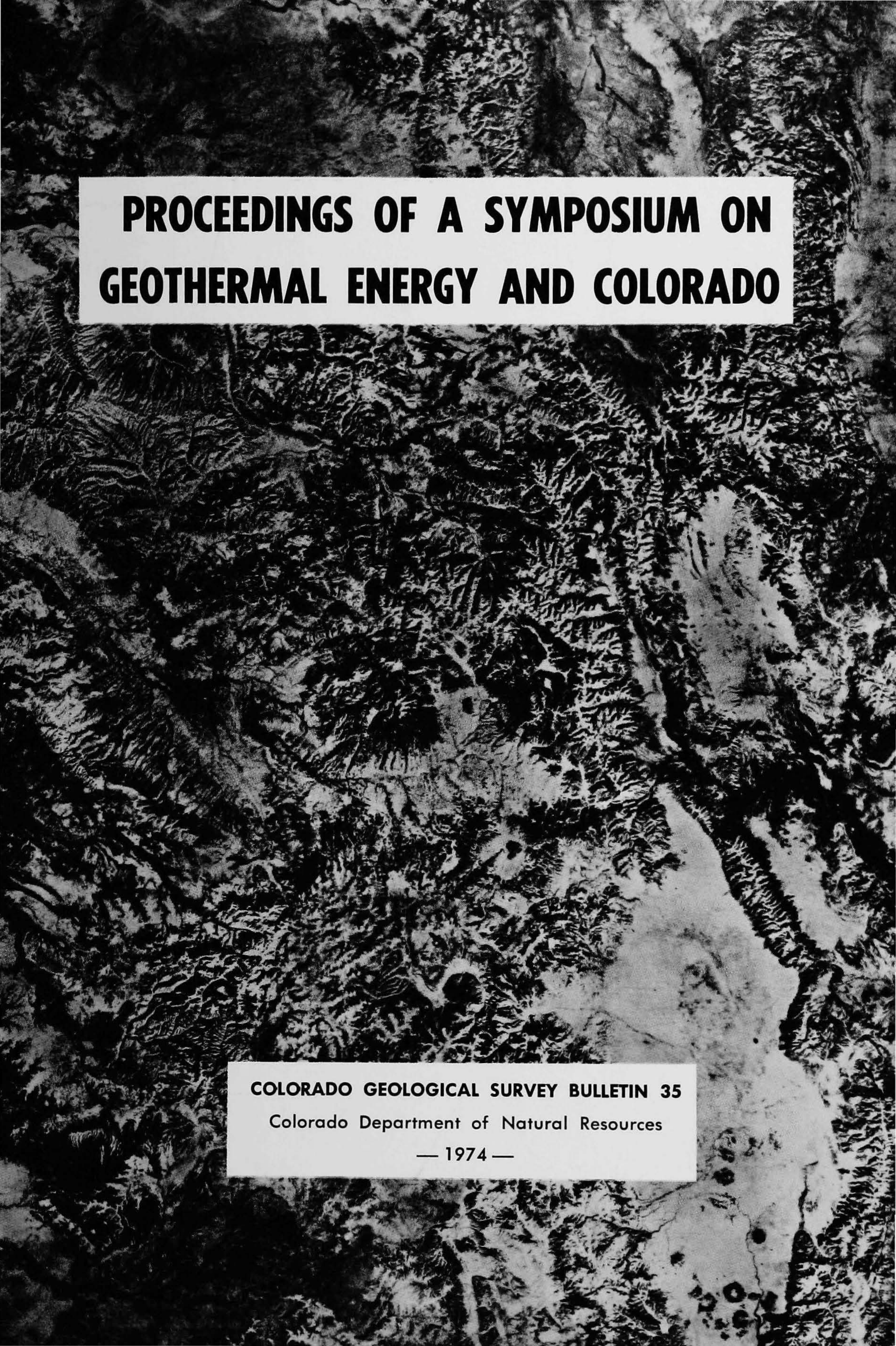

PROCEEDINGS OF A SYMPOSIUM ON GEOTHERMAL ENERGY AND COLORADO

COLORADO GEOLOGICAL SURVEY BULLETIN 35

Colorado Department of Natural Resources

— 1974 —

STATE OF COLORADO

John D. Vanderhoof, *Governor*

DEPARTMENT OF NATURAL RESOURCES

Thomas W. Ten Eyck, *Executive Director*

COLORADO GEOLOGICAL SURVEY

John W. Rold, *State Geologist and Director*

MISSION OF THE COLORADO GEOLOGICAL SURVEY

The Colorado Geological Survey was legislatively re-established in February 1969 to meet the geologic needs of the citizens, governmental agencies, and mineral industries of Colorado. This modern legislation was aimed at applying geologic knowledge toward the solution of today's and tomorrow's problems of an expanding population, mounting environmental concern, and the growing demand for mineral resources.

SPECIFIC LEGISLATIVE CHARGES:

"Assist, consult with, and advise state and local governmental agencies on geologic problems."
"Promote economic development of mineral resources."
"Evaluate the physical features of Colorado with reference to present and potential human and animal use."
"Conduct studies to develop geologic information."
"Inventory the state's mineral resources."
"Collect, preserve and distribute geologic information."
"Determine areas of geologic hazard that could affect the safety of or economic loss to the citizens of Colorado."
"Prepare, publish, and distribute geologic reports, maps, and bulletins."

COLORADO GEOLOGICAL SURVEY BULLETIN 35

PROCEEDINGS OF A SYMPOSIUM ON GEOTHERMAL ENERGY AND COLORADO

Edited
by

RICHARD HOWARD PEARL

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COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
State of Colorado
Denver, Colorado

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FORWARD

In the last few years, and especially since passage of the Federal Steam Act of 1970, more and more interest has been shown in geothermal resources as a potentially viable source of energy. While the existence of geothermal resources and the fact that it could be put to beneficial use has only recently been called to the attention of most people geothermal resources have been used almost since the days of antiquity by man. There are records of almost all cultures utilizing thermal springs for medicinal and other purposes.

Since 1904 at Larderello, Italy, naturally occurring steam and heat have been used to generate electricty. This usage of geothermal energy has continued since then and has spread around the world to the point where today over 1,000 megawatts of electricty are now being generated by geothermal heat. While the longest continued use of geothermal steam and heat for the generation of electricty is at Larderello, Italy, the largest geothermal-electric field in the world is the Geysers field located some 90 miles northeast of San Francisco, California. In addition to being used to generate electricty, geothermal heat is used extensively throughout the world for such other purposes as space heating and agricultural purposes. Here in the United States extensive use is made of geothermal heat for space heating in such states as Oregon, Idaho, and Colorado.

An analysis of the geology of the United States shows that conditions are favorable for the development of geothermal energy in the Ozarks, southeastern United States, the Gulf Coast, and the mountain states of the west.

The United States Geological Survey has appraised the public lands in the western United States for their geothermal resource potential. It was estimated that there were nearly 98 million acres that either overlay Known Geothermal Resource Areas or had Prospective Value for geothermal resources. One million acres in western Colorado were classified as having Prospective Value for geothermal resources.

As a result of the appraisal and the passage of the Federal Steam Act many persons and companies have approached the Colorado Geological Survey concerning information about this resource in Colorado. Consequently, as very little information is available about this subject, and to bring this valuable resource to attention it was decided that a symposium concerning the geothermal resources of Colorado was needed.

The symposium was held at the Radisson Hotel, Denver, Colorado on December 6, 1973 and the following papers were presented. Geothermal energy and Colorado--An introduction, by J. W. Rold, Colo. Geological Survey; Summary of geology of Colorado related to geothermal energy potential, by L. T. Grose, Colo. School of Mines; Geophysics of Colorado and geothermal energy, by. G. V. Keller, Colo. School of Mines; Economic considerations for geothermal exploration in the western United States, by R. Greider, Chevron Oil Co.; Geothermal energy and the environment, by W. L. Miller, U.S. Bureau of Mines; Geothermal resources--Legal and tax considerations, by W. A. Burton, Jr., Chevron Oil Co.; Utility participation in a geothermal energy source, by. W. S. Landers, Public Service Co. of Colo.; Requirements for private industry in developing geothermal energy, by. M. H. Mossman, The Anschutz Corp.; Governmental leasing regulations, by R. T. Stone, U. S. Dept. of Interior; Rules and regulations relating to geothermal leases on Colorado state owned lands, by T. E. Bretz, Colo. Board of Land Commissioners; and Geothermal energy and the energy crisis, by W. L. Rogers, U. S. Dept. of Interior, banquet speaker.

Richard H. Pearl
Colorado Geological Survey

GEOTHERMAL ENERGY AND COLORADO -- AN INTRODUCTION

John W. Rold[1]
Denver, Colorado

I have been asked to open this meeting, explain why the meeting is being held, outline some of the objectives which we hope to meet in the next two days, and present an introduction to the subject of geothermal energy.

The objectives of this conference are first and foremost educational. We will attempt to answer the following questions. What is geothermal energy? What is the geothermal energy potential of Colorado? If and when geothermal resource development comes, what will be the impact on Colorado, not only from an economic standpoint but more importantly from an environmental standpoint? To help answer these questions and others, we have brought together some persons knowledgable in the various facets of the subject of geothermal energy. Another objective is to bridge the gap between the person who said to me this morning, "Well, what is geothermal energy?" and those technical persons who have worked in the field for months or years.

The timing of this conference is excellent because we don't have to spend any time convincing you in the audience that there is an energy shortage. The energy shortage which the United States is experiencing today dictates that many new and different sources of energy need to be developed. President Nixon, in his energy message of November 1973, stated that it should be the policy of the United States to develop new and alternate sources of energy so that by 1980 we will be completely independent of foreign imports. To accomplish that goal will require intensive development of such diverse forms of energy as: nuclear, solar, oil shale, coal, coal gasification, tar sands, secondary and tertiary recovery of hydrocarbons, and geothermal heat. It is to discuss this last energy source that we are here today.

It is obvious to a number of persons that geothermal energy has a role to play, and could help to solve the United State's future energy needs. Just when and how much it will help are two of the questions that are yet to be answered.

How very little is presently known about the geothermal resources of Colorado and the level of that knowledge is illustrated by a true story about how the Colorado Geological Survey became involved in the field of geothermal resources a few years ago. In the summer of 1971, a geothermal geologist with one of the major oil companies came through Denver and stopped in our office to discuss Colorado's geothermal potential. We told him that we had not yet become involved with geothermal resources, that we really didn't know very much specifically about the geothermal resource potential of Colorado, and that there was not much help that we could give him. He shook his head and left. About three days later a newspaper reporter called

[1]Colorado Geological Survey

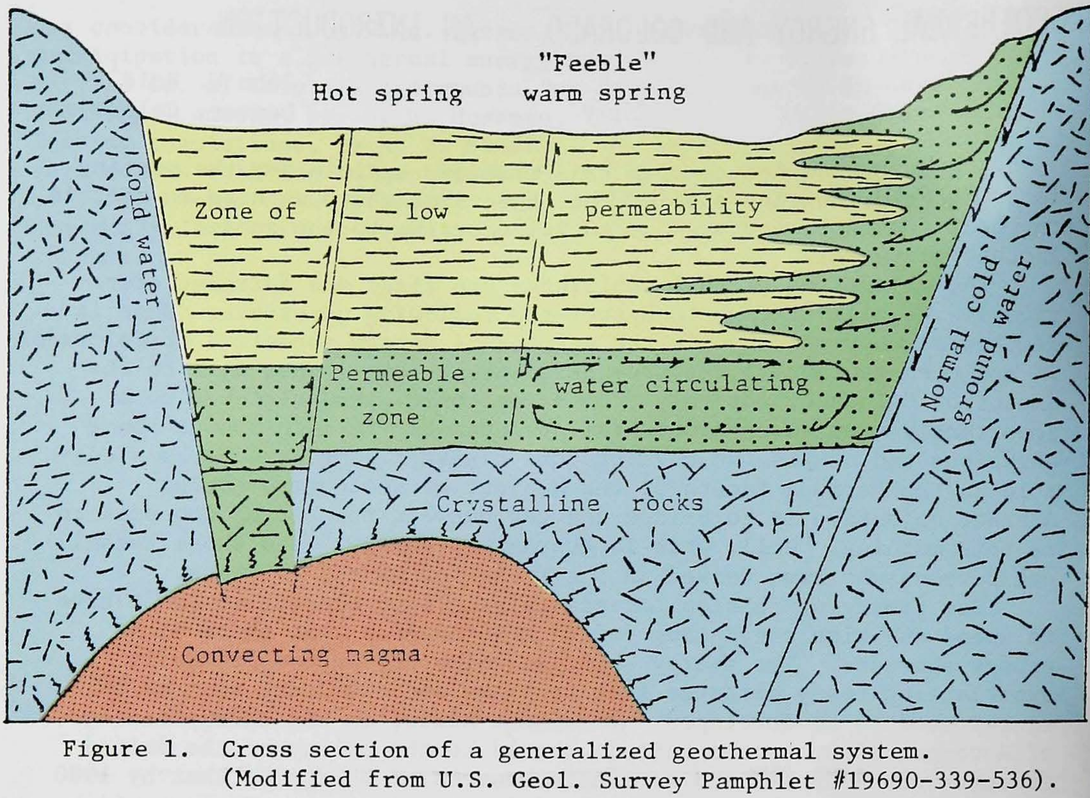


Figure 1. Cross section of a generalized geothermal system. (Modified from U.S. Geol. Survey Pamphlet #19690-339-536).

Figure 2. Old Faithful Geyser, Yellowstone National Park.

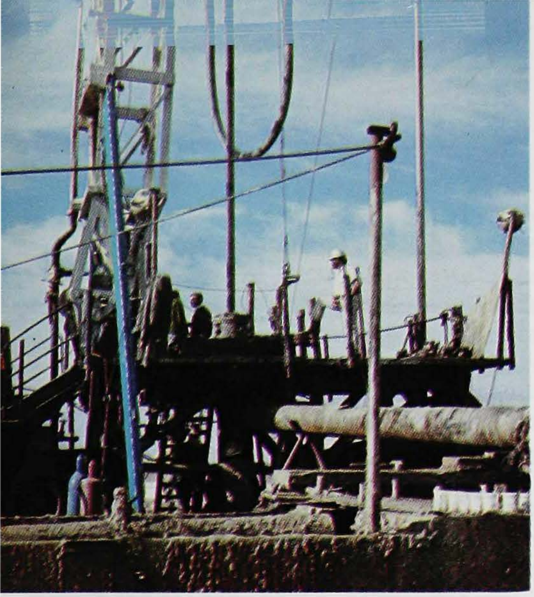


Figure 3. Typical oil field drilling rig drilling for geothermal steam and hot water at Cerro Prieto, Mexico.

