water can be stored or transmitted is through fractures in the rock. The fracture systems in the Rocky Mountain Region are very complex and make analysis and use of this type aquifer difficult. The shallow fractures have been tapped for modest water supplies for many years, and the deeper fractures have been tapped only slightly the last few years.

The hydrogeology of the fractured granitic rock is only slightly understood. Modern drilling equipment and techniques, coupled with downhole geophysical logging and improved analysis techniques are slowly providing us with more knowledge about the water-yielding characteristics of these complicated aquifers.

PRACTICAL RESEARCH AND MANAGEMENT

Areal Ground Water - Surface Water Relationship

Many areas of Colorado are underlain by water-bearing geologic formations which are only slightly understood. Although some areas of the state have been studied by the U. S. Geological Survey and other agencies and consultants, the hydraulic and hydrologic relationships between the surface water systems and the ground water systems are yet to be universally understood. Flows of surface water in major streams have been well documented, but generally, little consideration is given to the underlying geologic and ground water conditions in that documentation of data. Conversely, geologic investigations with respect to rock types, stratigraphy and structure have been somewhat extensive, but generally with little consideration given to hydrology and ground water geology.

Local and Regional Studies

Ground water consultants provide basic research and information to many landowners, land developers and individuals who depend upon ground water supplies. During the course of this work, experienced ground water consultants have gained an understanding of the details of geology, hydrology, surface water and ground water resources in many specific areas throughout the state. Most clients can afford only an understanding of their specific areas and the immediate vicinity, whereas an understanding of the areal and sometimes regional hydrogeologic conditions should be available to the county officials and their planning consultants in order to properly plan the development of their county. The consultant may know enough about the aquifers in many localities to advise on optimum development of water supplies, but on each water development project, interpretation of data is on a detailed scale, in much the same manner as was done in the preparation of some of the exhibits in this report. We define optimum water development as the greatest degree attained or attainable under implied or specified conditions for projected future requirements. Specifications on development must be based on accurate data for specific areas.

We hope that many legislators and some state officials have abandoned their belief that matching funds from federal agencies is the only way to finance investigations of the types needed to more fully understand the water resources of our state. Investigations by the full spectrum of professional people in water resources will provide comprehensive data, interpretations, professional opinions and recommendations toward proper management of ground water supplies. The cost of some studies are beyond local and state agency budgets and federal financing and personnel are needed. However, many studies can best be conducted by consultants under contract to local, state and federal agencies.

The Colorado Division of Water Resources, through both developing professional personnel and contracting with consultants has gained and are developing a better understanding of the relationships between surface water and ground water. This better understanding is helping the State Engineer implement an improved administration of the water resources of the State.

Local Planning Involves Ground Water

Consultants and the planning staff of Routt County, as an example, decided over a year ago that they need to understand the geologic and hydrologic conditions of their county in order to direct reasonable comprehensive planning and development of their county. Routt County has been experiencing a dramatic growth rate during the past few years. Routt County personnel asked Willard Owens Associates, Inc., to prepare a proposal to study the hydrogeologic conditions of Routt County, delineate areas of engineering geologic problems, and delineate areas of ground water resource availability. They felt that this would provide them with sufficient data for use in evaluating proposed land development of properties within Routt County.

In order to understand what should be done to fulfill the request of Routt County personnel, a proposal was prepared and presented to the County. The proposal included Exhibit II, which is a generalized geologic map of Routt County. The proposal has not been decided upon, and the study has not yet been done. It was hoped that Exhibit II would serve as a general guide until a more detailed investigation has been completed. Recent local studies have disclosed geologic conditions somewhat different than those shown in Exhibit II . When the proposed investigation has been completed, decisions made by the Zoning Commission can be based on better documented geologic and hydrologic information. Presently, the County Commission can decide on land development plans only on a local basis, based on information provided by the developer and his consultant for each specific area.

As is the case for the entire State of Colorado, each county needs an understanding of potential water supplies to serve as a basis for comprehensive planning. Potential water supplies include both ground water and surface water.

Water Quality - Aquifer Protection

Week-long conferences and seminars are held on this subject by many professional and technical societies and agencies. This brief presentation is given merely to point out that water quality control and protection of our aquifers are needed in order to protect the vast ground water resources of the State. The Colorado Division of Water Resources is now requiring that water wells be completed in only one aquifer in an attempt to keep the natural aquifers separated. This is a major step toward preventing mingling of waters of variable qualities and potential contamination of aquifers of high quality water.

Various county health departments and the Colorado State Health Department have implemented plans or are preparing plans toward water quality monitoring in order to delineate sources of ground water pollution. Such data is needed for enforcement of the water quality standards established by the various governmental agencies.

Rules and regulations adopted and enforced by the Colorado Board of Examiners of Water Well Contractors and Pump Installers require well completions which will protect the ground water aquifers as much as possible. Those regulations also require that test holes be plugged and/or completely filled in order to protect the aquifers. Unfortunately, drillers of holes into or through the aquifers, other than water well drillers, are not regulated in such a way that the aquifers are protected from other types of exploratory drilling.

These are only a few of the many points that need to be raised with respect to the quality of water of our aquifers and the protection of the ground water from pollution and contamination. Fortunately, governmental agencies, water well contractors and industry in general are cooperating in the protection of our ground water resources. The current interest in protection of our environment must include interest in the quality of our underground water.

Ground Water in Alluvium - Nonbeneficial Losses

Shallow ground water which occurs in sand and gravel alluvium, is generally a direct portion of the surface water system. Usually, it is simply the underground part of the stream, and withdrawal of the shallow ground water will ultimately affect the quantity of water in the stream and available to surface water diverters.

This shallow ground water is being administered now as surface water, and so long as it occurs in the proximity of the surface stream, it should be administered as such. This doctrine was affirmed in the Colorado vs. Felhauer lawsuit, decided upon by the Colorado Supreme Court.

Unfortunately, past and current surface-water-oriented thinking has extended this tributary concept into the far reaches of both generally dry stream beds and valleys of high natural evaporation and transpiration losses. The withdrawal of water from the alluvium by wells miles away from the surface streams and in such remote areas will not materially affect the flow rate in distant streams. This situation is significant in many large areas within the South Platte and Arkansas River drainages.

The situation is compounded because of compacts and treaties in which the State of Colorado is a party, involving the major rivers flowing out of the State. At the time Colorado entered these agreements, there was more than enough water for our in-state needs. Now, although the water is greatly needed, we are committed to allow millions of acre-feet to flow to neighboring states and the Republic of Mexico. It would be difficult, to say the least, to have these River Compacts and treaties re-organized to give Colorado a larger share in the water that originates within the State. Perhaps similar situations regarding ground water can be avoided.

Currently, adjudicated irrigation wells which have been in operation over twenty years, and which are over twenty miles from flowing streams, are being or ultimately will be shut off during water short years. This is the present policy in spite of the fact that hydrogeologic conditions are such that many of the wells will have little or no affect on the distant surface flow.

Wet years will rebuild the water table between many of the remote wells and the streams. Also, in some areas the water available to the wells will be lost to nonbeneficial evaporation and transpiration if not withdrawn and used by the well owners.

Proper management of water in these aquifers with a shallow water table would reduce nonbeneficial water losses to evaporation and transpiration. Such management would allow salvage of that lost water through use of wells to maintain water tables below the evapotranspiration zones. At present, such management plans are presented as plans of augmentation through the water courts on a project subdivision development basis.

This characteristic of "remoteness" of many shallow aquifers was one of the bases for designation of Lost Creek, Camp Creek, Kiowa-Bijou Creek, Black Squirrel and Upper Big Sandy ground water basins. It is unfortunate that this concept is not applied to administration of water in areas outside of the designated ground water basins.

One example of this is the Barr Lake-Beebe Draw area north of Denver, located as shown on Exhibit III. Exhibit IV is a cross-section which shows the relationship between the ground water in the sand and gravel and the surface water in the lakes, canals, sloughs and streams. The cross-section, when located on U. S. Geological Survey topographic maps (not included in the text of this presentation),shows it passes through large areas indicated as marsh areas, where the water is at or near the surface. In these areas, many acre-feet of water are lost annually to non-beneficial consumption by evaporation and transpiration in water-logged land.

The Colorado Division of Water Resources has determined that the water supply in the alluvium between Barr Lake and Milton Reservoir is "unreliable". They claim the wells will be shut off three days a week during irrigation seasons and ultimately will be shut off permanently due to administration based on the surface water prior appropriation policy.

The rationale of this administrative procedure in the Barr Lake-Beebe Seep area, and in similar areas in the state, is questionable. Either the application of the statutes or the statutes themselves need to be changed to allow optimum use of the water resources by modifications of the doctrine of prior appropriation. However, the administrators need more data on the hydrogeology of such areas, much of which is being accumulated by Federal and State agencies. In some cases, details of the hydrogeology of areas have been acquired by consultants under contract with landowners, developers and state or local agencies.

Areal investigations by consultants under contract to agencies such as the Division of Water Resources, the Colorado Water Conservation Board, and the Colorado Geological Survey would provide geologic and hydrologic data bases for optimum management of the ground water within each area investigated. The results of such investigations and the consultants' opinions and recommendations could then be critically reviewed by peer professionals for the preparation of a multi-bases document for presentation to the legislature for their consideration toward workable legislation.

Ogallala Formation - High Plains Basins

The Ogallala formation is the primary aquifer of the Northern High Plains and, to a lessening degree, the Southern High Plains designated ground water basins, Exhibit I . The Ogallala formation, which is a semi-consolidated sedimentary formation in the eastern portion of the state, is made up of layers of clay, silt, sand and gravel. The streams which cross this formation in the Northern High Plains carry surface water from the state, largely in the Republican River drainage system and, to some extent, in the Arkansas River drainage.

While employed by Woodward-Clyde-Sherard & Associates, Inc., Willard G. Owens and other personnel conducted an investigation of the Northern High Plains to determine the general geologic and hydrologic characteristics of the area to determine whether the area qualified to be designated as a ground water basin. The area was so designated and is named the Northern High Plains Designated Ground Water Basin. For all practical purposes, the Ogallala formation forms the only major water-bearing formation in that basin. Unconsolidated sand and gravel, as well as the Arikaree, Brule and Chadron formations are good aquifers in portions of the basin.

The Southern High Plains was studied by R. W. Beck and Associates for the same purpose. In the Southern High Plains Basin, the major aquifers are the Ogallala formation, the Dakota and Cheyenne sedimentary formations, and unconsolidated sand and gravel in stream valleys.

Much work has been done in the two High Plains designated ground water basins and much ground water has been developed and put to use. Many more exploratory and investigative programs must be conducted to understand the properties of the Ogallala formation or any other formations of the state in order to adequately manage, administer, develop and utilize the ground water resources within the formations.

Within most of the designated ground water basins and in other areas of the state, the rate of withdrawal of ground water exceeds the rate of natural recharge; i. e., water levels are declining. This situation is often referred to as "ground water mining".

In our opinion, rates of "mining" of the ground water in the Ogallala formation and in many other geological formations of the state have been exaggerated, even by highly technical people who have interpreted initial artesian, or pressure, losses as depletion of water. Detailed investigations for individuals and corporations in the Northern High Plains have disclosed that many of the numerous sand and gravel layers in the Ogallala formation contain water under pressure. This pressure, which is recorded as water levels in wells, is rapidly relieved during initial pumping, but the drop in pressure (or lowering of water level in wells) slows with time.

This opinion is based mostly on results of irrigation wells completed and tested under our direction in the Northern High Plains, primarily, Yuma County. Correlation of strata with low dip eastward is good over many miles. Recharge to individual sand and gravel strata in the western portion of the Ogallala formation, combined with the eastward-dipping strata and confining clay layers, creates artesian conditions in the lower portions of the formation in the eastern areas.

The coefficient of storage of the Ogallala ranges from 0.003 to 0.29, further suggesting that portions of the aquifer are under artesian conditions while other portions are under water table conditions. The specific yield of the Ogallala in many areas far exceeds the coefficient of storage determined by pumping tests, indicating artesian pressure.

In Colorado Ground Water Circular No. 11, "Pumping Tests in Colorado", 1965, the coefficient of storage of an aquifer is defined as "the volume of water it (aquifer) releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Under water-table conditions, the coefficient of storage is nearly equal to the specific yield, which is defined as the ratio of (1) the volume of water a saturated material will yield by gravity to (2) its own volume." Results of pumping tests and histories of water levels indicate that the mapping of water pressure levels as free water tables is not warranted.

Unfortunately, published maps imply exhaustive depletion of water resources in a large portion of the Northern High Plains. Use of the color "red" on maps to delineate those areas of greater water pressure declines for the past eight or nine years has resulted in those areas being considered as critical areas. While water pressures decline, often large quantities of ground water are still economically available for use.

Within a portion of the "red zone" on published maps, we plotted water pressures as recorded by Colorado State University and/or the U. S. Geological Survey on a year to year basis. The plotting of the water pressures, or water levels in wells, show a relatively fast decline initially and then a deceleration in decline in the more recent years. Declining water pressures in the formation, and to some extent mining of water, are occurring as the water is withdrawn, but the water is used to support the economy essential to the entire plains area.

Concern over the initial declines has resulted in very restrictive state policy and local regulation on ground water development in most of the Northern High plains. Virtual termination of irrigation well permits has occurred in much of the basin, yet insufficient aquifer data have been acquired to fully understand and properly manage the water in the aquifer.

Field testing the aquifer and sampling to determine the specific yield (not coefficient of storage) is needed to supplement the basic work being done by the U. S. Geological Survey.

Geologically, the water-bearing and water-yielding characteristics of the Ogallala aquifer are not the same throughout the area of 9500 square miles of the Northern High Plains. However, the same "average" factors which govern whether or not a man can obtain a well permit are used throughout the entire basin.

Detailed investigations within specific areas of the Ogallala formation have provided sufficient data to show that the characteristics of the formation are not the same throughout the 9500 square mile area and that the water resources in some areas are not being put to optimum utilization. These data have been presented to the state through hearings in the form of formation samples, geophysical logs, and results of pumping tests. However, it has been expedient from an administrative standpoint to assume fixed parameters for the entire area rather than administer the water on the basis of its availability. Also, little has been attempted in the way of inducing natural recharge to place more of the periodically surplus surface water underground for future use. This could, at the same time, alleviate flooding problems which are common with normally "dry" streams in eastern Colorado. Colorado State University personnel conducted recharge research on the Arikaree

River near Cope, Colorado. More investigations on the feasibility of artificial recharge are advisable in this important aquifer.

Although the "average" factors are applied in the 9500-square mile area, no programs toward improvement of recharge have been implemented, and limited practical investigative projects are underway. We have discussed this with the staff of the Ground Water Commission, and we hope that they will deviate from their dependency on estimates given in preliminary reports and on theoretical approaches by the U. S. Geological Survey. In addition to the theoretical approaches, a practical drilling, sampling and testing program needs to be undertaken to determine the aquifer characteristics for specific areas.

Browns Park and Other Formations - Northwest Colorado

Because the entire extent of the Browns Park formation outcrop has not been mapped in Routt County, only the Browns Park formation area in Moffat County is shown on the State Geologic Map, not included in this report. The Browns Park aquifer serves several small communities in Routt County and also serves some commercial wells in Moffat County. We understand that the new State Geologic Map (still in process) will show much more detail on this and other formations.

Results of well drilling activities in the Routt County area have disclosed that the Browns Park formation is highly variable in thickness and, accordingly, yields of water wells are highly variable. Well yields from 5 to 200 gallons per minute have been recorded in the Browns Park formation near Steamboat Springs. Some of the wells have been completed and flow under artesian pressure.

The Browns Park formation differs from aquifers in the Denver basin in that the Browns Park is very irregular in its shape and thickness. As a result of investigations, much has been learned about the Browns Park formation; however, much is left to be discovered about its thickness, storage capacity, water quality, and its rate of recharge.

Recent field investigations suggest that the Browns Park formation is suited to artificial recharge by gravity infiltration or injection wells. Utilization of recharge facilities can extend the life of any aquifer and provide for a flexible water conservation program in years to come. Unfortunately, no facilities such as this are yet being considered by either the state or Routt County.

When a Routt County geologic investigation has been completed, much more will be known about the adequacy of the Browns Park formation as a water supply source to that county. Until more detailed data are obtained through well logs and testing, the results of well drilling in the Browns Park will be of limited value to the County in evaluating its overall water resource.

Whether or not ground water in storage in the deeper portions of the Browns Park formation is hydraulically connected to the surface water system in such a manner that its withdrawal in reasonable quantities will adversely influence the rate or direction of flow of surface water is a current problem facing state water administrators. Wisely, the Routt County planners have required test wells, the geophysical logs of which have provided valuable knowledge of the formation. More will be required to accumulate sufficient data to adequately manage and administer the water in the surface water and ground water systems.

Other aquifers in northwest Colorado are the Wasatch and Mesaverde formations. Little is known about the quantities and quality of water available from these sources, and development of water from the Green River and Wasatch formations in Moffat and Rio Blanco Counties is in its infancy. Both of those counties will need a total assessment of their ground water reserves to satisfy future growth.

Much hydrogeologic data relative to oil shale deposits are being compiled and interpreted. The U. S. Geological Survey hydrogeologists have expended tremendous effort to provide such data to the public, governmental agencies and industry in order to share their knowledge of the complex ground water systems. This work has been a good example of coordination of effort by federal and state agencies and industry, through which the public will benefit. The ground-water monitoring planned in the oil shale tracts in the Piceance Basin, shown on Exhibit I, will result in much more data on the areal aquifers. This will be another example of coordination of effort among ground-water consultants, state agencies and federal agencies.

HYDROGEOLOGY OF THE DENVER BASIN

The Denver basin is a geological structural basin which lies beneath all or parts of Boulder, Weld, Morgan, Jefferson, Adams, Denver, Arapahoe, Douglas, Elbert and El Paso Counties. The basin, shown on Exhibits I and V as used in this report, is the outer limit (lower formation boundary) of the Fox Hills formation, which dips inward toward the center of the Denver Basin.

The bedrock, or confined*, aquifers in the basin include the sands and sandstones of the following sedimentary geologic formations in order of their age and position, starting with the older and deeper to the younger and shallower: Fox Hills, Laramie, Arapahoe, Denver and Dawson. Please refer to Exhibits VI, VII and VIII.

Data on surface and subsurface configurations of the basin have been published by governmental agencies and individual investigators. One of the more useful publications to the field of hydrogeology is a map showing the approximate configuration of the top of the Laramie-Fox Hills aquifer. This is a joint publication of the Colorado Division of Water Resources and the U. S. Geological Survey, authored by J. R. Romero and E. V. Hampton of the respective agencies. Surface data are available from several other publications, most notably Reichert, (1955).

Geophysical logs of oil and gas wells are available

*A confined aquifer is a water-yielding geologic layer or series of layers which contains water under pressure due to a confining overlying layer.

from the Colorado Oil and Gas Conservation Commission and several commercial geophysical log libraries. The geophysical log library of Willard Owens Associates, Inc., with detailed information on water wells completed in the aquifers, is an additional source of data.

Exhibit V, Location of Denver Basin, shows the outer limit of that portion of the basin considered in this report. The outer limit, bottom, of the Fox Hills aquifer is not easily discernible in the field in most areas. The outer limit of the Fox Hills shown on Exhibit V was taken from the Geologic Map of Colorado, U. S. Geological Survey.

Configuration of the Denver Basin

The configuration of the portion of the basin considered here is represented on Exhibit V. The general stratigraphy and structure of aquifers and other sediments in the basin are represented on Exhibits VI, VII and VIII.

The top of the Laramie-Fox Hills aquifer becomes higher in altitude in all directions from an area near the Cherry Creek Reservoir at the southeast edge of Denver, where it is approximately 1800 feet below the surface. From that area, the top of the aquifer increases in altitude to more than 5500 feet along the west and southwest edges of the basin and then approximately 6000 feet along the southeast boundary of the basin. Maps showing the approximate configuration and depth of the top of the Laramie-Fox Hills aquifer, Denver basin, were prepared by Romero and Hampton. The Laramie-Fox Hills, Laramie, Arapahoe, Denver and Dawson aquifers slope downward toward the center of the basin from all directions.

On Exhibit V are trace lines A-A' and B-B' which are the locations of the geologic cross-sections discussed in this section. The two cross-sections, Exhibits VII and VIII, were compiled from geophysical logs and other available surface geology. All the major Denver basin bedrock aquifers are shown on the cross-sections. The geophysical logs used in the cross-sections were obtained from the Oil and Gas Conservation Commission, commercial log libraries and from our library of logs of water wells which have been compiled since about 1955.

The geophysical logs of the water wells show much more detail of the water-bearing formations than do the logs of oil and gas wells. The reason for less detail on oil and gas logs is that the major geophysical logging companies and oil and gas companies are usually not interested in the shallower formations and withdraw the geophysical logging equipment at speeds too great for detailed logging of the geology within 2000 feet of the surface. Proper logging rates to adequately determine the electrical and other characteristics of the formations and aquifers are 20 to 40 feet per minute. Also, the shallower aquifers are often not logged at all, since many of the oil and gas companies set casing through the aquifers to minimize chances of contaminating the water in the aquifers. Although the cross-sections are self-explanatory, we would like to point out the following interpretations.

Continuity and Correlation of the Bedrock Aquifers

Exhibit VII is a cross-section which shows the geologic formations and aquifers beneath line A-A' on Exhibit V, extending 71 miles from just north of Golden to about 12 miles east of Byers. The vertical scale is exaggerated 52 times so the details of the logs can be seen on an exhibit of reasonable length. The geophysical logs represent holes less than one foot in diameter, not the proportional width of the logs on the horizontal scale. The ground surface and the formations are much flatter than the exaggerated vertical scale on Exhibit VII implies.

The major sands of the aquifers are shaded on the geophysical logs to show both the overall aquifer continuity and the detailed variability of the sands within the aquifer. Portions of the aquifers are present at or near the surface, usually under soils, at the edge of the Denver basin, as demonstrated on the right side of Cross-Section A-A', Exhibit VII.

Exhibit VIII is a cross-section that shows the geologic formations and aquifers beneath line B-B' on Exhibit V for a distance of 119.8 miles, extending from just west of Colorado Springs northward to about 2 miles southwest of Greeley. The vertical scale of cross-section B-B' is exaggerated 83 times, so the ground surface and formations are flatter than Exhibit VIII implies.

Of particular interest and significance in the preparation and interpretation of cross-section B-B' was the knowledge gained in the Monument area. This area is represented as the topographic high at the water well log in Section 1, T. 11 S., R. 67 W., on Exhibit VIII. The deep water well, constructed in 1969, was thought to be completed in the Laramie-Fox Hills aquifer. Recently, Division of Water Resources personnel directed a test drilling and geophysical logging program in extending the depth of a new water well for the town of Monument. They interpreted the data as we had in 1969 and assumed the sands encountered to be the Laramie-Fox Hills aquifer. Much of the sand encountered is salt-and-pepper in color, which is typical of the Laramie-Fox Hills sand. We have recently encountered salt-and-pepper sand in the Arapahoe formation west of Denver.

Two of our ground water geologists questioned previous log interpretations, so additional geophysical logs of oil and gas exploratory holes were purchased for additional information. The additional log shown on cross-section B-B' shows the correct positions of the aquifers in the area. Now we know the approximate depths through the aquifers in that area, and much more water is available for development from the Dawson, Arapahoe and Laramie-Fox Hills aquifers than was previously believed.

More detailed studies can be expected to disclose additional information on the aquifers. Current state requirements of geophysical logs, along with driller's and geologist's logs of deep water wells are adding to the volume of available data on the basin aquifers. Sophisticated sampling and testing of the aquifers would provide even more information on the quantity and quality of water stored in the aquifers in representative areas of the Denver basin.

Ground Water Storage in Confined Aquifers

Preliminary estimates based on insufficient data in the 1960's were that the Laramie-Fox Hills aquifer stores 60 million acre-feet of water within the Denver basin. Also, preliminary estimates were that the Dawson, Denver and Arapahoe aquifers contain 80 million acre-feet of water.

Based on data compiled as part of this presentation, our present conservative estimate is that 308,000,000 acre-feet of water are stored in the Denver, Arapahoe, Laramie and Fox Hills aquifers. We estimate that the Dawson aquifer contains an additional 33,000,000 acre-feet of stored water for a total of 341,000,000 acre-feet of water stored within the major sands of the bedrock aquifers of the Denver basin. Calculations of storage were made by measuring sand thickness in each aquifer as recorded on the electrical logs along the geologic cross-sections A-A' and B-B', and other representative data points. Areal extent of the aquifers and specific yields used by the Division of Water Resources were also used in the calculations. Approximately one-half of the water in storage can be considered at this time as economically recoverable. The primary assets of the bedrock aquifers are their storage capacity and their availability for recharge during wet periods of low water demand.

The Dawson aquifer poses a unique calculation problem because its upper contact is topographically controlled. Within the Dawson aquifer, a total of 31 gas and oil logs and water well logs were analyzed for net sand content. Using these data points, a preliminary net sand contour map was constructed and used to determine water in storage.

Shown on Exhibit V are the locations of approximately 140 data points we used in preliminary calculations. All of the data points need to be studied in detail to determine the quantity of water stored in each aquifer. Adequate test drilling, sampling, geophysical logging and analyses are needed to determine more accurately the specific yields of the aquifers. All of the aquifer characteristics need to be determined in order to calculate the volumes of water stored in the aquifers. Current state-required well use rates are recorded and compiled. With accurate storage volumes and use rates, the ground water can be managed to protect those with vested rights to use the ground water.

In addition to the water stored in the sands, there is much water stored in much of the shales interlayered with the sands. In the future, as the hydrostatic and lithostatic pressures are reduced, much of the water in the shale will migrate into the sand aquifers and be available for use. We have not attempted to calculate the quantity of water available in the shales since much is yet to be learned about the water-holding and water-transmitting characteristics of the Denver basin shales.

Also, we have not attempted to calculate the volume of water stored in the many minor sand layers in the aquifers. The cross-sections delineate only the major sands.

Natural Recharge to Confined Aquifers

The water-bearing sands which make up the bedrock aquifers are exposed at the surface, or underlie the soils or water-saturated alluvium in the streams. The major streams within the Denver basin region are shown on Exhibit V. They are the South Platte River, Cherry Creek, Box Elder Creek, Kiowa and Bijou Creeks, Fountain Creek, Black Squirrel Creek and Big Sandy Creek. The topographic high within the region, with respect to surface drainage, is near the junction of Douglas, Elbert and El Paso Counties. Surface water drains outward in all directions from this point as shown on Exhibit V. The South Platte River drainage system alone includes hundreds of square miles of mountainous terrain west of the Denver basin region.

All of the streams shown on Exhibit V and others not shown cross surface exposures of the aquifers and have recharged them for thousands of years. The quantity of water that seeps into these aquifers as recharge is unknown. We know that the recharge rate is low, based on the characteristics of the soils and percolation tests run in various areas, but the areas of recharge are quite extensive. No test drilling or infiltration rate determinations have been attempted to locate the better recharge areas. This type of field work needs to be conducted. Maximum coordination of effort and cooperation among the hydrogeologic consultant, the drilling contractor and state administrative agencies will be a necessity if the aquifer characteristics are to be determined accurately for use in ground water management.