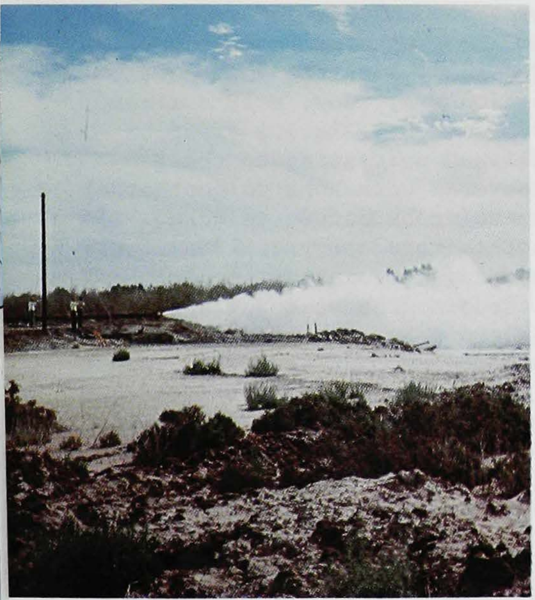


Figure 4. Testing a recently drilled geothermal well at Cerro Prieto, Mexico.

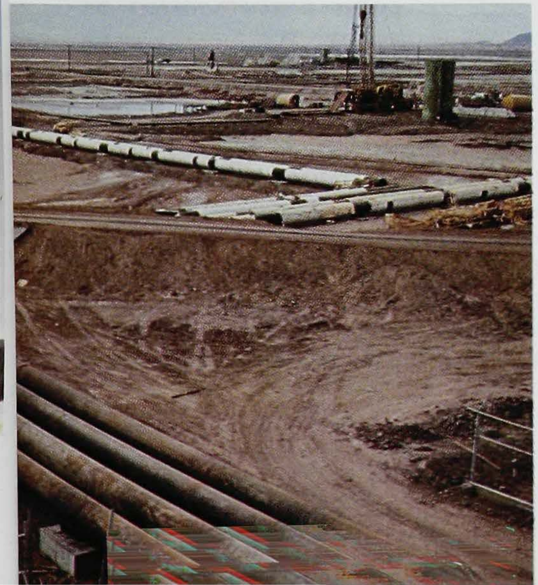


Figure 5. Steam gathering lines, Cerro Prieto, Mexico.

about the very same subject. One of the questions posed was, "What is geothermal energy?" Using simple terms, I did my best to explain it. The next question asked was, "Is there any potential for geothermal energy in Colorado?" In answering that question using what little knowledge that I had, I tried to explain that, yes, Colorado did have some potential and that there was a possibility that there could be some geothermal resource development in the future here in Colorado. Well, the meager amount of information that I presented really impressed the reporter, and passing the State Geologist off as quite an expert in the field of geothermal resources, she wrote an interesting article about geothermal energy in Colorado. As would be expected, the major oil company man saw the article and called and wondered why we had been so modest and secretive with him. Also, as a result of that article the persons planning the El Centro, California conference on geothermal energy thought that the Colorado Geological Survey would be the logical ones to present a paper on the geothermal conditions of Colorado. Because I was occupied right then, I turned the request over to one of our staff. His first question was, "Now, wait a minute, just what is geothermal energy?" About three months later, after he had studied everything that had been published pertaining to the geothermal resources of Colorado, attended several workshops on geothermal energy, and had given his paper at that meeting he became an acknowledged "expert" on the subject. I think that this story tells a little about the subject, for there are not very many sciences or specialties in science where a man could spend only three months studying and working on a broad subject part time and become an acknowledged expert.

About this same time, the Colorado Geological Survey started receiving numerous requests for information on the geothermal resources of Colorado. Therefore to answer some of these questions and to help others just getting into the subject of geothermal resources, we took the material presented at the February 1972, El Centro, California meeting, expanded upon it and published Special Publication #2, "Geothermal Resources of Colorado". The response to that report has been so great that we have sold over 700 copies and have reprinted the report.

Many people tend to think of geothermal energy as a new source of energy, yet it is really one of the oldest sources. The Romans were using geothermal heat for space heating over two thousand years ago. It has also been used for generating electrical energy for over 70 years. Some of us were talking this morning about the use of geothermal energy for the generation of electrical power. It was mentioned that using geothermal energy for this purpose may outdate the generation of electricity by hydro-power. To give you an idea of the magnitude of this resource, it has been estimated that the heat energy to a depth of 6 miles (10 Km) under the United States equals the energy derived from burning 900 trillion barrels of oil (one barrel contains 42 gallons). It has also been estimated that, if the center of the earth could be cooled by 1°F, enough energy would be released to run all existing power plants for 20 million years. While these are imposing figures, they don't have much meaning because the technology to utilize this deep-seated heat is not available. As most of you are aware, the natural heat of the earth's interior (geothermal heat) flows from the interior to the surface at a very slow rate. If this heat could be captured, it could be used to generate more useful forms of energy such as electricity or to heat homes or buildings.

Many estimates have been made regarding what the ultimate geothermal-electrical generating capacity in the United States will be. These estimates range all the way from thousands and thousands of megawatts (1,000,000 watts) down to 30,000 M.W. No matter which estimate is used, when you realize that 30,000 M.W. almost equals the current hydro-electric generating capacity in the United States, you realize that geothermal energy does have considerable potential. At the present time, geothermal energy is used throughout the world in such countries as Italy, New Zealand, Japan, Russia, Mexico, and at The Geysers area in California to generate over 1,000 M.W. of electricity.

Among some of the countries where geothermal heat is used today for space heating are Japan, Iceland, Hungary, Russia and the United States. In the United States, all or portions of the buildings in Klamath Falls, Oregon; Boise, Idaho; and Pagosa Springs, Colorado, are heated with geothermal heat. A housing area of 20,000 persons in Budapest, Hungary is totally heated by geothermal heat.

While the natural heat-flow from the center of the earth is normally too diffuse to capture, as we have just seen there are many areas in the world where pockets of geothermal heat found close to the surface have been developed and put to beneficial use. It is to anomalous areas of concentrated heat such as these that exploration and developmental efforts are now being directed by many companies and individuals.

These geothermal heat resource areas, like any natural resource deposit, are governed by the geological environment in which they occur. And like any other natural resource deposit, if they are to be economical, they must meet several conditions. First, there must be a heat source. As shown in Figure 1, this heat source is usually visualized as a cooling magma. This heat source must be sufficiently large to give off continuous heat for a period of time long enough to amortize the original investment cost and to realize a profit. There must be, above the heat source, a reservoir of permeable rocks (Figure 1). This reservoir must be shallow enough to be reached by present day drilling methods. The reservoir should be several tens of cubic miles in extent and should be sufficiently permeable to allow for a high rate of flow of steam or hot water. The heated waters or resulting steam must flow to wells for sufficient periods of time to allow the venture to pay off. The hot fluids found within the reservoir should not contain an excessive amount of dissolved solids; otherwise, they will precipitate out and plug the surface equipment.

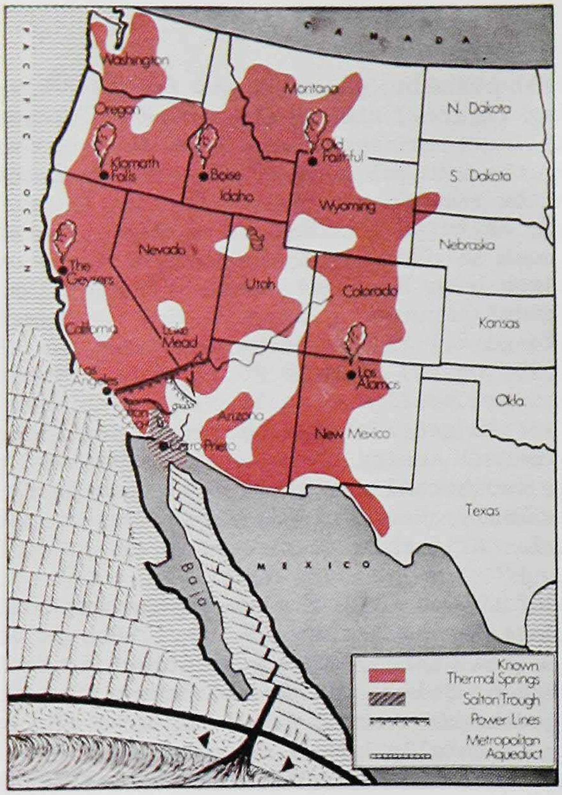


Figure 6. Map of western United States showing areas having potential for geothermal resources based on occurrence of thermal springs. (From U.S. Bureau of Reclamation).

Some type of capping mechanism, usually an impermeable cap rock, must be present above the reservoir to prevent premature escape of the hot water or steam from the reservoir. As shown on Figure 1, it is quite common for these reservoirs to be cut by faults along which the heated water may move to the surface very rapidly and in doing so may boil or flash to steam. If this occurs, then a geyser may be formed, like Old Faithful (Figure 2), or a steam vent is formed. On the other hand, if the fault is closed or "tight", then the fluid cannot move up as rapidly and in doing so begins to cool. When the fluid reaches the surface, it may be so cooled that only a warm spring exists.

From comments that I have made, you might have drawn the conclusion that oil companies are actively engaged in the development of this resource. There is a reason for their involvement. Most of the exploration and development technology used by the oil industry is directly applicable to geothermal resources. Figure 3 shows a typical oil field drilling rig drilling for geothermal steam and hot water at Cerro Prieto, Mexico. While the technology of the oil industry is applicable to geothermal resources, I like to stress that the level of knowledge concerning exploration and development of geothermal resources

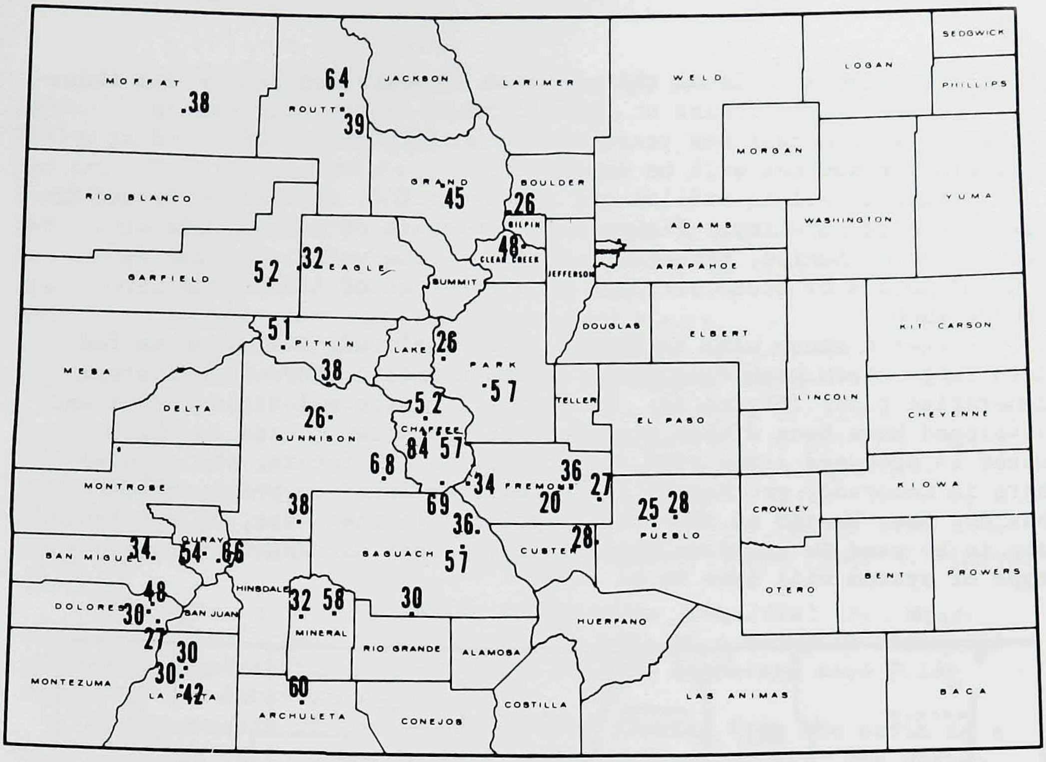


Figure 7. Location and reported temperatures (^{o}C) of 41 thermal springs in Colorado

Figure 8. Mount Princeton Hot Springs, Colorado

is at about the same level that existed 75 years ago in the oil industry. We are still looking at the oil seeps -- the hot springs. Hopefully in the next few years new technology wholly directed at geothermal resources will be developed.

After a well is drilled and is successful, it must be tested to determine its capacity. Figure 4 is a picture of such a well at Cerro Prieto, Mexico, undergoing testing. The well is producing 800,000 pounds of steam per hour at a pressure of 675 pounds per square inch.

After a steam well is drilled and completed, the steam is fed into large steam gathering lines and then into a conventional steam generating plant (Figure 5). To date all geothermal fields found and developed have been either dry steam or wet steam fields in which water is produced along with the steam. In the future, and probably here in Colorado, geothermal fields will be found in which the water has not been heated to the boiling point. In that case, if the fluids are to be used to generate electricity, a heat exchanger or some other type of system will have to be used.