The dip, or slope downward, of the aquifers from southwest to northeast is greatly exaggerated on Exhibit VIII, Cross-Section B-B'. However, the piezometric (water pressure) level of the Laramie-Fox Hills aquifer slopes downward to the north-northeast (Kuhn, 1968). We believe the natural piezometric level of the other aquifers also has a northeast trend. This means that the natural areas of recharge to the aquifers is in the south and southwest portions of the Denver basin.

As water is withdrawn from the aquifers in the central part of the basin, piezometric levels will change and recharge will take place at various places along the perimeter of exposure of each aquifer. Control of surplus surface water over those exposures could provide additional recharge to the bedrock aquifers.

Artificial Recharge to Confined Aquifers

Hopefully, induced or artificial recharge and flood control facilities to promote recharge will become additional assets of this resource. Development of greater recharge should be investigated in the near future to utilize surplus surface water and take advantage of the vast storage capacities of the aquifers. Much more is yet to be learned to determine the natural rates of recharge to the aquifers and how surplus surface water during wet seasons and flood periods can be used to increase the natural recharge. Discussion of the details of what would be required to make these determinations is beyond the scope of this presentation.

We understand that an investigation into the feasibility of artificial recharge to the Dawson formation is now underway by the U. S. Geological Survey.

Administration of Denver Basin Bedrock Aquifers

Exhibit I delineates those portions of the designated ground water basins which overlie the Denver basin. The administration, management, development and use of the ground water in the deeper aquifers is somewhat different within each designated basin and each ground water management district, whereas the remaining area is under the direct administration of the Division of Water Resources. The geologic and hydrogeologic characteristics of the bedrock aquifers in no way correlate with the political boundaries of counties, designated ground water basins or ground water management districts. Therefore, the bedrock aquifers need to be managed in a consistent manner throughout the Denver basin, and not under 3 or 4 different sets of regulations except as made necessary by the characteristics of the aquifers themselves. Some of the districts are adopting criteria set forth in Senate Bill 213. This is helping to standardize the management of the bedrock aquifers.

The North Kiowa-Bijou Ground Water Management District conducted a geologic study of the bedrock aquifers. The purpose was to obtain sufficient hydrogeologic data to serve as a base for their rules and regulations for management of the deep ground water. A similar, but more general, study was done of the Big Sandy Creek drainage basin under contract for the Division of Water Resources. Both studies were conducted by Willard Owens Associates.

BEEBE DRAW - ADAMS AND WELD COUNTIES

Beebe Draw is a combination of natural drainage, importation of surface water, sub-surface ground-water flow and high evapotranspiration. Beebe Draw, located as shown on Exhibit III, encompasses a surface-water drainage area of approximately 176 square miles, extending from Barr Lake southeast of Brighton northward to the South Platte River in the vicinity of Kersey.

The lateral boundaries of the drainage basin roughly follow Speer Canal on the west and Neres Canal on the east.

General Geology

Beebe Draw is located in the north-central portion of the Denver basin and is underlain by the Denver and Arapahoe formations in the vicinity of Barr Lake and the Laramie formation in the vicinity of Milton Reservoir. Those bedrock formations are overlain by a soil mantle made up of clay, silt, sand and gravel, ranging from a few inches thick along the lateral boundaries to more than 100 feet thick in the central part of Beebe Draw. Sand and gravel in the central part of the draw is water-saturated, providing a good storage reservoir for ground-water supplies. Sand and very sandy soil deposited by ancient winds dominate the surficial conditions between Hudson and the lower Latham Reservoir. Those seeps and leaks from those canals adds to the natural ground water within Beebe Draw. Much of the irrigation water applied within the drainage area also migrates downward and adds to the natural ground water within the draw.

The configuration of the bedrock surface and movement of ground water in the sand and gravel deposits within Beebe Draw are shown on Exhibits III and IV. Unfortunately, there is not enough information on water table and bedrock surface elevation to accurately define the hydrogeologic conditions within Beebe Draw, especially in the Barr Lake area and north of Hudson, where the Beebe Draw and Box Elder Creek drainages converge, and then, diverge.

Evaporation and Evapotranspiration Losses

It is apparent that more water is supplied to the water-saturated sand and gravel of Beebe Draw than can be transmitted through those materials northward to the South Platte River. Because of this, the water table is close to or above the ground surface in many areas north of Hudson, such as Colfer Slough. Field inspection and aerial photographs of the area show that the water table is at or very near the surface in many areas from Barr Lake northward to the South Platte River in both the Beebe Draw drainage and the Box Elder Creek drainage. More detailed information is required to calculate non-beneficial water losses of the area.

Such information is necessary to adequately appropriate, administer, and manage the surface water and ground water supplies of Beebe Draw. Our preliminary calculations show that more than 9000 acre-feet of water is lost non-beneficially to evaporation and evapotranspiration annually within the Beebe Draw area. These water losses represent a volume of water which could be put to beneficial use by means of high-capacity wells completed in the water-saturated sand and gravel of Beebe Draw.

A complete hydrogeologic investigation will be necessary to understand the details of the hydrogeologic conditions within Beebe Draw. Existing information is sufficient to outline a detailed exploratory program designed to provide additional data for adequate administration and management of the water supplies within Beebe Draw.

Vested water rights must be protected in Beebe Draw and all other surface drainage systems of Colorado. However, non-beneficial losses for the sake of strict adherence to the surface water appropriation doctrine cannot be wise management of our water resources. Requiring that irrigation well owners purchase surface water rights in order to pump ground water that will quite likely be lost to non-beneficial consumption anyway is a burden on taxpayers which, in many cases, can be removed.

THE SAN LUIS VALLEY

The water-saturated clay, silt, sand, gravel and lava flows of the San Luis valley in south-central Colorado make up one of the largest aquifers in the United States. Although the hydrogeology of the valley and the relationship between the ground water and the surface water are not adequately understood, most of the area is presently considered by the State as a single water system for administrative purposes. Although geologists with Federal resource agencies and with consulting firms have provided good preliminary information on the shallow ground water system, much investigation is needed to learn the hydrogeologic characteristics of the many surface water and the ground water systems that make up the hydrogeology of the San Luis valley.

Willard Owens Associates, Inc., has been working in the valley and have run electrical and temperature geophysical logs in holes to depths of over 2500 feet. Also, we have been working with personnel of the Colorado Division of Water Resources in electrical and temperature logging of test wells being drilled by the Rio Grande Water Conservation District. The deeper hydrogeology of the valley is being investigated slowly, and it is hoped that the efforts of the Colorado Division of Water Resources, the Rio Grande Water Conservation District and geophysical logging by Western Well Logging, Inc.

and others, and consulting work results in an understanding of the surface water - ground water relationship in the valley. This will be needed to provide optimum management, administration, development and use of the water resources in the valley.

Location and Physiography

The San Luis valley in south-central Colorado is bordered on the south, for the purposes of this presentation, by the New Mexico-Colorado border, to the east by the Sangre de Cristo mountains rising to 14,000 feet, and to the west by the San Juan mountains rising from 9600 to 14,000 feet. The valley is characterized by low topographic relief, sloping gently from west to east. The average elevation is 7700 feet. The San Luis hills rise 500 to 1000 feet above the valley floor in the southern part of the valley. The valley is approximately 25-35 miles wide and 115 miles long, comprising a total of about 3500 square miles in portions of Saguache, Conejos, Costilla, Rio Grande and Alamosa Counties.

The southern half of the valley is drained by the Rio Grande River and the northern half drains into the so-called Closed basin. The valley has an arid climate with less than 9 inches of precipitation per year.

Geology

The San Luis valley is a structural basin bordered by faults on the east and west. The structure and faulting on the west side of the valley is largely obscured by overlying volcanic rocks. The San Luis valley probably was a highland area throughout much of geologic time and did not begin to receive sediments until approximately 13 million years ago.

The Sangre de Cristo mountains to the west are largely comprised of very old granite-like rocks. The San Juan mountains to the west are largely younger volcanic rocks. (see Exhibit IX).

The San Luis valley was formed as a result of the slow uplift of the Sangre de Cristo mountains on the east and the drowndrop of the exposed granite rocks of the valley along a complex series of faults. As the faulting occurred, water-saturated silt, sand and gravel eroded from the uplifting mountains filled the valley. Intermittently, volcanic flows from the San Juan mountains to the west covered portions of the valley and were in turn buried as sediment continued to fill the valley.

Oil test wells and geophysical gravity data indicate that as much as 32,000 feet of unconsolidated sediments may be present in portions of the valley. The gravity data indicates there is a series of faults in the basement granite along which separate blocks of granite were raised and lowered relative to one another. The depth to the granite varies, depending upon the location in the valley.

Hydrogeology

In the past, the valley has been divided into two aquifers, according to the hydrogeologic conditions. They are the unconfined and confined aquifers. The underlying confined aquifer is separated from the unconfined aquifer by a series of clay beds and volcanic flows. However, neither the clay beds nor the volcanic rocks are continuous throughout the basin. Thus, there are places where the two aquifers are locally inter-connected. The unconfined aquifer extends from the ground surface to a depth of approximately 200 feet. The ground water table throughout the valley is generally less than 12 feet below the ground surface.

To augment the amount of surface water used for irrigation, numerous wells have been constructed in the unconfined aquifer. These wells yield approximately 1000 gallons per minute.

Recharge to the unconfined aquifer is largely a result of subirrigation and seepage from canals and streams. It is believed that little recharge is from precipitation because of the small annual amount in the valley proper. It is thought that, without the annual recharge through subirrigation, the unconfined aquifer would be dried up in a short period of time. The unconfined aquifer is largely made up of silt, sand and gravel and is generally very permeable. However, the permeability varies with location.

The confined aquifer extends from the base of the unconfined aquifer at approximately 200 feet to the granite at an average depth of approximately 7000 feet. Wells constructed in the confined aquifer are normally 800 to 1000 feet deep and flow 1000 to 4000 gallons per minute under artesian conditions. The piezometric, or pressure, water level of the confined aquifer ranges from the ground surface to 40 or 50 feet above the ground surface. The U. S. Geological Survey has conservatively determined the storage in the confined aquifer as 2 billion acre-feet. They also estimate that water is withdrawn from the confined aquifer at approximately 100,000 acre-feet per year. At this rate, assuming no recharge, enough water is in storage in the confined aquifer to last approximately 20,000 years, although much of the water lies thousands of feet beneath the land surface. The quantity of water which can be withdrawn economically has not been determined.

Recharge to the confined aquifer occurs at the edges of the valley through streams, snow runoff and precipitation. Recent work in the San Luis valley by Willard Owens Associates, Inc., has indicated that there are anomalous zones of very cold water which may indicate permeable zones separated from the overlying and underlying sediments and not directly related to surface or deep aquifer water. However, this might indicate that some zones allow water to migrate from the surface much more rapidly than is commonly believed. If this is indeed the case, the anomalous cold water could indicate that more significant amounts of water recharge the aquifers than has been taken into account. One opinion is that a large part of the recharge may be occurring in the San Juan mountains, a long distance from the valley, where the water is recharging between lava flows and migrating to and stored in the valley. At the present time, it is impossible to determine how much water is actually being recharged annually and how much is in storage. It is believed by some that extensive development of the confined aquifer would induce more recharge and thus decrease the annual flow in the surface streams. This theory is apparently supported by the measured decrease in the surface flow of the streams following partial development of the confined aquifer. However, previous studies have not been extensive enough to completely consider all of the losses from the surface stream that are occurring. It is conceivable that surface stream losses are not directly attributable to recharge going into the confined aquifer.

Water Problems

To date, management of the water resources in the San Luis valley has been based upon very little information. While there have been many studies on the hydrogeologic characteristics of the unconfined aquifer, very little is known about the confined aquifer. It is the confined aquifer that holds the most promise for development in the future due to the large amount of naturally stored water. We feel that to most efficiently manage the available water, more information must be obtained on the confined aquifer.

In the past, it was believed that the valley may be all one aquifer and tributary to the surface streams. However, our work in the valley indicates that there may be additional aquifers beyond the two that have been generally recognized. These additional aquifers are contained in what has been lumped as the confined aquifer. But while these additional aquifers may not be continuous over a large area, they can be recognized in specific areas. This is evidenced by geophysical logging and well completions which show contrast between the different water-bearing zones.

In the past, many of the wells have been left at open discharge with no means of control and many wells have been abandoned without plugging the well to prevent loss of pressure and water. During the development of wells penetrating both the confined and unconfined aquifers, inadequate drilling procedures have resulted in the inter-connection of the confined and unconfined aquifers in many places. These procedures have allowed huge amounts of water to be wasted annually. They are the cause of flooding of many areas and deposition of salts in the soil. In addition to the flooding that occurs, large amounts of water are lost through evaporation.

The practice of subirrigation, while it may be inexpensive, tends to raise the water table to the root zone, thus increasing evapotranspiration. Although specific studies have not been conducted to determine the amounts lost to evapotranspiration, the volume of water lost is considered to be substantial.

Water Resource Management

Water resources in the San Luis valley are currently administered through the practice of severely limiting any future ground water development. This is being done on the basis of the idea that the aquifers are connected to the surface system and that wells are damaging prior vested surface water rights. While this may be at least partially true, we believe that it is unwise to severely limit the development of the vast amount of water in storage in the San Luis valley when the water could be put to beneficial use.