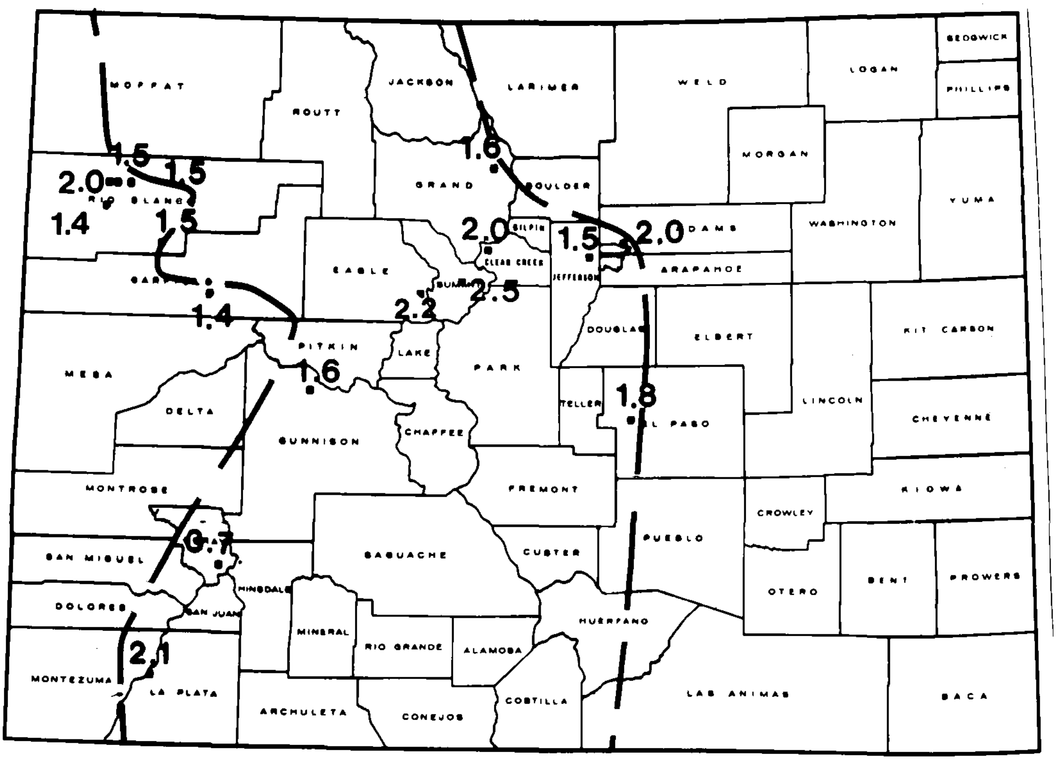


Figure 9. Map showing the 16 published heat-flow measurements that have been made to date in Colorado. Values given are in H.F.U. 1.5 H.F.U. world wide average heat-flow rate.

Figure 6, taken from a U. S. Bureau of Reclamation report, based primarily on the occurrence of hot springs in the western United States, shows the area in the western United States which they feel has potential geothermal resources. In their opinion, much of western Colorado has potential. Incidentally, the U. S. Geological Survey, a few years ago, estimated that there were approximately 1 million acres in western Colorado that had prospective value for geothermal resources. This land was in the immediate vicinity of the many hot springs in western Colorado. The Colorado Geological Survey, on the other hand, believes that this figure is too low and there is more nearly 25 million acres having prospective value in central and western Colorado.

Turning closer to home, in 1920, the Colorado Geological Survey published Bulletin 11, Mineral Waters of Colorado, in which is given the location, volume of flow, temperature and chemical analysis of over 200 thermal springs (temperatures in excess of 70°F) in Colorado. Resampling of these springs began in 1966. To date, 41 of them have been relocated, measured and sampled. Figure 7 shows these 41 thermal springs.

What does a thermal spring in Colorado look like? one, Mount Princeton Hot Spring, Figure 8, is the site of a recently announced geothermal exploration project which will be discussed more fully by one of the later speakers.

Measurements of the amount of heat flowing from the earth is a very valuable exploration tool in geothermal resources. The world-wide average of heat flowing from the earth's center is 1.5 H.F.U.'s. Anything in excess of that value warrants attention. Sixteen measurements of heat-flow have been made in Colorado and published. Fig. 9 shows the distribution of these measurements and values determined. If one draws a line between areas of high or moderate heat flow and normal or subnormal heat flow here in Colorado, it is seen that most of western Colorado is located in an area of above normal heat flow and therefore should be considered as an area that has potential geothermal resources.

In conclusion, this conference hopefully will begin to build a bridge of understanding between the person who asked this morning, "What is geothermal?", and the technical person tryping to figure out, "How the heck do I turn a geothermal heat anomaly into a commercial project which will not only furnish power to the energy hungry people of the United States, but also make some money for my company". This bridge should be strengthened with later papers to follow.

SUMMARY OF GEOLOGY OF COLORADO RELATED TO GEOTHERMAL ENERGY POTENTIAL

L. T. Grose[1]
Golden, Colorado

ABSTRACT

The Rio Grande rift system and peripheral areas in south-central Colorado are characterized by late Cenozoic volcanism, tensional block faulting and thick graben fill, thermal springs and wells, and abnormally high heat flow. All of these factors raise expectations for the occurrence of commercial geothermal (hydrothermal) energy sources which may be within reach of the drill.

INTRODUCTION

This paper is an overview of those aspects of the geology of Colorado that relate to a first-phase assessment of the geothermal energy potential within the State. The subject is discussed on a regional basis and in reconnaissance rather than on a local anomaly basis or in detail.

Geothermal energy investigations in Colorado, as compared to those in the Basin and Range Province and the Far West States, are presently in the initial reconnaissance state. In Colorado the recovery of geothermal energy from hydrothermal systems and hot dry rock masses seems possible within the framework of modern technologic capabilities. This report will briefly cover, on a regional basis, those basic thermogeologic and geologic features that relate directly to the hydrothermal energy potential of Colorado. Hot dry rock and even magma sources will be discussed inferentially.

MAJOR TYPES OF GEOTHERMAL RESOURCES

The four major types of geothermal resources are: 1) hydrothermal systems which include dry steam and hot water, 2) geopressured systems, 3) hot dry rock masses, and 4) magma systems. Knowledge and experience acquired over the last fifteen years in many countries relating to the exploration, development, and production of energy from hydrothermal systems places this form of geothermal resource well ahead of the other three regarding the potential for successful exploitation in the present and very near future is concerned. Knowledge and experience pertaining to assessment of energy derivable from geopressured systems, hot dry rock, and magma are in the earliest stages of development, and therefore are largely speculative at the present time.

GEOLOGICAL CHARACTERISTICS OF GEOTHERMAL AREAS

All geothermal exploration programs must assess in the reconnaissance phase the following thermogeological characteristics of the region under investigation: 1) volcanism, 2) tectonism, 3) surface thermal phenomena and hydrologic regime, and 4) heat flow. If these

[1]Colorado School of Mines

characteristics appear favorable, then several exploration methods utilizing detailed geology, geophysics, and geochemistry should usually be applied for prospect refinement and initial exploratory drilling (Banwell, 1970,1973; Combs and Muffler, 1973; Grose, 1971,1972; McNitt, 1973; Sigvaldeson, 1973; and White, 1970).

Some important aspects of the above characteristics which may indicate environments favorable for the occurrence of a potentially commercial hydrothermal energy source are:

1. Volcanism
   a. Volcanic activity should usually be younger than 5 million years (Pliocene to Quaternary in age).
   b. In continental environments silicic or intermediate rocks usually are preferable compared to basic and alkalic basic rocks.
   c. Shallow plutons, thick sills, and calderas are usually preferable compared to thin dikes and sills and slender pipes.
   d. The older the igneous mass, the larger and more equidimensional it should be to retard heat dissipation and loss.
2. Tectonism and Seismicity
   a. Normal faulting, rifting, and extension.
   b. Pliocene to Quaternary in age.
   c. Active faulting associated with swarms of microseismic events.
   d. Deep and repeated tensional faults with intersecting fault zones.
3. Surface thermal phenomena and hydrologic regime
   a. Hot springs.
   b. Low chloride content (less than 20 mg/l) of the spring water and small discharge of near-boiling water strongly suggests the presence of the more attractive vapor-dominated systems (White and others, 1971).
   c. Presence of a thick sequence of interlayered permeable and impermeable beds in a graben that is being recharged with meteoric waters.
4. Heat flow
   a. Above world wide average of 1.5 HFU (Heat Flow Units), preferably above 2.0 HFU.
   b. Above normal gradient (2.5 to 3.0^{o}C per 100 m), preferably above 4^{o}C per 100 m.

The following sections summarize aspects of these features which bear upon the general geothermal energy potential of Colorado.

VOLCANISM

Cenozoic volcanic geology of Colorado is discussed in numerous papers; some of the more comprehensive are: Epis (1968); Larson and Cross (1956); Lipman (1969); and Lipman and others (1970).

The greatest period of volcanic activity in Colorado occurred

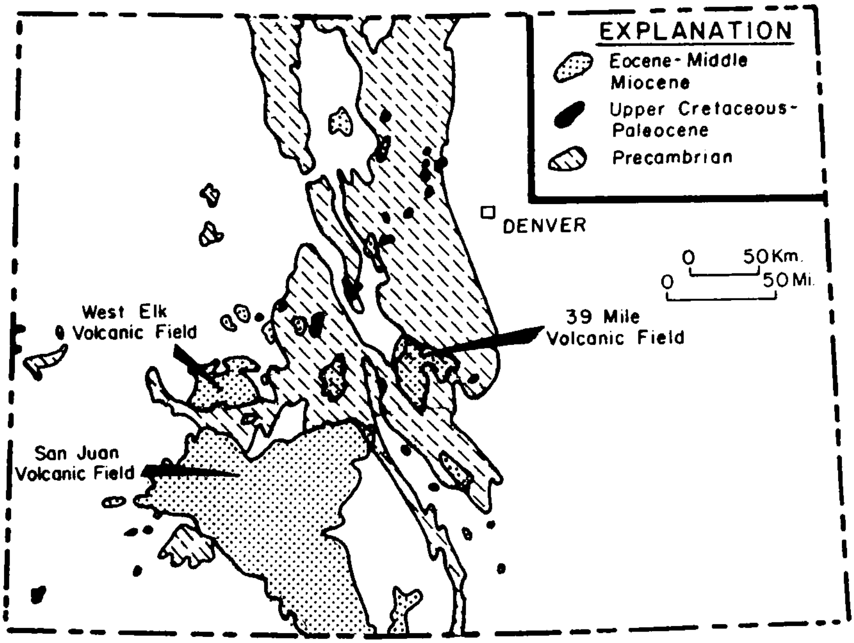


Figure 1. Upper Cretaceous to middle Cenozoic igneous rocks (Modified from Stevens and others, 1972).

from 40 to 20 m.y. (million years) ago (Oligocene through early Miocene). Erosional remnants of a once continuous volcanic field which was formed during this period of time include the San Juan, Thirty-nine Mile, West Elk and other smaller fields (Fig. 1). Rhyolitic to andesitic flows and breccias were extruded from many scattered composite volcanoes. Ash flow sheets erupted from at least fifteen calderas which were probably superjacent to shallow plutons. Total thickness of rocks formed during this period collectively amounts to several thousands of feet. Two peaks of volcanic activity, which occurred during this period, have been noted by Lipman and others (1970). During the first peak, 30 to 35 m.y. ago, 40,000 km^3 of andesitic flows and related rocks were formed. During the second peak, 30 to 26 m.y. ago, 20,000 km^3 of rhyolite-quartz latite ash flows were deposited (Fig. 2). This period of impressive volcanic activity ended about 22 to 30 m.y. ago, but probably, because of its antiquity, it bears little direct relationship to the present geothermal regime of Colorado.

A distinctly new period of volcanism began in association with the inception of crustal rifting about 22 m.y. ago and continued into the Quaternary. In south-central Colorado, rocks of this period are a bimodal association of basalt and silicic alkali rhyolite. The basaltic varieties greatly predominate over the other rock types and comprise a much smaller volume, only about 1,000 km^3, than those formed in the earlier period. Eruptive centers were small, isolated,

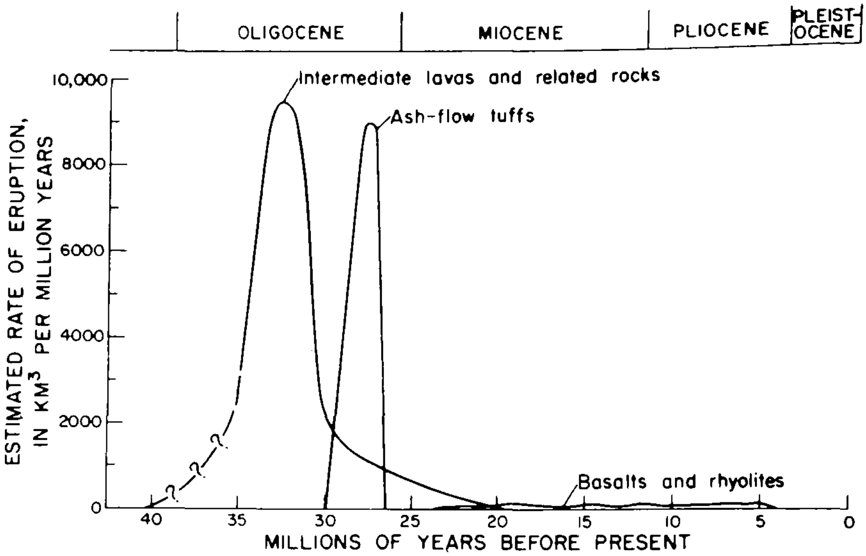


Figure 2. Relation between petrologic type, volume, and time San Juan volcanic field (From Lipman and others, 1970).