Further studies need to be done to determine the inter-connection between the two systems as well as the specific aquifer characteristics. We believe that test drilling and well testing should be conducted as a portion of these studies, as has been initiated by the Colorado Division of Water Resources and the Rio Grande Conservation District, under the direction of consultants who are familiar with the hydrogeology of the valley. Following completion of these studies, wiser decisions will be possible to better manage this resource. It may be apparent after the studies that the losses in stream flow today are not due to recharge of the confined aquifer, but to some other source.

The following recommendations should be considered: (1) The practice being conducted by the Rio Grande Conservation District of plugging test holes and abandoned wells be emphasized and encouraged; (2) All wells be properly designed and constructed and equipped with shut-off valves and totalizing flow meters to monitor and control the amount of water withdrawn and to control open discharge to non-beneficial uses; (3) Install a series of observation wells in the confined aquifer to determine the overall effects of ground water withdrawal in the valley; (4) It also may be apparent that the practice of sub-irrigation should be at least in some places replaced with sprinkler irrigation. This would tend to lower the water table below the root zone, thus reducing non-beneficial evapotranspiration losses; (5) It may also be possible to artificially recharge the confined aquifer in the San Luis valley and use it as a large storage reservoir. Studies and programs similar to this have been successfully conducted in Pakistan and Israel.

Very definitely, personnel of Willard Owens Associates, Inc., believe that a resource as necessary, vast, and vital as this should be utilized to its optimum extent. It may become necessary to alter present thinking of tributary versus non-tributary water to protect prior vested rights to the point that it may be better to consider full utilization rather than preferential utilization. In our opinion, serious consideration should be given to augmentation of surface flow by use of deep wells completed in the vast storage of the artesian aquifer.

HYDROGEOLOGY OF FRACTURED GRANITIC* ROCK

The mountain building process resulted in many areas of primary, secondary and tertiary fractures and faults throughout the mountains. The exact quantities of water stored in those rocks are not known and in most areas, the relationship of ground water in the rocks to the surface water system is not known.

Many geological investigations in the mountains of Colorado by federal and other agencies have been conducted, but conflicting theories are being taught concerning the fractured, water yielding portions of the granite mountains of our State.

The purpose of this section of the presentation is to point out the physical differences between the fractured aquifers (common in the mountain areas) and the sedimentary aquifers typical of the Denver basin, San Luis valley, Plains areas and portions of western Colorado.

Presented herein are recommendations relative to learning more about the hydrology of fractured rocks and how to apply newly acquired knowledge to better management, administration and conservation of the ground water in this type of aquifer.

*For the purpose of this presentation, all of the igneous and metamorphic rocks in the mountainous portions of Colorado will be termed "granite" for ease of presentation.

Current State Administration of Ground Water in Fractured Rock

Presently, the Division of Water Resources administers ground water in fractured media just as it does ground water in shallow alluvial aquifers, such as the sand and gravel of the South Platte River. This implies that ground water from all wells completed in any fractured rock is connected directly to the surface flow.

Under current regulations, commercial wells and certain groups of domestic wells, such as in a mountain subdivision, must be accompanied by a plan of water augmentation which releases surface water rights attached to the property (or acquired by its owner from some other source) to the surface streams to offset water which is allegedly consumed through use of a well or wells completed in the fractured rocks. This process is expensive, time consuming, and perhaps unnecessary in many cases.

Perhaps the Division of Water Resources administers the ground water as dictated by statutes, but proper management of the water resources should be included in the adminstration. Strict adherence to the doctrine of prior appropriation without consideration of management for optimum use is contrary to good resource management practices. Perhaps water management needs to be defined and implemented by statute.

Differences in Fractured Aquifers and Sedimentary Aquifers

Most sedimentary formations store and transmit water in their intergranular voids (open space between grains). These voids are comparable to those found in a jar full of marbles. On the other hand, granitic and metamorphic rocks have no inherent intergranular void spaces capable of storing and transmitting water. Therefore, water storage and transfer relies entirely upon fractures in the rocks. The fractures can be compared to the cracks between a stack of neatly placed bricks which do not have mortar in their joints. However, the geometry of the fractures in rocks is much more complex than the neat cubic geometry of a stack of bricks. Unfortunately, this simplistic concept is the basis for most ground water management in fractured rocks.

The subject of ground water management in fractured media has been treated too simply. Exhibit X shows a typical textbook example of fractured granite. Observe the simple fracture pattern and the direct connection to the surface. Spacings on the joints and other fractures are predictable and have simple geometry. This is not actually the case.

Roadcuts on I-70 west of Denver exhibit the complex arrangement of the cracks and joints. Exhibit X also shows a more realistic concept of the way fractured rocks appear in the Rocky Mountain Region.

The rocks in the Front Range are a little over one billion years old. Accordingly, they have been deformed during several mountain building episodes which have lead to the complex system of joints, fractures, and faults. Please note on Exhibit X that two types of faults are present. Type A is a fault which is filled with a substance called mylonite (finely crushed rock) which is incapable of transmitting water. The Type B fault is a brecciated fault which is highly fractured and will store and transmit water through the open spaces caused by the fracturing. Where these zones appear at the surface, the material is highly decomposed and tends to slow recharge to the zone. Also notice the complex arrangement of intrusions which are common in the front range area.

Recognizing the complexity typical of the fractured rocks in the Front Range and other areas of Colorado, the question is asked: "How can something so complex be managed effectively?" Obviously, more data is required by the agencies who are responsible for administration and management of the ground water.

Ground Water in the Fractured Rock of Colorado

Referring to Exhibit I, which was adapted from the Geologic Map of Colorado, approximately 5.6 million acres of Colorado are underlain by fractured granite. We estimate that approximately 3.5 million acre-feet of water is stored in the fractures in the upper 700 feet of these rock bodies. Much more water is stored in deeper fractures, but little is known about the deep storage capacity at the present time. Of course, this water resource is unevenly distributed throughout this area.

Most mountain wells tap only the upper 100 or 200 feet of the storage in fractured rocks. Yields from these wells are generally low, ranging from less than 1 gallon per minute to 5 or 6 gallons per minute. The average mountain home requires only 300 to 400 gallons of water per day, or about 1/4 to 1/2 gallon per minute. Locally, fractured granitic aquifers may yield as much as 60 to 100 gallons of water per minute under a significant artesian head. However, wells of this capacity are uncommon.

The theory which is being taught in some of our leading universities is that saturated fractures generally terminate within 200 or 300 feet of the surface. According to this theory, the rock mass becomes essentially solid and contains very little water below those depths. On the basis of advice of Willard Owens Associates, Inc., and the speculation of some clients and well drillers, wells have been drilled to approximately 1000 feet into the granite. Water-bearing fractures have been encountered and ground water developed from the deeper fractures. Prior to drilling such deep holes, we recommend that the location be selected based on an analysis of the fracture systems in the area.

We have found that the diverse geologic history and structural complexity of the rock of the Front Range area are amenable to the occurrence of ground water in the deeper fractures. We believe that the use of deeper, more sophisticated wells can tap the deeper water-bearing fractures which are very remote to the surface system.

Through the geophysical services of Western Well Logging, Inc., electrical, gamma radiation and density logs were obtained for a few wells completed in the fractured granite. (see Exhibit XI). These logs provide valuable information for properly designing wells and understanding the subsurface conditions. Through these, we "see" underground. Open voids in faults and fractures in granitic rocks do not transmit surface water as pipes or cavernous formations would. Recharge of water to these fractures takes place over extensive areas through weathered rock and soil and then migrates slowly downward to the water table to supplement the water that has been naturally stored for centuries.

The Colorado Division of Water Resources has assumed that all water in fractured granite is tributary to surface water systems and administers it as such. The Division has assumed that the withdrawal of ground water from wells of any depth completed in the fractured granite will interfere with water in the surface water system in such a way that the effects on vested water rights will be detrimental. In some cases this may be true; however, this is not true in many of the cases.

From what has been learned from practical experience with fractured rocks, and from information derived from the Masters Thesis of Reitz (1971), we have concluded that two zones of fractures are common in the Rocky Mountain Region:

1. A shallow surficial zone with several sets of joints, weathered rock and numerous shallow joint sets which penetrate generally less than 100 feet below the surface.
2. A deeper zone of fractures which exists below the upper zone.

The surficial or shallow zone is hydraulically related to surficial waters. As in other deep non-tributary aquifers, the deeper fracture zone is only remotely related to the surface system. Hurr and Richards (1966) described this phenomena in their report on the "Ground Water Engineering of the Straight Creek Tunnel". In this report, an "active zone" and a "passive zone" were identified.

Recommended Conservation Measures

We recommend that the deep fracture zones in granitic rocks be considered as storage facilities for surplus surface water. This water is withdrawn from storage during the summer months to serve mountain communities and thus takes some burden off the surface streams during periods of high water demand.

We further recommend that the State supplement U.S.G.S. research by supporting independent investigations into the significance and future uses of ground water in fractured rocks by conducting a number of programs.

1. Interpret the geologic and hydrologic conditions in selected mountain communities.
2. Implement a three-year program of observing water levels in existing wells in those mountain communities. Correlation of this data with river runoff and precipitation levels can be very helpful in establishing the true effect of withdrawal of ground water from fractured rocks on the surface streams.
3. Test well drilling could help clarify questions in several areas.
    a. Carefully placed deep test holes (1000 ft. or more) with sophisticated geophysical logging and testing in areas of potential artificial recharge facilities to serve mountain communities. This would provide knowledge of the aquifers, and perhaps establish the feasibility of storing surplus surface water in the fractured media.
    b. Test hole and water level observations in

unpopulated areas. Comparison of data gained in unpopulated areas could be helpful in establishing and estimating the impact population has on the natural hydrogeologic conditions. This information could help in preparation of water conservation programs for mountain communities.

State and County support is needed for specific water resource evaluations in each county. Because all counties have different needs, each county should be approached separately on this basis, but share the cost of such investigations with the State. We recommend that such investigations be conducted by hydrogeologic consultants under contract to the Colorado Division of Water Resources, Colorado Geological Survey, or other State agencies. Again, this should be done in addition to and separately from the U.S.G.S. basic research studies to provide more specific data and definitive recommendations toward management of these ground water supplies.

SUMMARY STATEMENT

This report has discussed the significance of the hydrogeology of Colorado, including that of the Denver basin, the designated ground water basins of eastern Colorado, the San Luis Valley, the Brown's Park formation of Routt and Moffatt Counties, and the fractured aquifers which underlie a great portion of the state. Each of the areas discussed has unique problems and unique needs in developing and managing water supplies.

This brief overview cannot replace detailed studies of the complex geology and ground water conditions found in each area. Data must be gathered and specific conclusions and recommendations must be presented. Future legislation affecting ground water use, management and administration should be based on such documented hydrogeologic information, not on overall theory.

In summary, we recommend the following actions be endorsed by the Colorado Legislature and other appropriate agencies:

*Practical drilling, sampling and testing programs should be undertaken to determine aquifer characteristics in each specific area.

*The combined aquifers throughout the Denver basin should be studied, developed and managed under one set of guidelines, not according to political boundaries such as county lines and water district boundaries.

*Management plans need to be used in designated ground water basins and applied over large areas to reduce evaporation and transpiration losses and increase beneficial uses.

*Particularly in the San Luis Valley, studies should be made to determine the amount of interconnection between the sub-surface aquifers and surface systems, by test drilling deep wells and well logging, leading to changes in water management practices.

*Each county government, singly or in logical groups, should conduct engineering geology and water resource studies to gain sufficient knowledge on which to complete comprehensive land use plans.

*In mountain community areas, where social pressures are creating rapid development, consideration should be given to using deep fracture zones as storage facilities for surplus runoff water captured from snowmelt. Observation of existing wells, plus test drilling, would also be desirable to coordinate use of ground water and surface streams while projecting growth impact on resources.

*Information given in this report should be used as a basis for understanding Colorado ground water.

This information can be used as a foundation upon which specific knowledge of Colorado's aquifers can be developed through implementation of the recommendations given in this report.

*When sufficient knowledge of each aquifer and area is available, legislation and administrative regulations governing water development and management should be tailored to each district, basin or county.

*Studies need to be conducted by various agencies and consultants, with input of divergent views and interpretations, with review and critical analysis of findings, opinions and recommendations.

Selected References

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Hurr, T. R. and Richards, D. B., 1966, Ground water engineering of the Straight Creek Tunnel (pilot bore), Colorado: Bulletin of the Association of Engineering Geologists, vol. 3, No. 2, p. 80-90.

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*Pearl, R. H., 1971, Bibliography of hydrogeologic reports in Colorado: Colorado Geological Survey Bull. 33, 39 p.

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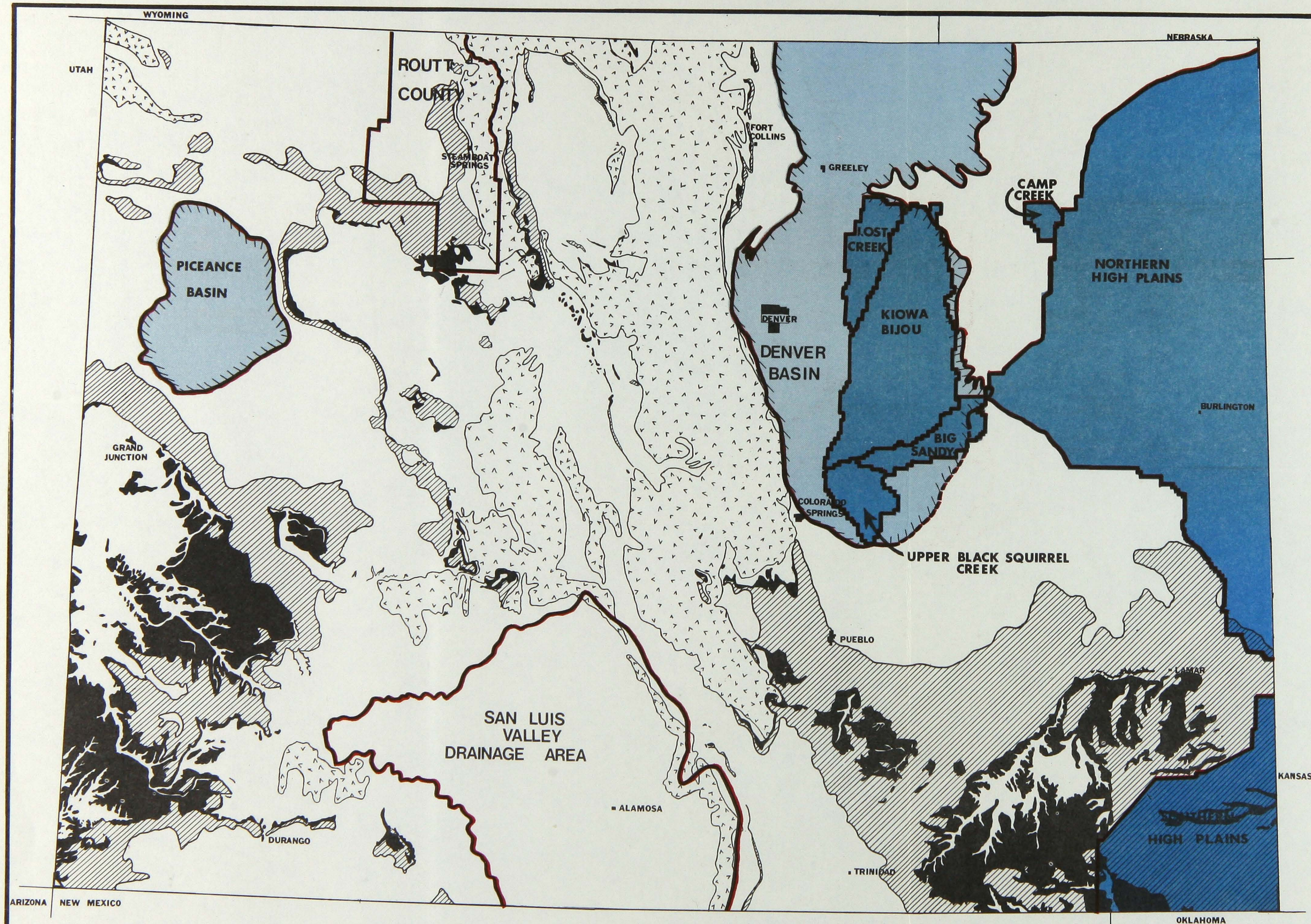
Reichert, S. O., 1956, Post-Laramie stratigraphic correlations in the Denver basin, Colorado: Bull. of the Geological Society of America, Vol. 67, No. 1, p. 107-112.

Reitz, Donald D., 1971, Analysis of joint patters in Pikes Peak and Cripple Creek granites of Rock Creek, El Paso County, Colorado: Louisiana State University, Dept. of Geology, unpub. M.S. thesis.

Smith, R. O., Schneider, P. A., Jr., and Petri, L. R., 1964, Ground water resources of the South Platte River basin in western Adams and southwestern Weld Counties, Colorado: U. S. Geological Survey water-supply paper 1658, 132 p.

*This is an excellent bibliography of hydrogeologic reports. We would recommend the reader use this publication to begin research on almost any hydrogeologic topic within Colorado.



EXPLANATION

- APPROXIMATE AREA WHERE THE DAKOTA SANDSTONE IS A POTENTIAL AQUIFER
- DAKOTA SANDSTONE

ZONES OF PRIMARY RECHARGE

- FRACTURED "GRANITE-LIKE" ROCK
- STRUCTURAL GEOLOGIC BASIN

BOUNDARY OF DENVER BASIN DEFINED BY LOWER CONTACT OF FOX HILLS SANDSTONE

BOUNDARY OF PICEANCE BASIN DEFINED BY GEOLOGICAL STRUCTURE

- DESIGNATED GROUND WATER BASIN

DRAFTED FROM COLORADO GEOLOGIC MAP, U.S. GEOLOGICAL SURVEY, 1935

N

SCALE 0 10 20 30 40 50 MILES

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MODIFIED COLORADO GEOLOGIC MAP

EXHIBIT I

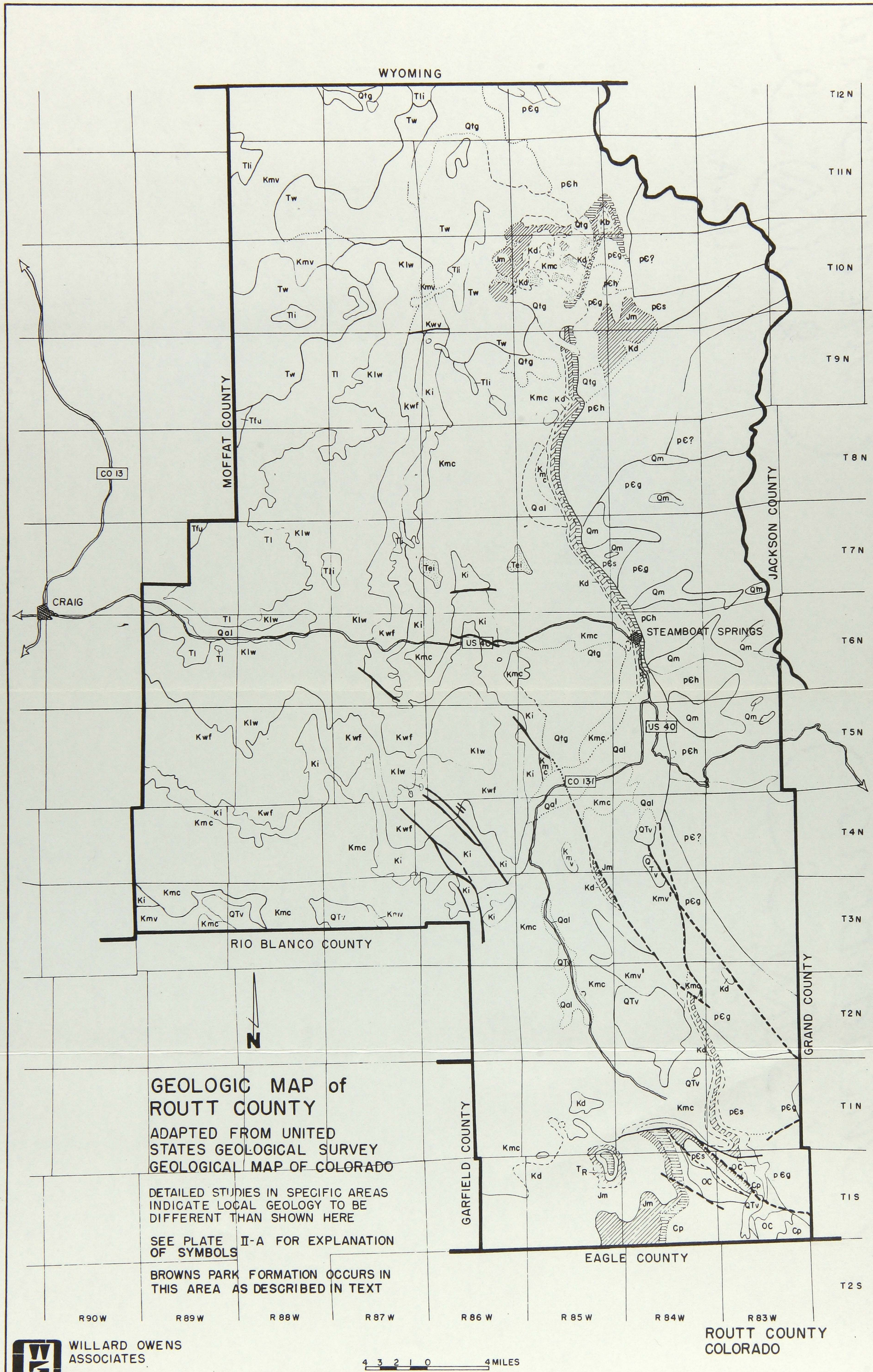

GEOLOGIC MAP of
ROUTT COUNTY
ADAPTED FROM UNITED
STATES GEOLOGICAL SURVEY
GEOLOGICAL MAP OF COLORADO
DETAILED STUDIES IN SPECIFIC AREAS
INDICATE LOCAL GEOLOGY TO BE
DIFFERENT THAN SHOWN HERE
SEE PLATE II-A FOR EXPLANATION
OF SYMBOLS
BROWNS PARK FORMATION OCCURS IN
THIS AREA AS DESCRIBED IN TEXT
ROUTT COUNTY
COLORADO
WILLARD OWENS
ASSOCIATES
4 3 2 1 0 4 MILES
N
WYOMING
MOFFAT COUNTY
JACKSON COUNTY
GRAND COUNTY
RIO BLANCO COUNTY
GARFIELD COUNTY
EAGLE COUNTY
CRAIG
STEAMBOAT SPRINGS
CO 13
US 40
CO 131
T12 N
T11 N
T10 N
T9 N
T8 N
T7 N
T6 N
T5 N
T4 N
T3 N
T2 N
T1 N
T1 S
T2 S
R90 W
R89 W
R88 W
R87 W
R86 W
R85 W
R84 W
R83 W

EXHIBIT II

Period	Symbol	Description
QUATERNARY	Qal	ALLUVIUM
QUATERNARY	Qtg	TERRACE DEPOSITS
QUATERNARY	Qm	MORRAINE DEPOSITS
QUATERNARY / TERTIARY	QTv	ANDESITE AND BASALT
TERTIARY	Tb	BROWNS PARK FORMATION; occurs locally, but is not shown on the geologic map
TERTIARY	Tli	LATE TERTIARY INTRUSIVE
TERTIARY	Tw	WASATCH FORMATION
TERTIARY	Tfu	FORT UNION FORMATION
TERTIARY	Tl	LANCE FORMATION
TERTIARY	Tei	EARLY TERTIARY INTRUSIVE
CRETACEOUS	Klw	LEWIS SHALE
CRETACEOUS	Kmv (MESAVERDE GROUP): Kwf	WILLIAMS FORK FORMATION
CRETACEOUS	Kl	ILES FORMATION
CRETACEOUS	Kmc	MANCOS SHALE
CRETACEOUS	Kb	BENTON GROUP
CRETACEOUS	Kd	DAKOTA SANDSTONE
JURASSIC	Jm	MORRISON FORMATION
TRIASSIC	T_R	TRIASSIC UNDIVIDED
CARBONACEOUS	Cpm	PERMAIN UNDIVIDED
CARBONACEOUS	Cp	PENNSYLVANIAN UNDIVIDED
ORDOVICIAN-CAMBRIAN	OC	ORDOVICIAN AND CAMBRIAN UNDIVIDED
PRECAMBRIAN	p€g	GRANITE AND RELATED ROCKS
PRECAMBRIAN	p€h	HORNBLENDE GNEISS AND GREENSTONE
PRECAMBRIAN	p€s	SCHIST AND GNEISS
PRECAMBRIAN	p€?	UNDIVIDED META-MORPHIC AND IGNEOUS ROCKS