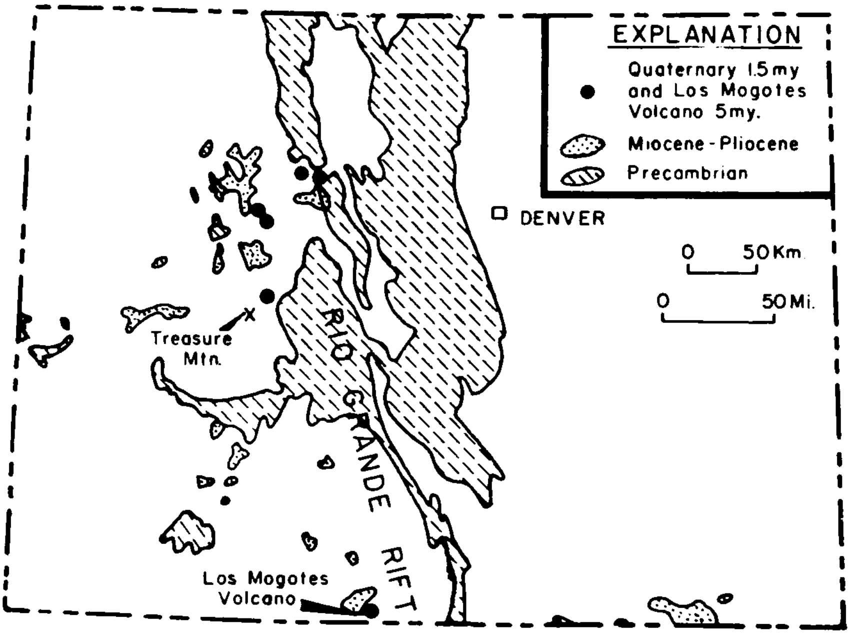


Figure 3. Upper Cenozoic igneous rocks (Modified from Stevens and others, 1972).

and widely scattered within a 150 km wide area peripheral to the Rio Grande rift system (Fig. 3). Alkali basaltic rocks radiometrically dated at 24-20 my., 14-9 m.y., 8 m.y., and 1.5-0.04 m.y. in age locally occur in northwestern Colorado (Larsen and others, 1973). In west-central Colorado small cinder cones and associated flows having erupted during the last 1.5 m.y. are found at five localties (Fig. 3), the youngest eruption occurred about 4,000 years ago near the town of Dotsero (Fig. 4). This eruption is the most recent volcanic activity in Colorado. In the Elk Mountains, 20 miles southwest of Aspen, the Treasure Mountain pluton (Obradovich and others, 1969) is the youngest known granitic body (12 m.y. in age) in Colorado (Lipman, personal comm., 1974). In the eastern part of the San Juan volcanic field, volcanic activity has produced a small volume of thin flows of basalt and rhyolite rocks dated variously between 25 and 5 m.y. in age. These rocks are included generally within the Hinsdale Formation (Larsen and Cross, 1956). The Hinsdale Formation also includes the youngest volcanic rocks in the San Juan region: the 5 m.y. old alkalic olvine basalt from the Los Mogotes shield volcano (Fig. 3), and the 4.8 m.y. old No Aqual rhyolite plug dome located some 15 miles south of the Colorado-New Mexico border along U.S. High-

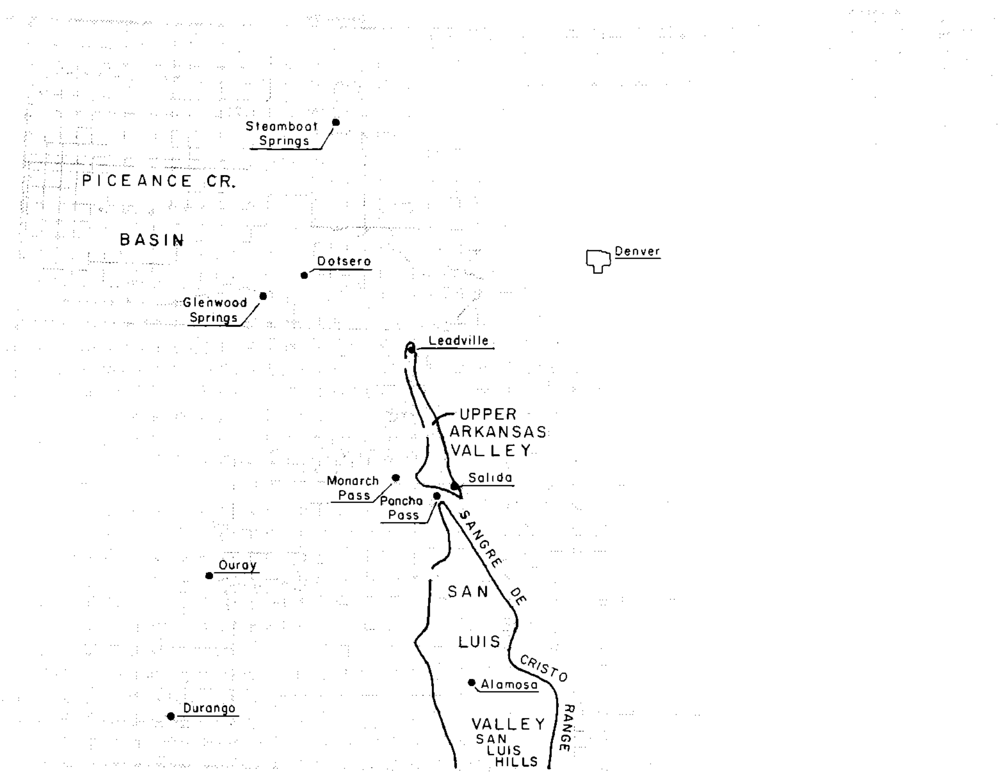


Figure 4: Geographic Index Map

way 285 (Lipman, 1970). East of the Rio Grande rift and the Rocky Mountain front on the plains of southeastern Colorado and northeastern New Mexico is a flow-on-flow sequence of alkalic basalts of late Pliocene to Holocene age. Included herein are the Raton, Clayton, and Capulin basalts of Collins (1949). The youngest basaltic vent in this area, the Capulin Cone, 15 miles south of the Colorado-New Mexico state line, was active 10,000 to 4,500 years age (Baldwin and Muehlberger, 1959).

Within the Rio Grande rift proper in the southern portion of the San Luis Valley of Colorado and New Mexico, olivine tholeiitic basalt flows assigned to the Servilleta Formation have accumulated to over 800 feet in thickness. These rocks have been dated at 4.5 to 3.6 m.y. and they comprise the youngest volcanic rocks within the northern part of the Rio Grande rift system in Colorado (Lipman, 1969). These intrarift tholeiites which erupted through the higly faulted and attenuated crust of the Rio Grande rift stand in contrast to the alkalic basalts erupted through the relatively unfaulted thick continental crust on both sides of the rift. On the basis of mineralogical, chemical, and experimental fractionation data, the Servilleta basalts are believed to have been derived from depths of 15 to 20 km while the peripheral alkali basalts were concurrently generated from depths of 35 to 70 km (Lipman, 1969). This suggests that the Rio Grande rift is underlain by an upward protrusion of hot mantle rocks (Fig. 5) and hence forms a locus of abnormally high heat flow having isotherms of relatively higher values at shallow depths. These conditions are analogous to certain volcanotectonic rifts in the Basin and Range Province and in the East African-Red Sea rift system.

The geothermal regime of Colorado does not appear to be locally or strongly controlled by known surface volcanic phenomena. However, it is entirely possible that latent deep igneous masses may be found to occur in association with the Rio Grande rift system, for geologically speaking, the system as a whole is still an active volcanotectonic region of anomalously high heat flow.

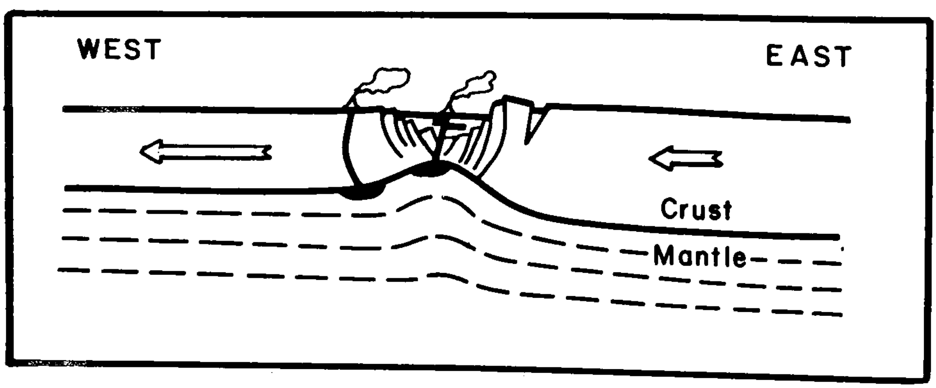


Figure 5. Schematic cross section of the Rio Grande rift system in south-central Colorado (From Chapin, 1971).

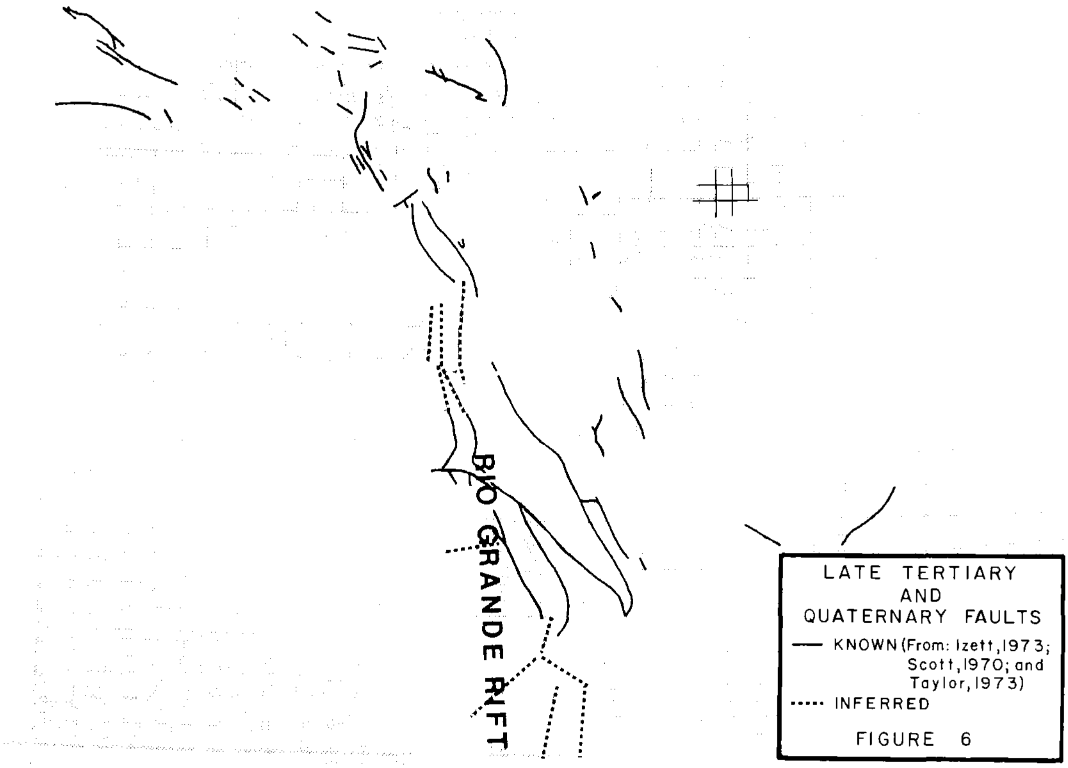


FIGURE 6

TECTONISM AND SEISMICITY

Of the middle and late Cenozoic (post Eocene or post Laramide) tectonic geologic history of Colorado, relatively little has been known until recently when several articles by Chapin, (1971); Chapin, and others, (1970); Izett, (1973); Knepper, (1974); Lowell, (1971); Scott, (1970); and Taylor, (1973) were published.

After the end of the Laramide orogeny in Eocene time 25 to 20 m. y. ago, which produced most of the structural relief but little physiographic relief in Colorado and coincident with the ending of the major San Juan volcanic period and the beginning of the bimodal basalt-rhyolite volcanic period (Christiansen and Lipman, 1972; and Epis and Chapin, 1973) the single most important tectonic feature, relative to the geothermal resources of Colorado began to form, the Rio Grande rift system (Fig. 6).

The tectonic features and genesis of the Rio Grande rift system are discussed by Chapin, (1971,1971a). In Colorado the morphotectonic expression of the system extends northward from New Mexico through the San Luis Valley and the upper Arkansas Valley to Leadville (Fig. 4). The San Luis Valley is the deepest graben along the entire rift zone with sedimentary and volcanic fill totaling possibly as much as 30,000 feet as interpreted from gravity data (Gaca and Karig, 1966). The eastern boundary along the base of the Sangre de Cristo Range is normal faulted. The western side of the valley consists mainly of

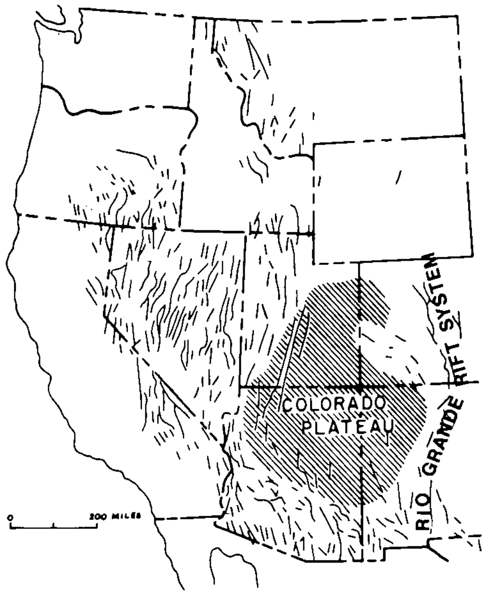


Figure 7. Rio Grande rift system and other faults in the Basin and Range Province (*in* Gilluly, 1972, and modified from tectonic map of the United States, 1961, publ. by U.S. Geol. Survey and Amer. Assoc. Pet. Geol.).

east-dipping mid-Tertiary San Juan volcanic rocks projecting beneath the thick graben fill of the valley.

The geometry of the normal faults within the grabens of the Rio Grande rift system is little known. However, the presence of exposed older (pre-Miocene) "basement" rocks within the rift, such as those in the San Luis Hills in the southern part of the San Luis Valley (Fig. 4)(Burroughs, 1971) and those in the Poncha Pass area (Knepper, oral comm., 1974) and the presence of oblique and cross faults along the rift margins suggest that the depression is a complex of intra-rift hosts and grabens, indicating a pattern of crustal extension.

A complex transverse horst in the vicinity of Poncha Pass and Salida divides the San Luis Valley from the upper Arkansas Valley (Knepper and Marrs, 1971). The upper Arkansas Valley is apparently strongly faulted on both sides with the graben fill complexly deformed. Gravity and magnetic features of the region are discussed in a paper by Tweto and Case (1972).