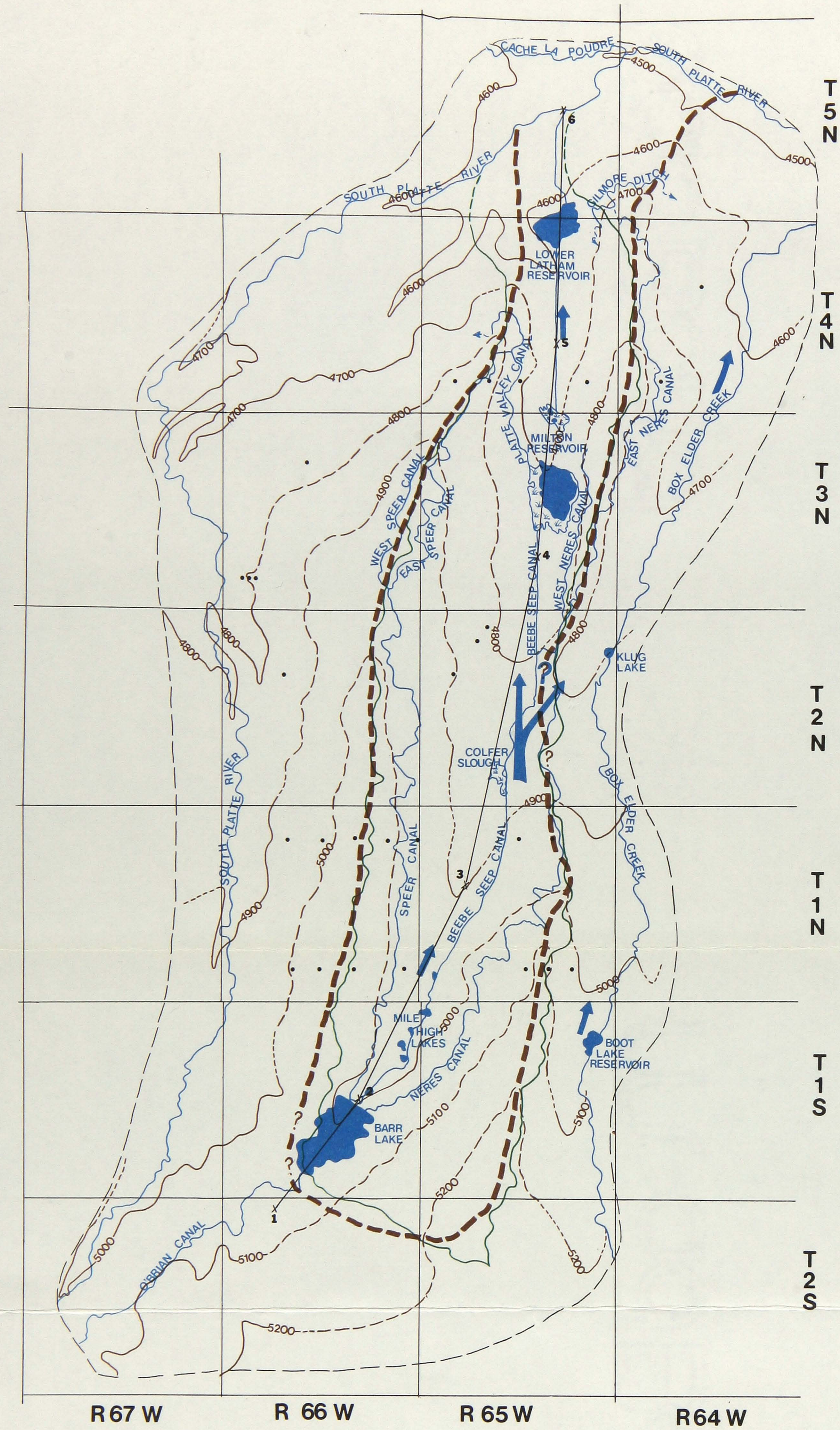
FORMATION CONTACT, DASHED WHERE APPROXIMATE, DOTTED WHERE COVERED

FAULT, DASHED WHERE APPROXIMATE, DOTTED WHERE COVERED

ROUTT COUNTY LINE

EXPLANATION OF SYMBOLS ON GEOLOGIC MAP OF ROUTT COUNTY - EXHIBIT II

EXHIBIT 11-A



EXPLANATION

- BOUNDARY OF STUDY AREA
- SURFACE DRAINAGE BOUNDARY
- SWAMP
- LAKE OR RESERVOIR
- CANAL
- TRACE LINE OF GEOLOGIC CROSS SECTION
- 5000 CONTOURS ON TOP OF BEDROCK* (FEET ABOVE MEAN SEA LEVEL)
- 5000 INFERRED BEDROCK CONTOURS
- INFERRED SUBSURFACE DRAINAGE DIVIDE ? INDICATES QUESTIONABLE DATA
- DATA POINTS*
- DIRECTION OF SUBSURFACE GROUND WATER FLOW

* CONTOURS ON TOP OF BEDROCK SURFACE AND DATA POINTS ADAPTED FROM PLATE 4 OF GROUND WATER RESOURCES OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO; U.S. GEOLOGICAL SURVEY WATER SUPPLY PAPER 1658: BY REX O. SMITH, PAUL A. SCHNEIDER, JR., AND LESTER R. PETRI

N

4 3 2 1 0 4 MILES

BEEBE DRAW DRAINAGE AREA GEOLOGIC CONFIGURATION MAP

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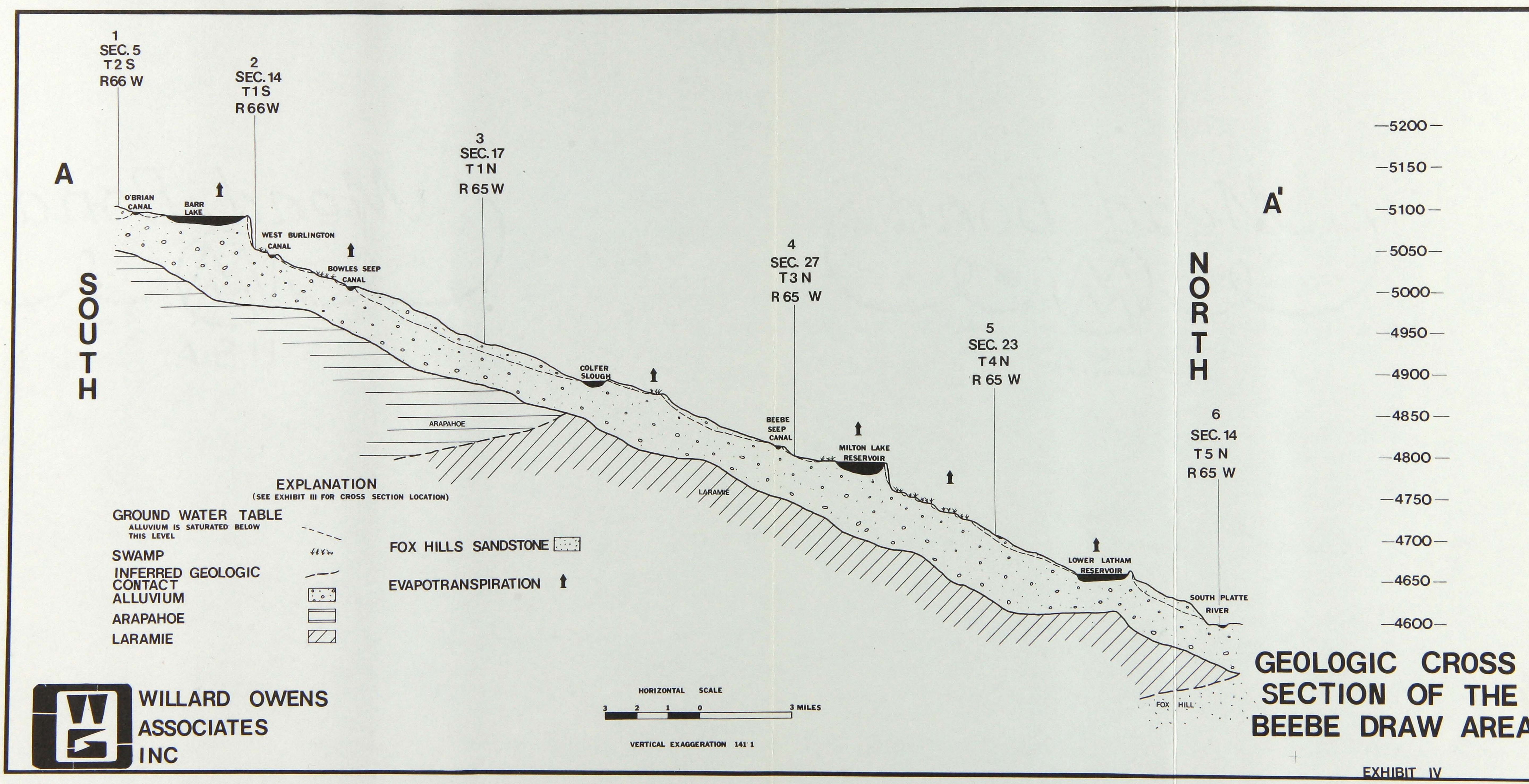
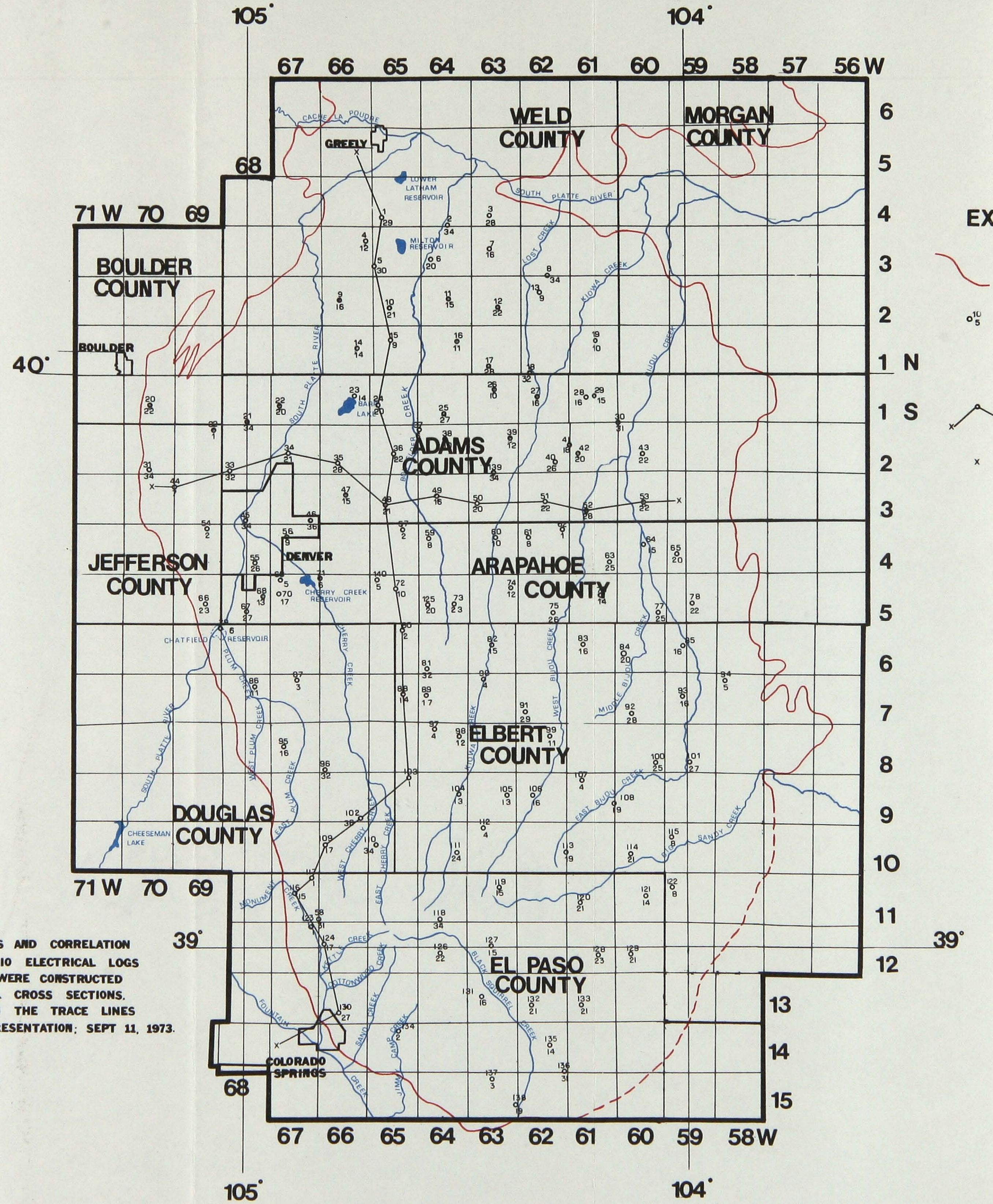
EXHIBIT III



GEOLOGIC CROSS SECTION OF THE BEEBE DRAW AREA

EXHIBIT IV



EXPLANATION

BOUNDARY OF THE DENVER BASIN DEFINED BY LOWER CONTACT OF THE FOX HILLS SANDSTONE

DATA POINT: ELECTRICAL LOG LOCATION
- 10 REFERENCE INDEX NUMBER
- 5 LOCATION BY SECTION

TRACE LINE OF GEOLOGICAL CROSS SECTION

x DENOTES EXTREMES OF CROSS SECTION NOT LOCATION OF ELECTRICAL LOG.

AREA OF THIS STUDY

COLORADO

BASE MAP FROM ARMY SERVICE MAPS (B.E.P.M.), CORPS OF ENGINEERS U.S. ARMY, WASHINGTON, D.C. 1953-54
SCALE 1: 250,000

NOTE.

DUE TO THE ANALYSIS AND CORRELATION OF AN ADDITIONAL 110 ELECTRICAL LOGS NEW TRACE LINES WERE CONSTRUCTED FOR THE GEOLOGICAL CROSS SECTIONS, WHICH DIFFER FROM THE TRACE LINES OF THE ORIGINAL PRESENTATION; SEPT 11, 1973.