Normal faulting, which may be regarded as an integral part of the greater Rio Grande rift system, extends well north of Leadville along both flanks of the Gore Range and along the west flank of the Park Range beyond Steamboat Springs to near the Wyoming state line (Figs. 4,6, and 8).

The continuing development of the Rio Grande rift system in Colorado is attested to by the many fault scarps found (Knepper and Marrs,

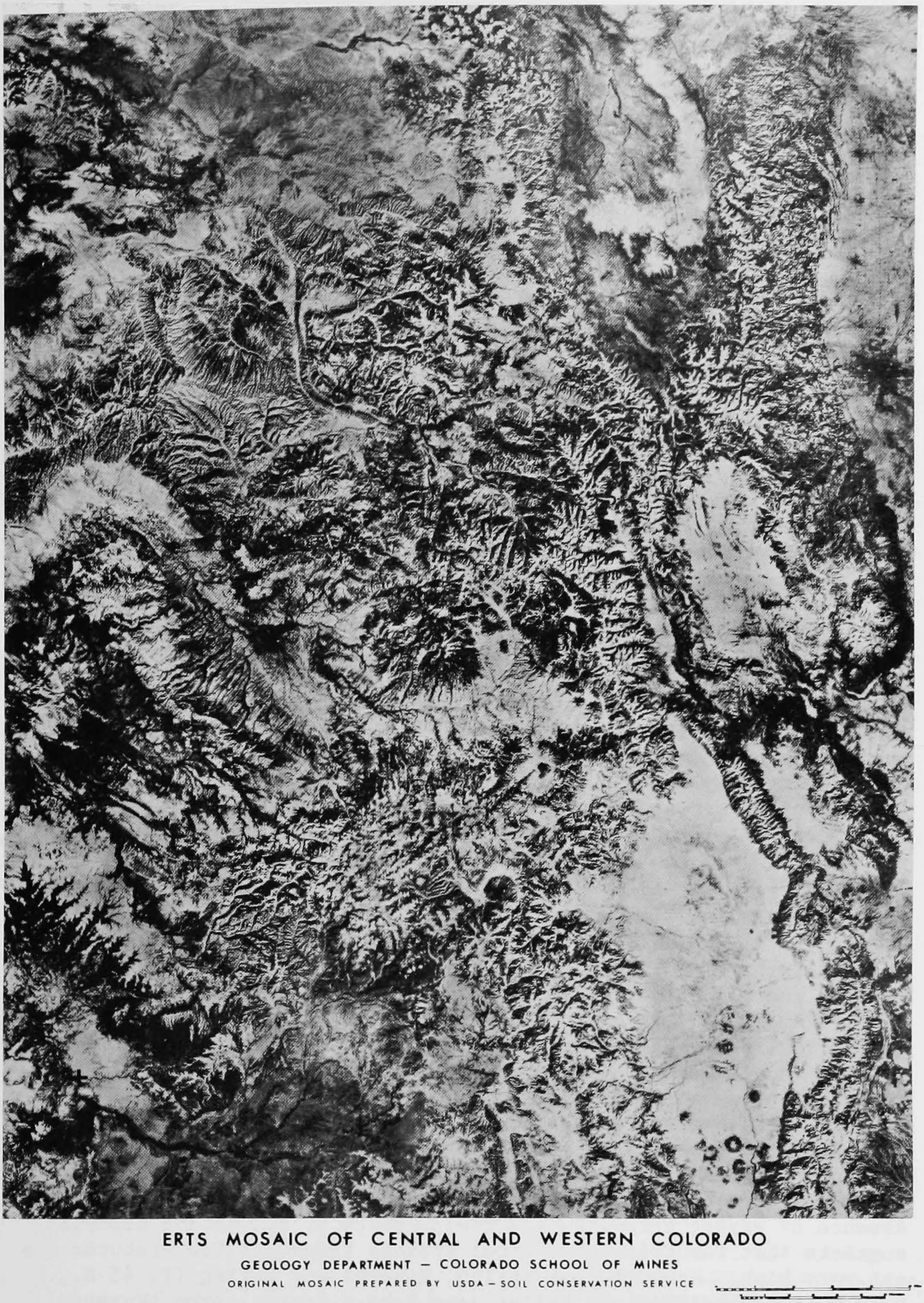


Figure 8. Mosaic of central and western Colorado made from ERTS (Earth Resources Technology Satellite) multispectal scanner images. Rio Grande rift zone of New Mexico-Colorado extends from lower right to upper left center. Dark area approximately one-third down from top on right side of photo. is Denver metropolitan area.

1971; Scott, 1970; Tweto, 1961; and Upson, 1939). In a wide zone generally peripheral to the Rio Grande rift proper (Fig. 6), numerous faults have recently been detected (Izett, 1973; Scott, 1970; Taylor, 1973; Tweto and others, 1970) that have been periodically active during the last 20 m.y.

The occurrence of active normal faulting in, and peripheral to, the Rio Grande rift system during the last few million years points up a pattern of crustal extension and thinning characteristic of the Basin and Range geothermal province covering much of the Cordillera farther west (Fig. 7). Indeed the Rio Grande rift system appears to be an extension of the Basin and Range province northward into Colorado caused by a westward movement of the Colorado Plateau block relative to the Great Plains block.

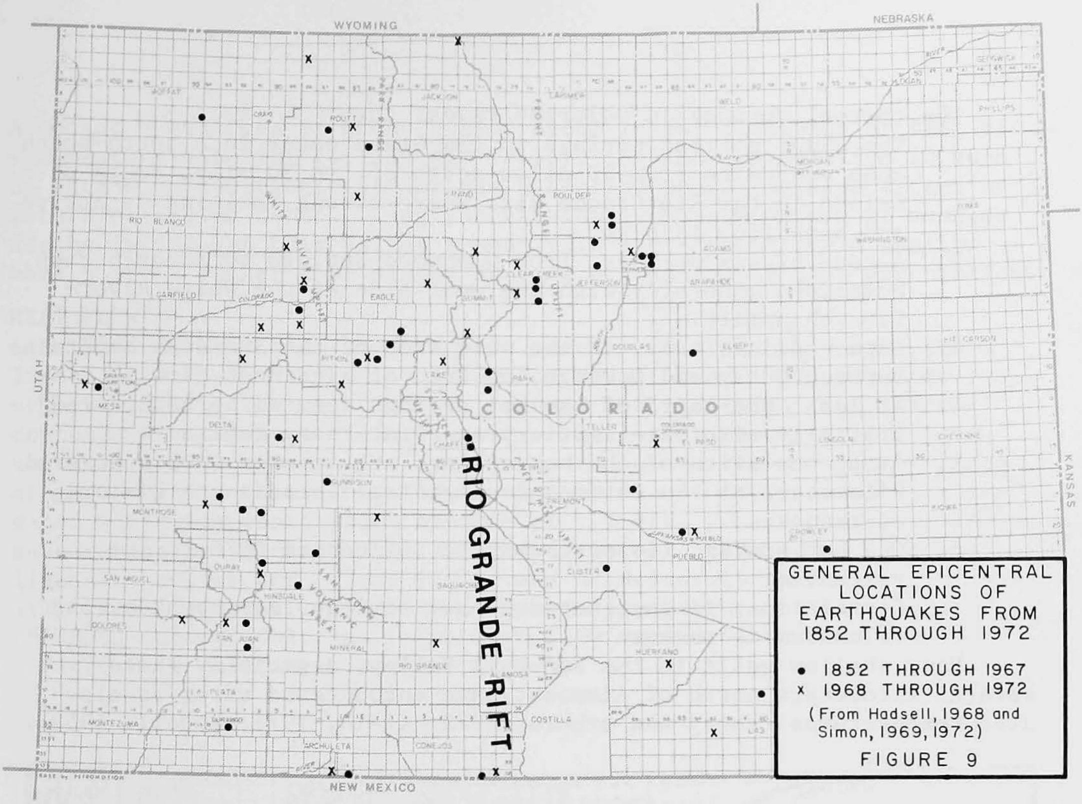
The occurrence of Pliocene and Quaternary rifting in Colorado along deep and intersecting fractures producing deep and thickly filled grabens compares favorably with many known rift zones in productive geothermal areas of the world. The tectonic regime of the Rio Grande rift system in Colorado is highly favorable for the occurrence of commercial geothermal energy cells.

Historic seismicity of Colorado, spanning over a century (Fig. 9) (Hadsell, 1968; and Simon, 1969, 1972) appears to be unrelated to specific tectonic features, but in general appears to reflect faintly the northeast-southwest trending "Colorado Mineral Belt". Although over 20% of the earthquake data may be skewed to population centers and distorted by man's activities, a surprising fact is that few of the epicenters are known to correlate with faults of the tectonically active Rio Grande rift system. Perhaps microseismic surveys along geothermal anomalies within the rift zone will reveal above normal activity. Little has been published on this subject in Colorado.

THERMAL SPRINGS

Physical and chemical data are provided for over a third of the 113 hot springs and wells in Colorado by George and others, (1920); Mallory and Barnett, (1973); Pearl, (1972); and Waring, (1965).

Figure 10 shows the location and temperature contours of the above hot springs and wells. Obviously the highest temperatures follow the Rio Grande rift system and secondary highs occur in the western San Juan Mountains and possibly along the Front Range. The hottest springs in Colorado are located on large faults at the south end of, and along the west side of, the upper Arkansas Valley. The hottest spring in Colorado is Hortense Hot Spring, having a maximum temperature of 84^{o}C (183^{o}F) (Pearl, 1972). The lack of siliceous sinter deposits, absence of geyser activity, and the presence of travertine deposits suggests that the Colorado thermal springs reservoir temperatures are not very high. However, one spring, Mineral Hot Spring (T. 45 N., R. 9 E.) in the San Luis Valley does have a sinter apron (Knepper, personal comm., 1974).

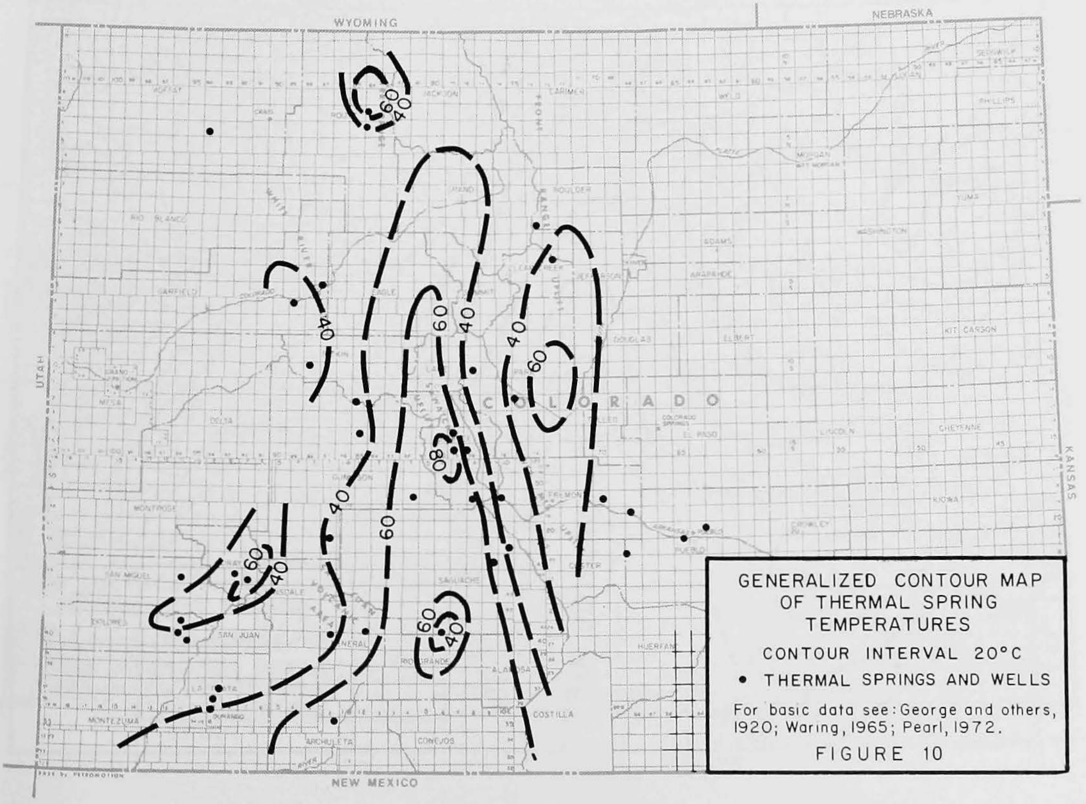


GENERAL EPICENTRAL LOCATIONS OF EARTHQUAKES FROM 1852 THROUGH 1972

• 1852 THROUGH 1967
x 1968 THROUGH 1972

(From Hadsell, 1968 and Simon, 1969, 1972)

FIGURE 9



GENERALIZED CONTOUR MAP OF THERMAL SPRING TEMPERATURES

CONTOUR INTERVAL 20°C

• THERMAL SPRINGS AND WELLS

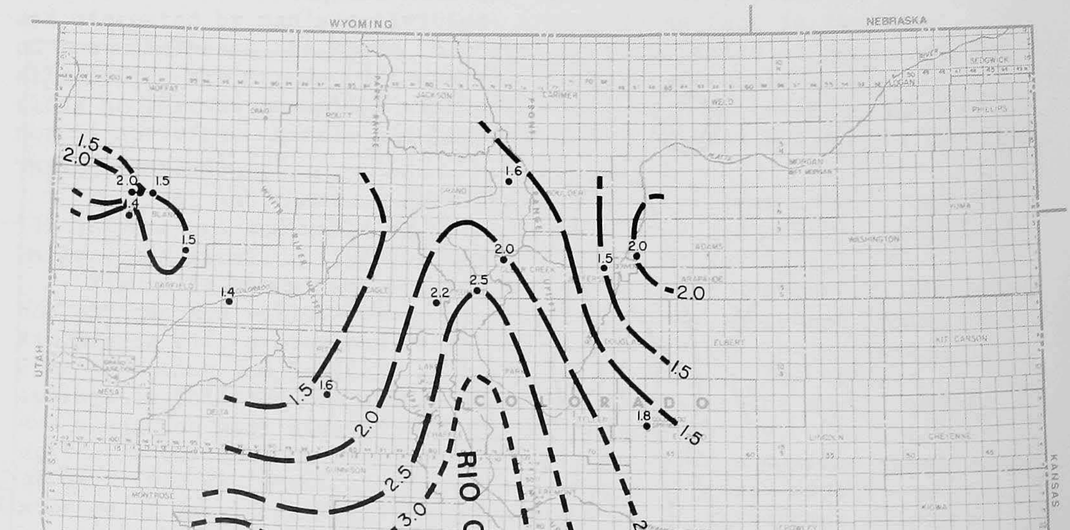
For basic data see: George and others, 1920; Waring, 1965; Pearl, 1972.

FIGURE 10

The thermal springs in Colorado reveal that:

1. The eight hottest springs in the State occur in a north-south zone extending from 30 miles north of, to 30 miles south of, Salida in the Rio Grande rift where strong faulting is active and heat flow is high.
2. A zone of six springs, from Glenwood Springs to Monarch Pass, coincides generally with the west side of the White River-Sawatch uplift.
3. Eight springs occur on the west side of the San Juan Mountains between Ouray and Durango, an area of high heat flow.
4. At least one-third of the hot springs seem to be associated spatially with late Tertiary and Quaternary faults.
5. About one-sixth of the hot springs are located within several kilometers of the estimated epicentral location of historic earthquakes.
6. One hot spring, (Dotsero) may be influenced by Holocene volcanism.
7. Correlation, if any, between hot springs, earthquakes, and volcanism is obscure.

Many shallow wells in the San Luis Valley, especially those several kilometers north of Alamosa, have encountered water at elevated temperatures (Emery and others, 1972; Klein, 1971; Powell, 1958).



PRELIMINARY CONTOUR MAP OF HEAT FLOW VALUES

CONTOUR INTERVAL 0.5 HFU

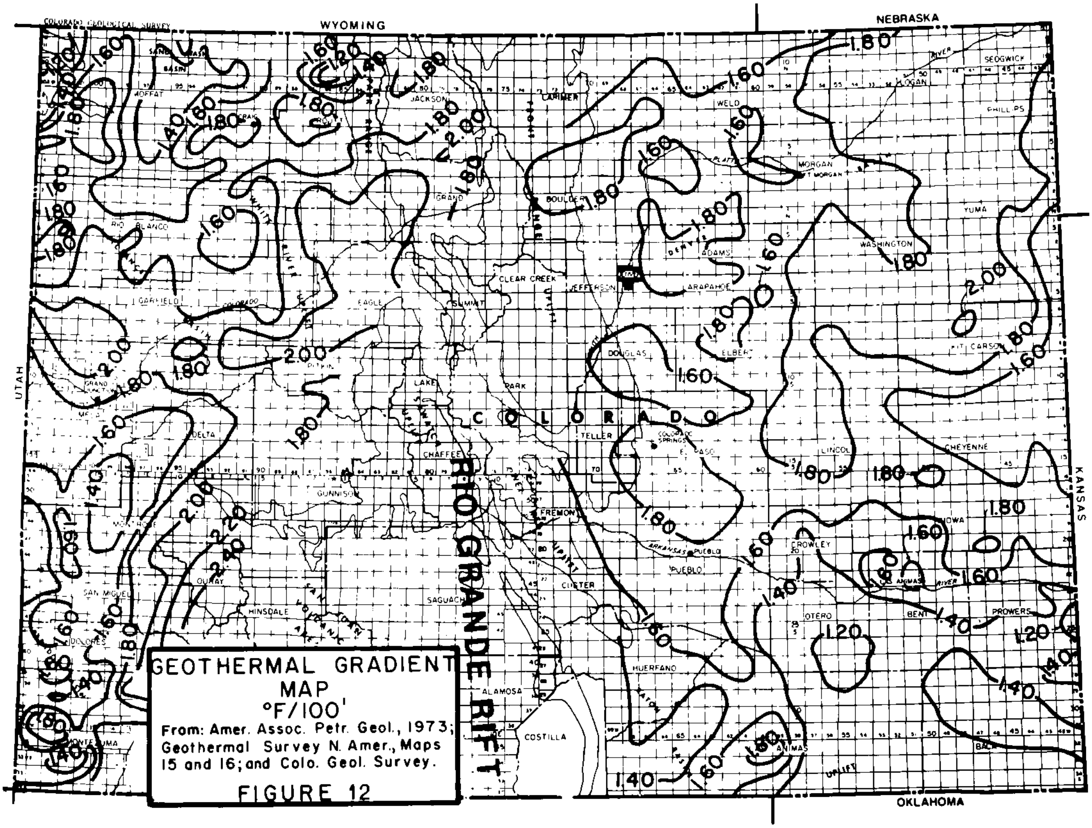
For basic data see: Birch, 1950; Decker, 1969; Roy and others, 1969; Sass and others, 1971.

FIGURE 11

Abundant quantities of ground-water occur in the thousands of feet of sedimentary material filling the Valley. Shallow circulation in such an extensive hydrologic system has a cooling and dispersive effect on waters heated at depth. Thus the existence of warm waters at shallow depths in the San Luis Valley probably indicates relatively shallow heat sources rather than simply heating by abnormally deep circulation.

HEAT FLOW

Sixteen heat flow measurements made in Colorado have been published (Birch, 1950; Decker, 1969; Roy and others, 1968; Sass and others, 1971). Their locations, values, and preliminary heat flow contours are illustrated in Fig. 11. The lowest measured heat flow value, 1.4 HFU (microcal/cm^2/sec), occurs in the Piceance Creek Basin of northwestern Colorado. These values are essentially at the estimated worldwide continental average of 1.5 HFU. The highest published measurement in Colorado is 3.7 HFU near Ouray. Data soon to be published by Reiter and others (1973; and M. Reiter, personal comm., 1974) will reveal abnormally high heat flow in the Rio Grande rift region of south-central Colorado. The heat flow contours shown in Fig. 11 reflect this positive heat-flow anomaly.



GEOTHERMAL GRADIENT MAP °F/100'
From: Amer. Assoc. Petr. Geol., 1973; Geothermal Survey N. Amer., Maps 15 and 16; and Colo. Geol. Survey.

FIGURE 12

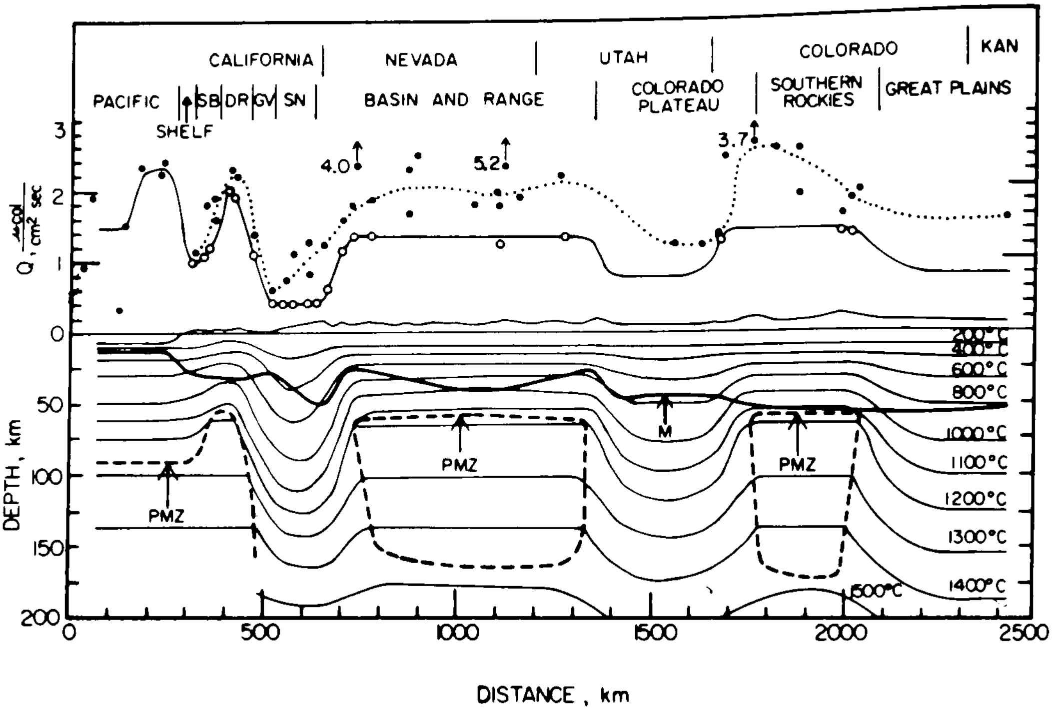


Figure 13. Heat flow, crustal thickness and calculated temperatures in cross section across the western United States at about 38°N latitude. Solid dots represent observed heat flow, Q, at the surface; open circles represent reduced heat flow. M indicates the Mohorovicic discontinuity. PMZ indicates the inferred Partial Melt Zone in upper mantle. SB-Salinian Block, DR-Diablo Range, GV-Great Valley, SN-Sierre Nevada (From Roy and others, 1972).

The regional geothermal gradient map of Colorado (Fig. 12), which may be generally regarded as an indicator of heat flow, demonstrates normal gradients and heat flow in the areas of sedimentary rock outcrops where abundant oil well data is available. These areas, for the most part, do not coincide with the Rio Grande rift system.

An east-west crustal and upper mantle cross section (Fig. 13) across the western U.S.A. at about 38 deg north lat., which passes through Colorado south of Salida shows an interpretation of the temperature and heat flow regime according to Roy and others, (1972). The area on Fig. 13 defined as Southern Rockies is essentially the Rio Grande rift system in Colorado. Similarities between the Rio Grande rift system and the Basin and Range geothermal province are evident, except for the interpreted crustal thickness within the rift zone. However, the origin and setting of the volcanic rocks and the extensional faulting discussed earlier suggests that the crust thins beneath the Rio Grande rift zone as illustrated schematically in Fig. 13

The heat flow of probably twice the normal crustal average that appears to coincide with the Rio Grande rift system in Colorado is a significant positive factor in regional geothermal potential evaluations.

CONCLUSIONS

The model of the Rio Grande rift system in Colorado is an attractive one for the occurrence of economic geothermal (hydrothermal) energy. It incorporates Pliocene volcanic rocks with a possibility of younger buried intrusions, active tensional faulting, thermal springs and wells, and a thick graben fill of porous and permeable water-saturated beds, and abnormally high heat flow. The crust in the rift is believed to be extended, thinned and underlain by an upward protrusion of hot mantle rocks capable of large-scale heat transfer and capable of creating sources of heat which may be reached by the drill.

This model of the Rio Grande rift is afflicted with uncertainty because of lack of critical subsurface and other data. However, with the application of skillful and imaginative exploration methods followed by deep drilling at carefully selected sites, commercial development of geothermal energy could be realized within the State of Colorado in the next few years.

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GEOPHYSICS OF COLORADO AND GEOTHERMAL ENERGY

George V. Keller[1]
Golden, Colorado

ABSTRACT

Lack of intense surface manifestations of thermal activity such as hot springs and geysers suggests that high-quality geothermal systems are not as easy to find in Colorado as in some other western states. Based on heat flow data, gravity data and seismicity data, the parts of the state where geothermal systems are most likely to occur are the western slopes of the Rocky Mountains and the Arkansas and San Luis Valleys. However, it must be recognized that the available data on the geophysics of Colorado are completely inadequate to evaluate the potential of specific geothermal prospects.

INTRODUCTION

Colorado is fortunate in having large known reserves of conventional fuels, including gas, oil, coal, and uranium. In addition, there is a possibility that significant resources of geothermal energy are available in the state. At present, geothermal energy is a very minor source of energy in the United States, but with our growing demand for electric power and the stress this has placed on the production of conventional fuels, serious consideration is being given to accelerated development of geothermal energy throughout the western part of the country.

Geothermal energy is known to occur in a variety of forms. The best known form of occurrence is in an underground reservoir of heated water or steam. In volcanic areas, these reservoirs are also found in areas of intense tectonic activity where recent water-laden sediment has been thrust deep into the earth's crust by faulting, as at the Geysers in California and at Larderello, Italy. In such occurrences, the heat that is recovered for electric power production is contained in the fluid-water or steam-in the reservoir, and commercial production is feasible only if there is sufficient permeability in the reservoir to permit rapid production of the fluids. Many existing geothermal wells produce steam at flow rates of several hundred thousand pounds per hour, with a minimum level of production for a marginal well being about 20,000 pounds of steam per hour.

Another form of geothermal system may exist when impermeable rocks are heated. In such a case, it is not possible to recover energy merely by drilling into the heated rocks. Up to the present time, there has been no successful development of such a system, which is termed "hot dry rock". It may be possible to produce power from such systems by augmenting the inherent permeability of the rocks through fracturing using injection of fluids at high pressure or detonation

[1]Colorado School of Mines

of explosives in the hole. Augmented permeability may permit production of hot reservoir fluids if they are present, or if they are not, heat might possibly be extracted by circulating a heat-exchange fluid through the fractured rocks.

A third manifestation of geothermal systems may exist in over-pressured water reservoirs in deep sedimentary basins. When sediments are deposited rapidly in a basin, clay beds may seal off sand beds so that water cannot migrate from them as the column of sediments compacts under added load. The water pressure in the sands then becomes greater than hydrostatic, water will flow to the surface in great volumes when a drill hole penetrates such an over-pressured sand. When the sand has been buried to such a depth that the normal geothermal temperature is high enough to be of commercial interest--6 kilometers or more--such an over-pressured sand can be considered to be a geothermal reservoir. No such systems have yet been developed to produce electrical power, but consideration is being given to a prototype development project in Texas.

In evaluating the geothermal potential of Colorado, we can review the past geological and geophysical work which has been done to see whether or not conditions are favorable for the occurrence of any of these forms of geothermal systems. Modern volcanism is little evident in Colorado (see accompanying paper by L. T. Grose), and so, geothermal reservoirs related to volcanism are not likely to be abundant in the state. Little is known about the factors which control the emplacement of hot, dry rock systems, and in view of the lack of information, any of the exposed crystalline areas of the state may be considered prospective for this type of system. While a large part of the state is covered by a sequence of sedimentary rocks, there are few if any locations where depths to basement are great enough to give rise to temperatures high enough for geothermal development. The deepest section of sedimentary rocks may be present in the San Luis Valley, but it is not known whether or not overpressured reservoirs exist there.