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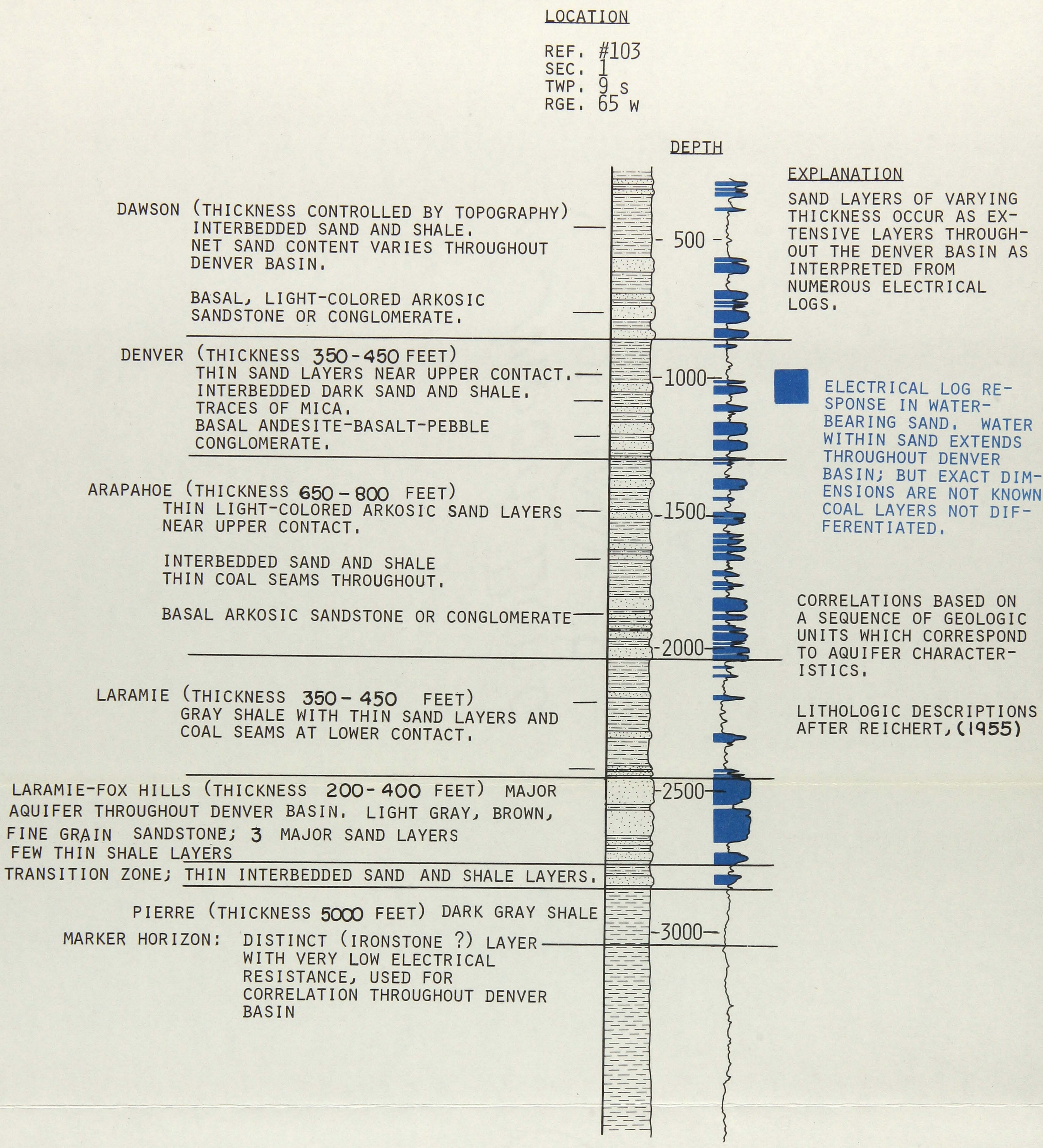
LOCATION OF THE DENVER BASIN

EXHIBIT V



TYPE ELECTRIC LOG AND GEOLOGIC COLUMN OF DENVER BASIN

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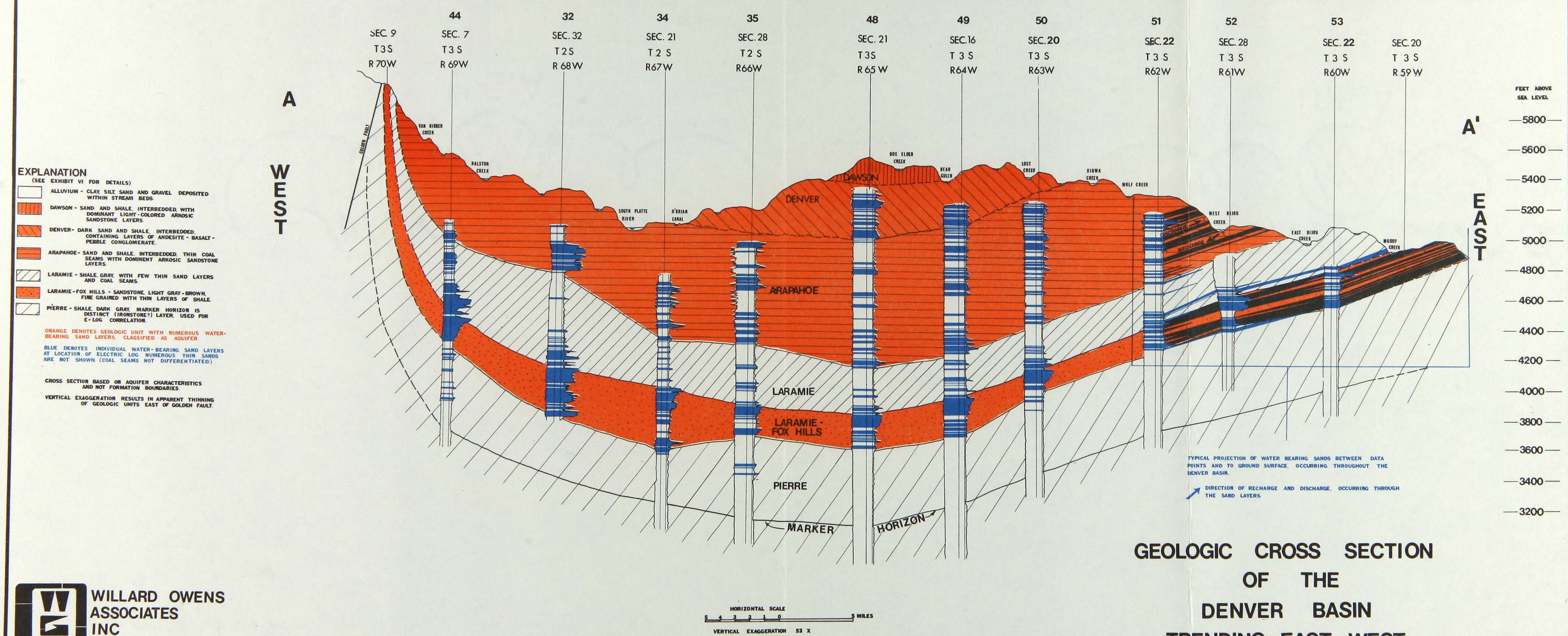
EXHIBIT VI



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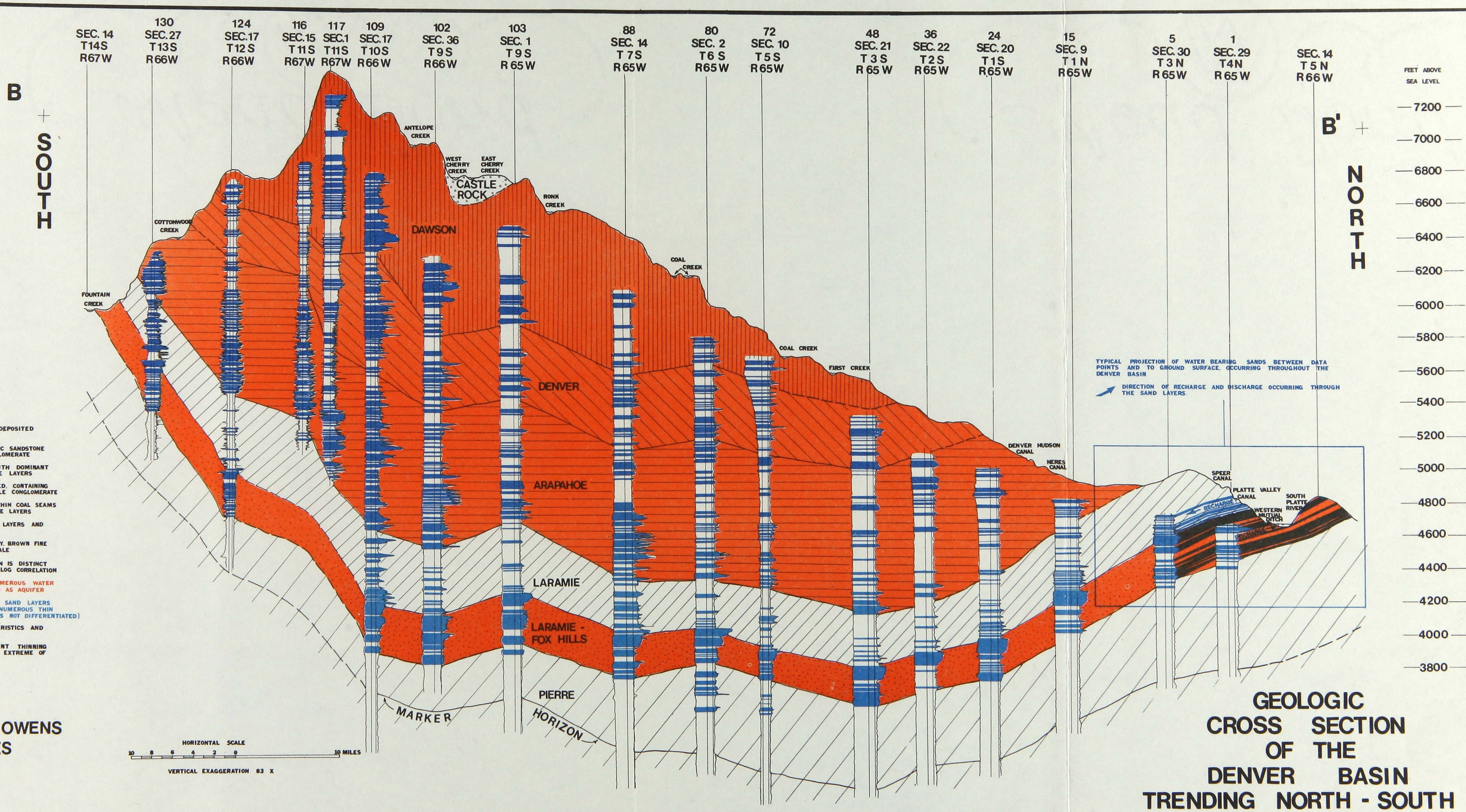
GEOLOGIC CROSS SECTION OF THE DENVER BASIN TRENDING EAST WEST

EXHIBIT VII



EXPLANATION
(SEE EXHIBIT VI FOR DETAILS)

ALLUVIUM - CLAY, SILT, SAND AND GRAVEL DEPOSITED WITHIN STREAM BEDS

CASTLE ROCK CONGLOMERATE - COARSE ARKOSIC SANDSTONE STREAKED WITH LENSES OF CONGLOMERATE

DAWSON - SAND AND SHALE, INTERBEDDED, WITH DOMINANT LIGHT COLORED ARKOSIC SANDSTONE LAYERS

DENVER - DARK SAND AND SHALE, INTERBEDDED, CONTAINING LAYERS OF ANDESITE - BASALT - PEBBLE CONGLOMERATE

ARAPAHOE - SAND AND SHALE, INTERBEDDED, THIN COAL SEAMS WITH DOMINANT ARKOSIC SANDSTONE LAYERS

LARAMIE - SHALE, GRAY, WITH FEW THIN SAND LAYERS AND COAL SEAMS

LARAMIE - FOX HILLS - SANDSTONE, LIGHT GRAY, BROWN FINE GRAINED WITH THIN LAYERS OF SHALE

PIERRE - SHALE, DARK GRAY, MARKER HORIZON IS DISTINCT (IRONSTONE?) LAYER, USED FOR E-LOG CORRELATION

ORANGE DENOTES GEOLOGIC UNIT WITH NUMEROUS WATER BEARING SAND LAYERS, CLASSIFIED AS AQUIFER

BLUE DENOTES INDIVIDUAL WATER - BEARING SAND LAYERS AT LOCATION OF ELECTRICAL LOG. NUMEROUS THIN SANDS ARE NOT SHOWN. (COAL SEAMS NOT DIFFERENTIATED)

CROSS SECTION BASED ON AQUIFER CHARACTERISTICS AND NOT FORMATION BOUNDARIES

VERTICAL EXAGGERATION RESULTS IN APPARENT THINNING OF GEOLOGIC UNITS AT SOUTHERN EXTREME OF CROSS SECTION

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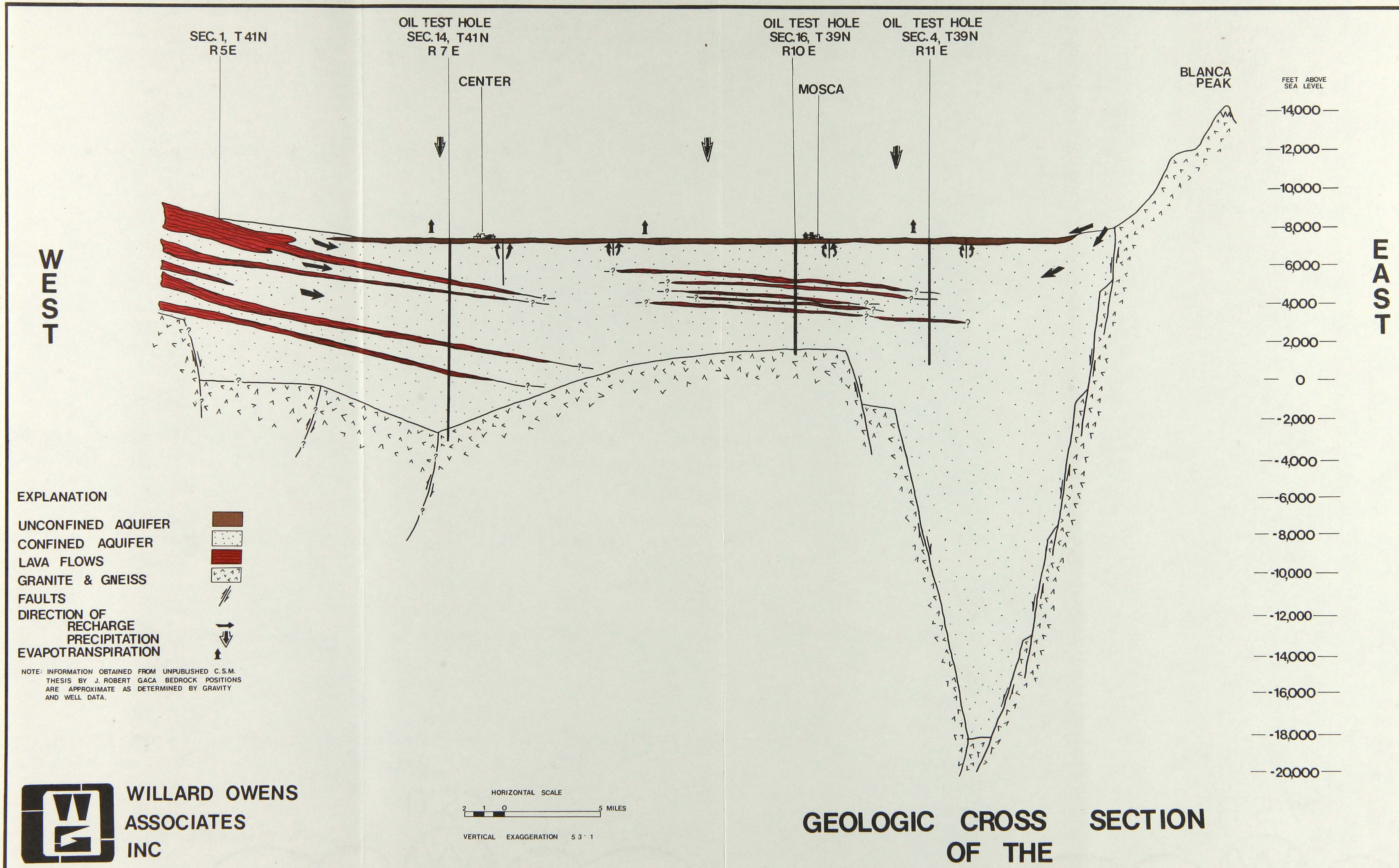
GEOLOGIC CROSS SECTION OF THE DENVER BASIN TRENDING NORTH - SOUTH