EXPLORATION FOR GEOTHERMAL SYSTEMS

Initial small-scale development of energy from geothermal systems took place more than a half century ago at the Geysers in California and at Larderello in Italy. However, it should be noted that all the major producing geothermal fields were discovered by drilling in the vicinity of thermal surface manifestations. Only in recent years has geological and geophysical prospecting been attempted in search for new geothermal systems, and it is too early to evaluate fully the effectiveness of the methods now in use.

The most direct evidence of the presence of a subsurface geothermal reservoir is the heat which escapes from it. Therefore, the first stage in exploration is the search for hot springs and other surface manifestations of high heat flow. Waring, (1965) has published a tabulation of thermal springs in the world, including those in Colorado. None of the Colorado springs listed by Waring issued at the boiling point. Many are only slightly warmer than the surface temperature.

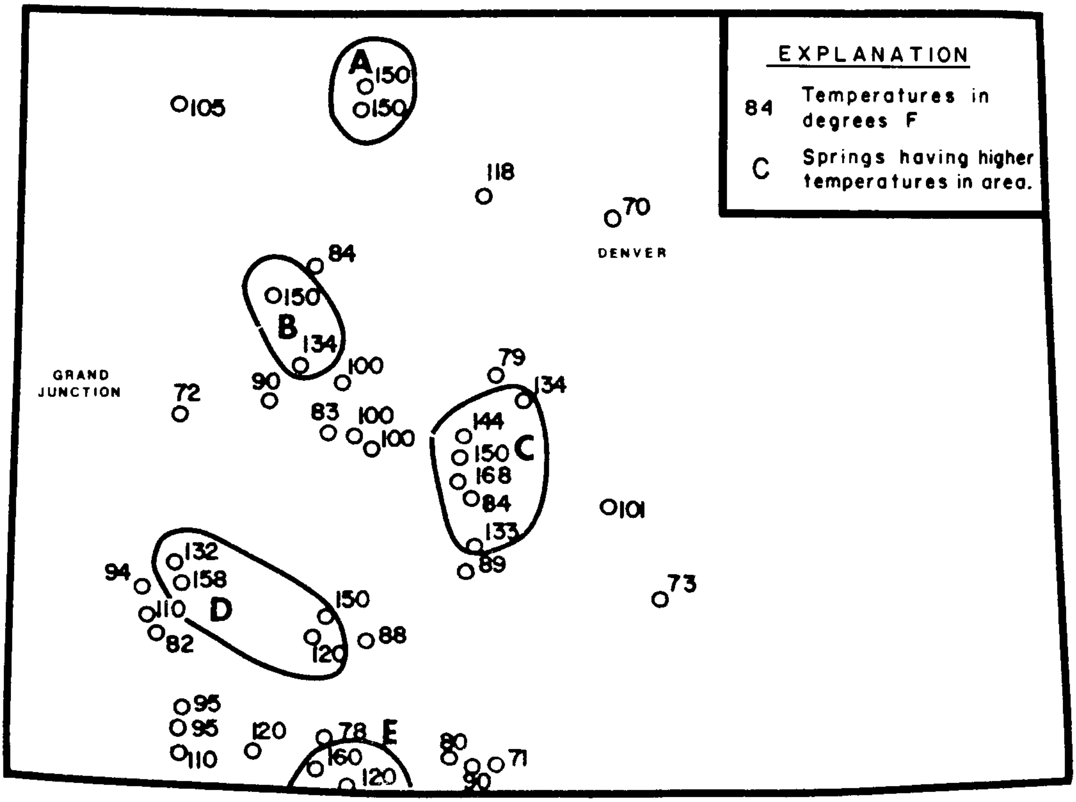

Figure 1. Location and temperature of thermal springs in Colorado.

Lack of intense thermal manifestations is discouraging from the point of view of developing geothermal energy, but not necessarily negative evidence. If the ground-water table is found well below the surface over a thermal area, thermal springs are likely to be weak indicators of subsurface heat. As may be seen from Waring's tabulation, thermal springs occur in the mountainous parts of Colorado, where rapid lateral movement of ground waters above the water table can dilute their significance markedly.

The locations of thermal springs tabulated by Waring are shown on the map of Colorado in Fig. 1. The five areas where springs issue at moderately high temperatures are circled and annotated with letters; these are, from north to south, A near Steamboat Springs, B near Glenwood Springs, C along the Collegiate Range south of Buena Vista, D in the San Juan volcanic belt, and E near Pagosa Springs. Temperatures as high as 150 to 160°F are reported by Waring for each of these areas.

Further information on the flow of heat from the ground in Colorado is available from a compilation of temperature gradients recently published by the American Association of Petroleum Geologists, (1973). Because the information used in this compilation was obtained

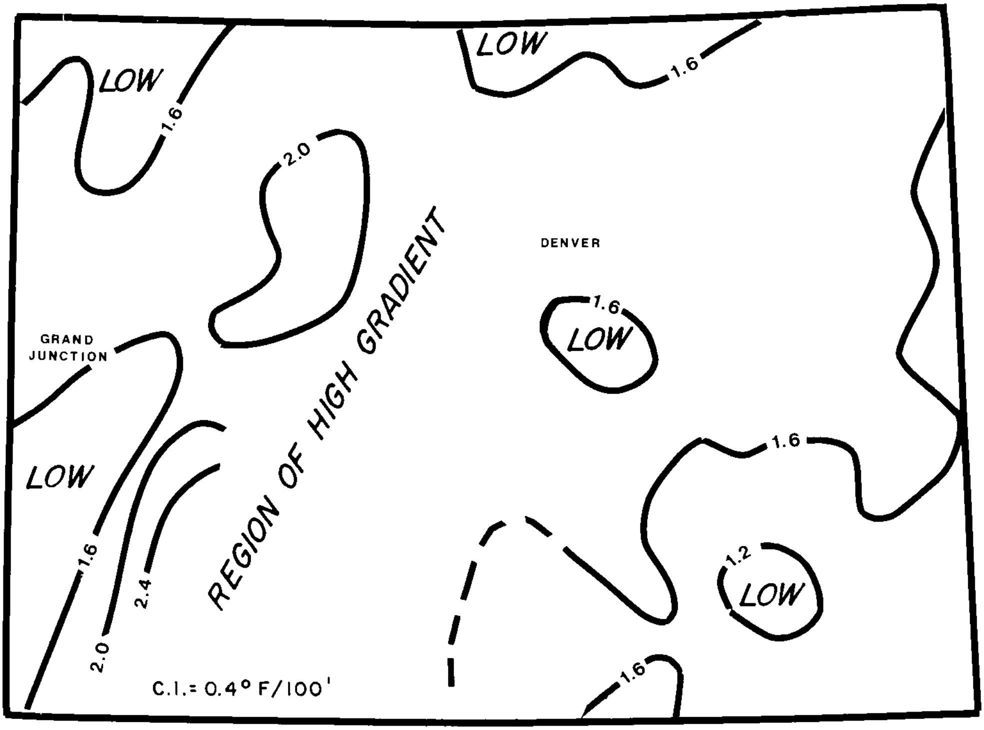

Figure 2. Geothermal gradient map (Modified after: Amer. Assoc. Pet. Geologists, 1973).

from oil wells, coverage is provided only for the eastern and western parts of the state, and not for the mountainous central portion. Contours of thermal gradients taken from the Amer. Assoc. Pet. Geol. compilation are shown on Fig. 2.

In eastern Colorado, the temperature gradients are close to normal for the types of rocks present in the sedimentary section. The northeastward trend of slightly higher values correlates with the position of the Las Animas Arch, and probably represents structural control over temperature gradients rather than a significant increase in heat flow.

In western Colorado, temperature gradients range from normal along the Utah border to quite high values along the eastern fringes of the sedimentary basins in which oil wells have been drilled. Considering all of these data, it appears that heat flow is normal and the prospects for the occurrence of geothermal systems poor in all of Colorado except for the western slope of the Rockies and the Arkansas-San Luis Valley areas.

Because surface expressions of thermal activity are not intense, further evidence suggesting that high heat-flow might exist would be reassuring. Such evidence is available from regional gravity surveys of the state of Colorado (Holmer, 1954; Qureshy, 1958; and Gaca, 1965).

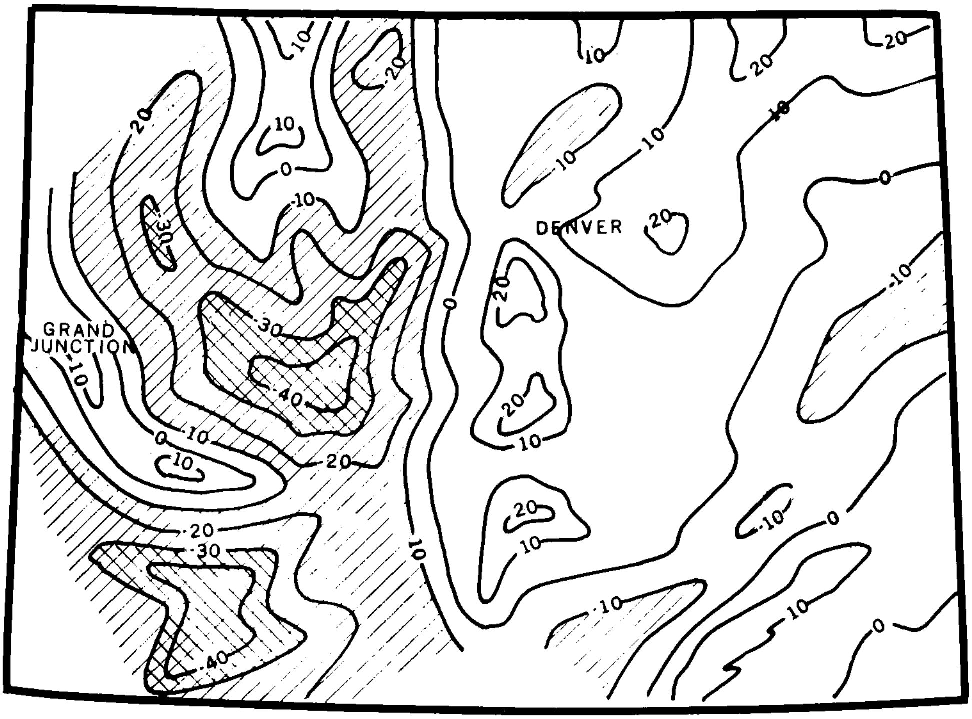

Figure 3. Pratt-Hayford gravity anomaly map of Colorado.

In discussing the results of gravity surveys made in mountainous areas, it is necessary first to correct for the éffects of isostasy-- the tendency for mountain blocks to float in isostatic balance in higher density rocks in the upper reaches of the earth's mantle. Qureshy, (1958) has made such calculations, based on a gravity survey published by Holmer, (1954), assuming various models for the way in which isostatic balance is achieved. The results of one such series of calculations are shown in Fig. 3. These are in the form of a residual gravity anomaly, persisting after corrections have been made for the presence of the mountain mass.

The feature from Fig. 3 that is of importance in geothermal exploration is the area of relatively low values of residual gravity along the western slope of the Rockies, and centered in two areas, one in the general vicinity of Steamboat Springs in the north, and the other central to the four groups of thermal springs in the south. A reasonable explanation of the low values for residual gravity, is that low-density rocks are present at the top of the mantle in these areas, and that the density has been lowered by high temperatures. The gravity data suggests that thermal springs along the west slope of the Rockies have their origin in high temperatures in the mantle. This is a favorable circumstance for the presence of geothermal systems at depth in the region.

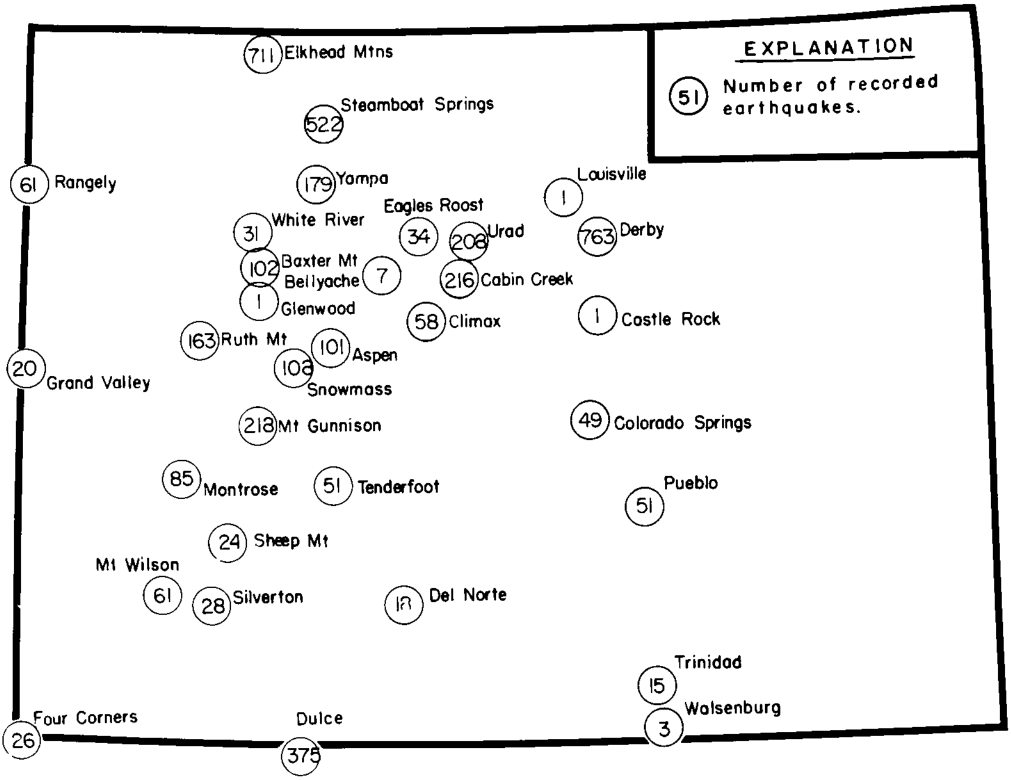

Figure 4. Seismicity map of Colorado showing earthquakes recorded during 1966-1972.