EXHIBIT VIII



GEOLOGIC CROSS SECTION
OF THE
SAN LUIS VALLEY
TRENDING EAST - WEST

EXHIBIT IX

TEXT BOOK DESIGN OF FRACTURED ROCKS

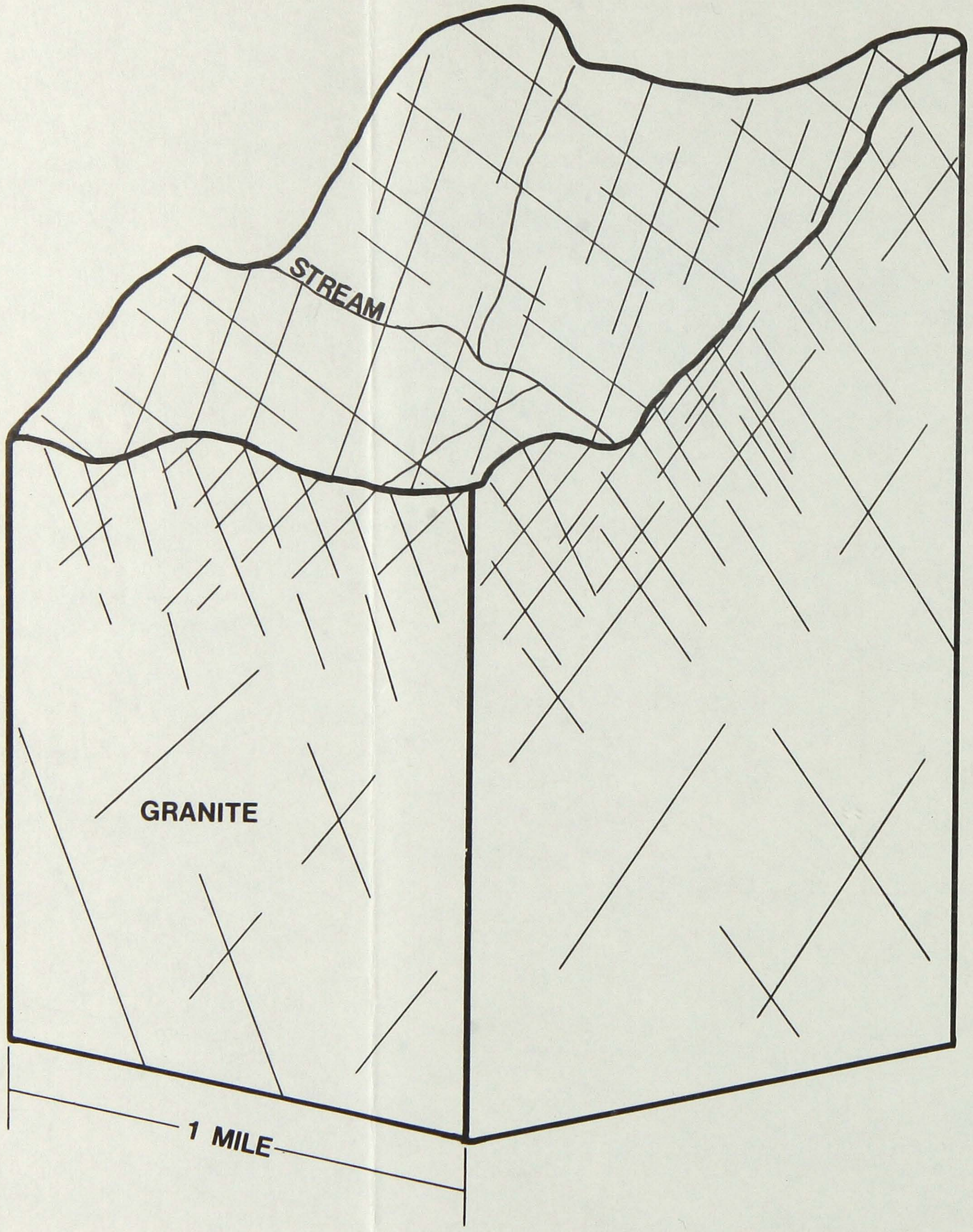
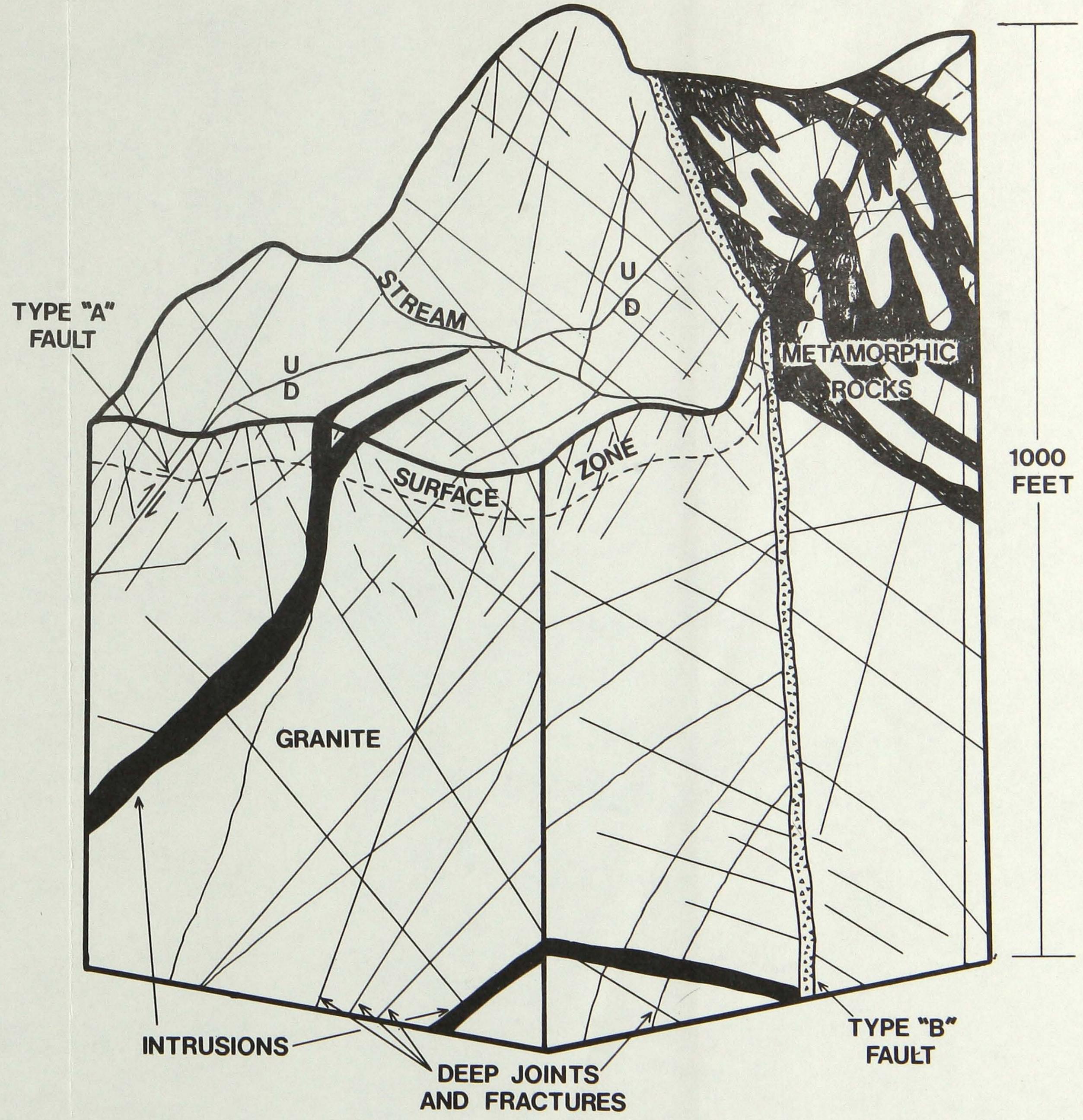


DIAGRAM OF FRACTURES TYPICAL OF THE FRONT RANGE



EXPLANATION

- FAULT, ARROWS DENOTE RELATIVE DISPLACEMENT
- SURFACE VIEW OF FAULT
  U-UPTHROWN SIDE
  D-DOWNTHROWN SIDE
- FRACTURES IN BEDROCK

VARIOUS TYPES OF INTRUSIONS OCCUR WITHIN THE FRONT RANGE

SOIL OF VARYING THICKNESS OCCURS AT THE GROUND SURFACE

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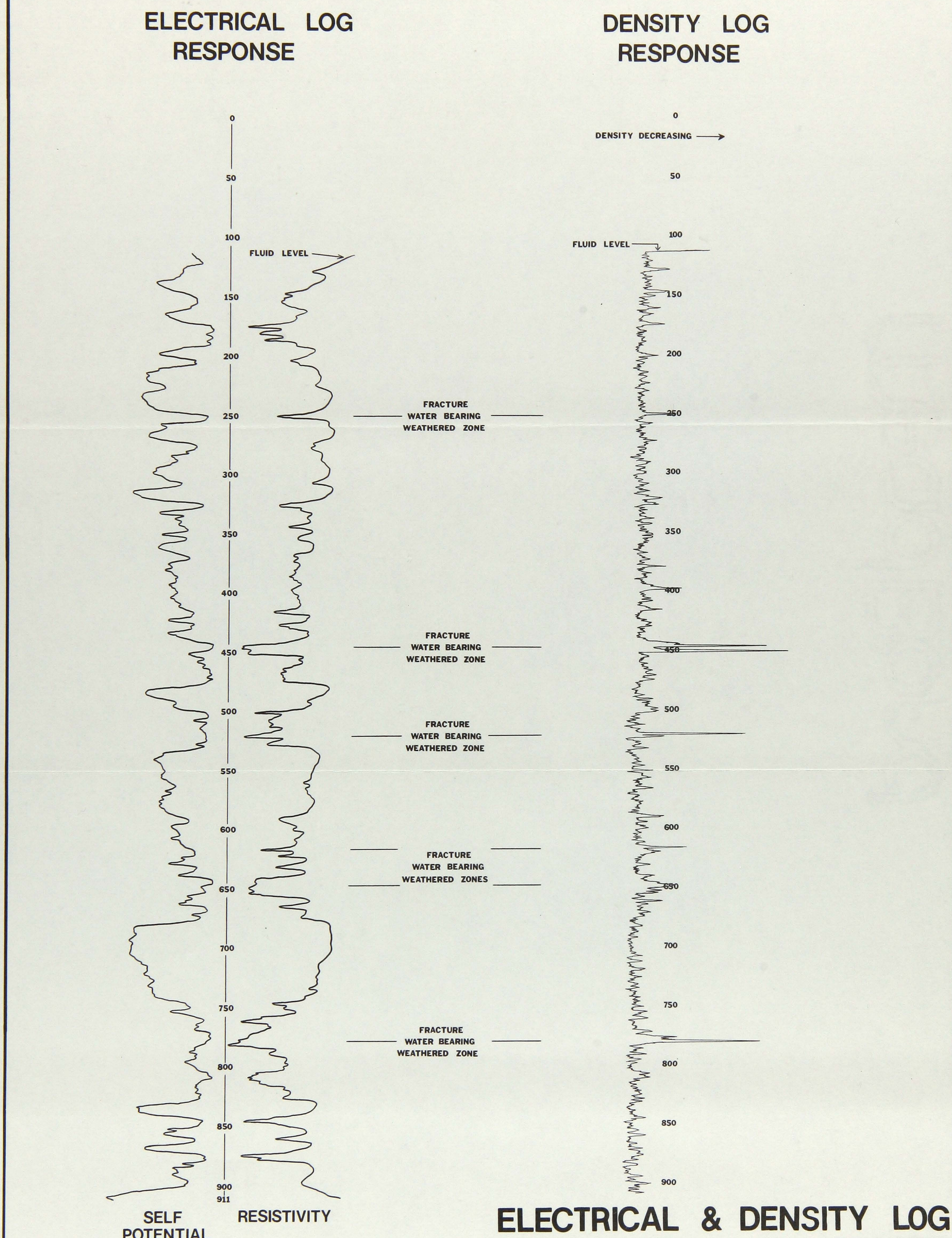
DIAGRAM OF FRACTURES IN "GRANITE-LIKE" ROCKS

EXHIBIT X



ELECTRICAL & DENSITY LOG RESPONSE IN FRACTURED "GRANITE LIKE" ROCK

EXHIBIT XI

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