Heat-flow data are useful in delineating regions that are favorable for the development of geothermal systems. Other methods, such as the study of seismicity, are often useful in locating geothermal systems more exactly. Heating of water in the rocks around geothermal systems causes locally high internal pressures in the rocks, which is believed to lead to diagnostic levels of small-scale seismic activity around geothermal systems (Ward, 1972). Summaries of seismicity in Colorado are available for the past 8 years, based on records obtained at Bergen Park (west of Denver) and at the Uintah Basin Observatory, in northeastern Utah (Simon, 1969, 1972). A composite of these summaries showing numbers and approximate locations of earthquakes over the past 8 years is shown in Fig. 4.

Many of the earthquakes listed on Fig. 4 are probably man-caused from explosions involved in mining operations, as has been indicated by a diurnal pattern of occurrence which corresponds roughly to the shifts used in mining operations. Even so, there appears to be patterns of seismic activity associated with all of the areas of hot-spring activity outlined on Fig. 1, except for those along the Collegiate range.

Locations of earthquakes based on records from two stations are not very reliable. Errors of ten miles or more are to be expected,

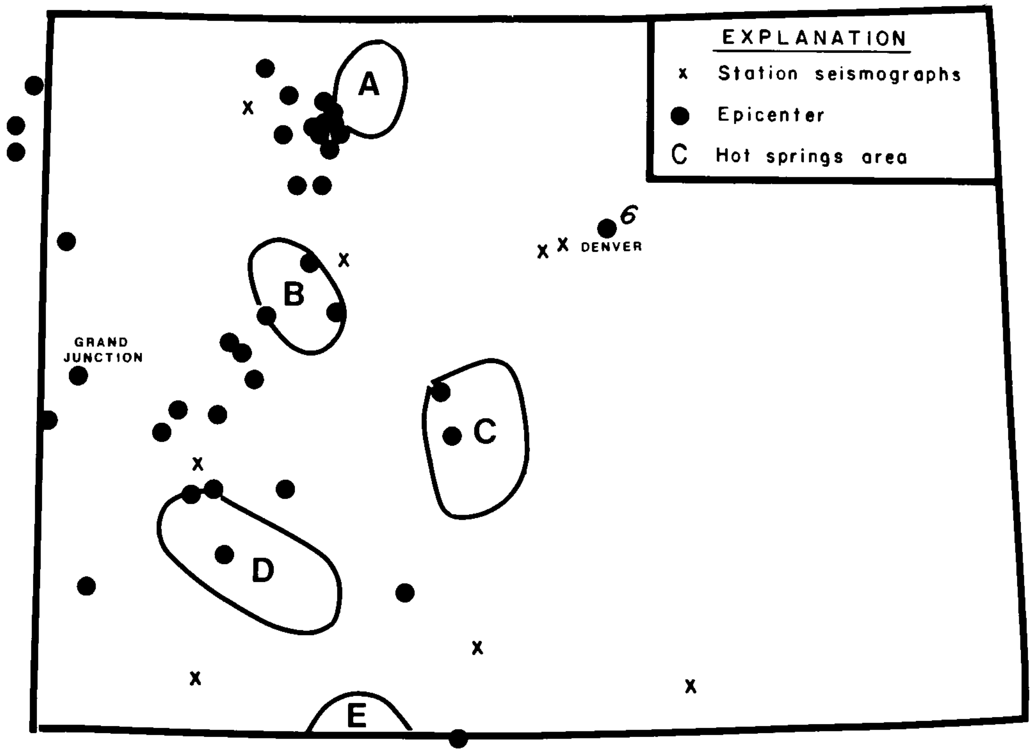

Figure 5. 1971 earthquake epicenter locations as determined from the NOAA/CSM seismic network.

so the patterns in seismicity cannot be studied in as much detail as is needed for geothermal exploration. A six-station seismograph network was operated for several months during 1972 by the Colorado School of Mines and the National Oceanic and Atmospheric Administration (NOAA). The earthquake epicenters located during this interval are shown in Fig. 5. The pattern is very similar to that obtained over the longer term with the two-station network, except that several earthquakes were detected along the Collegiate Range.

Unfortunately, operation of the NOAA/CSM network was suspended after a few months because of lack of support. It is clear that information on the seismicity of Colorado is inadequate for purposes of geothermal exploration, and that if development is to take place, such studies remain to be done.

DETAILED EXPLORATION FOR GEOTHERMAL SYSTEMS IN COLORADO

So far as I know, up to the present time, there has been only a very limited amount of detailed exploration for geothermal systems in Colorado. Geophysical methods used in detailed exploration include seismicity studies, electrical resistivity surveys, heat-flow surveys, and occasionally, gravity surveys. The purpose of detailed surveys is to locate the boundaries of a geothermal system and to provide an idea of the probable quality of the system prior to drilling.

As an example of the procedures used in detailed exploration a project that is currently underway by graduate students in the Department of Geophysics at the Colorado School of Mines (Garcia and others, 1972; and Jordon, 1974) will be described. The area chosen for this project is in the vicinity of Mineral Hot Springs and Valley View Hot Springs, in the northern part of the San Luis Valley. As shown on Fig. 6 these springs are located on east and west sides of a profound linear gravity low.

The San Luis Valley is the northernmost of the eight grabens which make up the Rio Grande rift. These grabens are a series of en-echelon depressions which extend for nearly 600 miles from Texas through New Mexico into Colorado. Based on gravity data (Gaca, 1965) the thickness of the sedimentary fill in the San Luis Valley may be

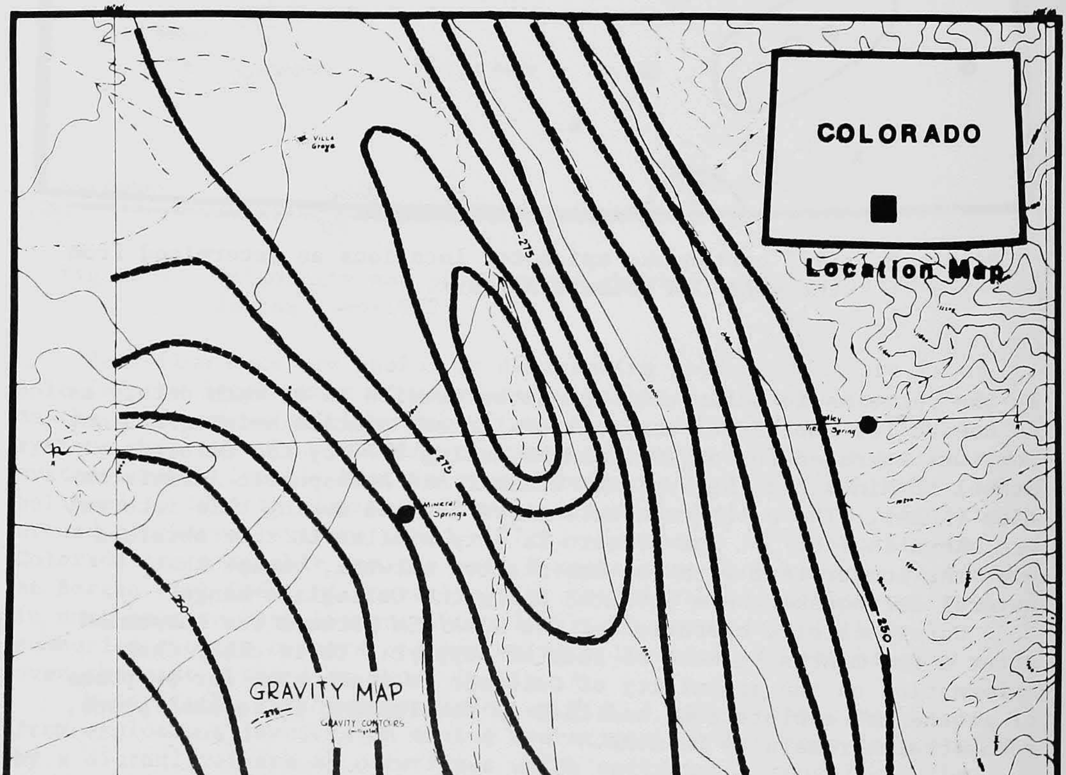

Figure 6. Gravity map of Valley View and Mineral Hot Springs area, northern San Luis Valley, Colorado.

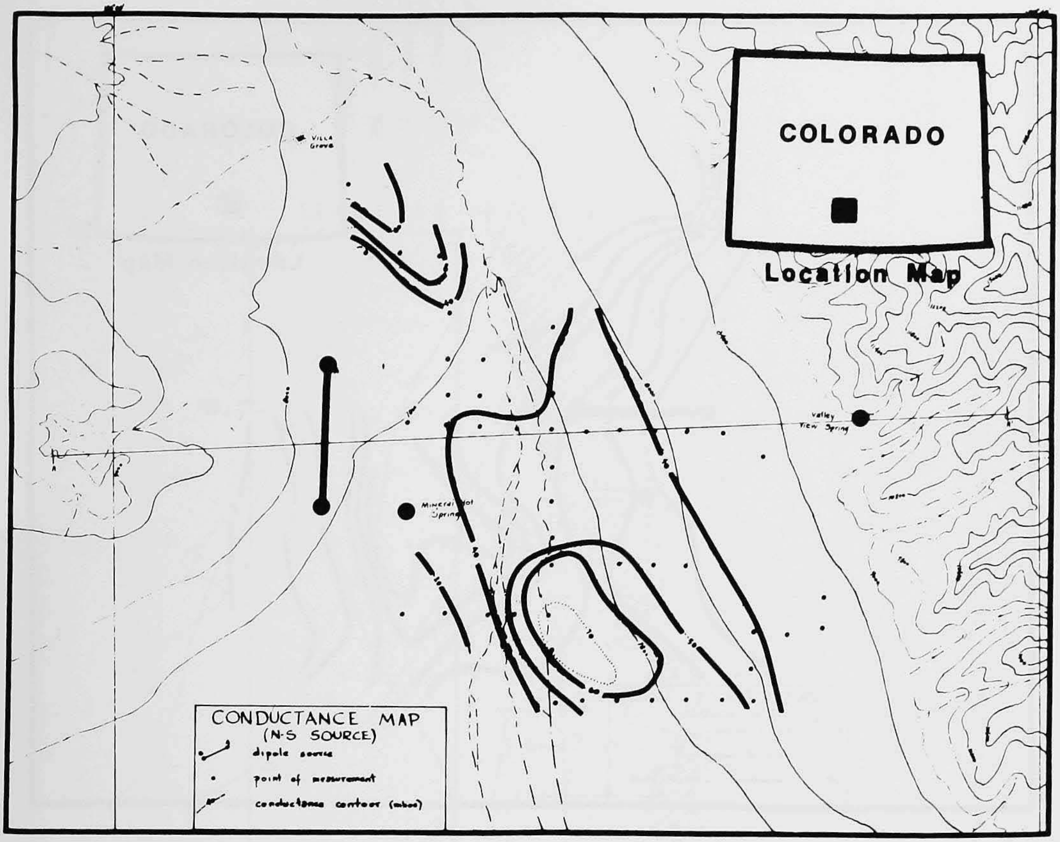

Figure 7. Electrical conductance (N-S source) map of Valley View-Mineral Hot Springs area, northern San Luis Valley, Colorado(from, J.R. Jordon, 1974).

as great as 30,000 feet.

Low density Tertiary age rocks in the San Luis Valley are of two types: volcanic rocks in the form of lava flows, breccias and tuffs, and clays, silts and sands. Quaternary age sediments occur as large alluvial fans along the margins of the valley. Basement rocks consists of both Paleozoic age clastic rocks and Precambrian age crystalline rocks.

Various types of electrical resistivity surveys were carried out as part of the project, to define the extend of the graben in the vicinity of the prospect. Elevated temperatures reduce the resistivity of a water-bearing rock markedly, so resistivity surveys are commonly used for location of geothermal reservoirs. One technique used on the Valley View-Mineral Hot Springs prospect was the dipole mapping technique in which a current field is developed in the earth by passing a large amount of electrical current through a wire grounded at both ends. For the surveys described here,

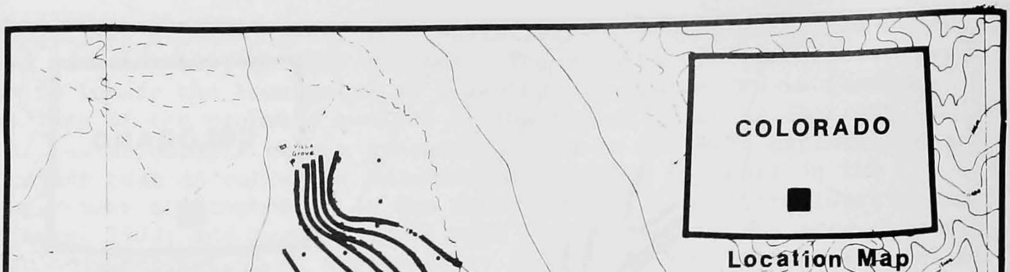

Figure 8. Electrical conductance (E-W source) map of Valley View-Mineral Hot Springs area, northern San Luis Valley, Colorado (from, J.R. Jordon, 1974).

currents of about 100 amperes were driven through a source wire approximately two miles long. The pattern of current flow is then mapped by making measurements of voltage in the ground at many points around the source wire. These measurements are then converted to values of apparent resistivity, and contoured on a map as shown in Figs. 7 and 8.

These two figures show the presence of an elongate zone of low apparent resistivity, trending northwest to southeast between the Valley View and Mineral Hot Springs. These low resistivities most probably trace the deeper part of the graben. There does not appear to be any particularly well developed areas of low resistivity around the two hot spring locations.

The dipole mapping method is primarily a means for detecting the lateral boundaries of a conductive region, and provides relatively little information on the depth extent for such regions. Other types of surveys can be used for this purpose, and for the study described here, both direct current and electromagnetic sounding methods were

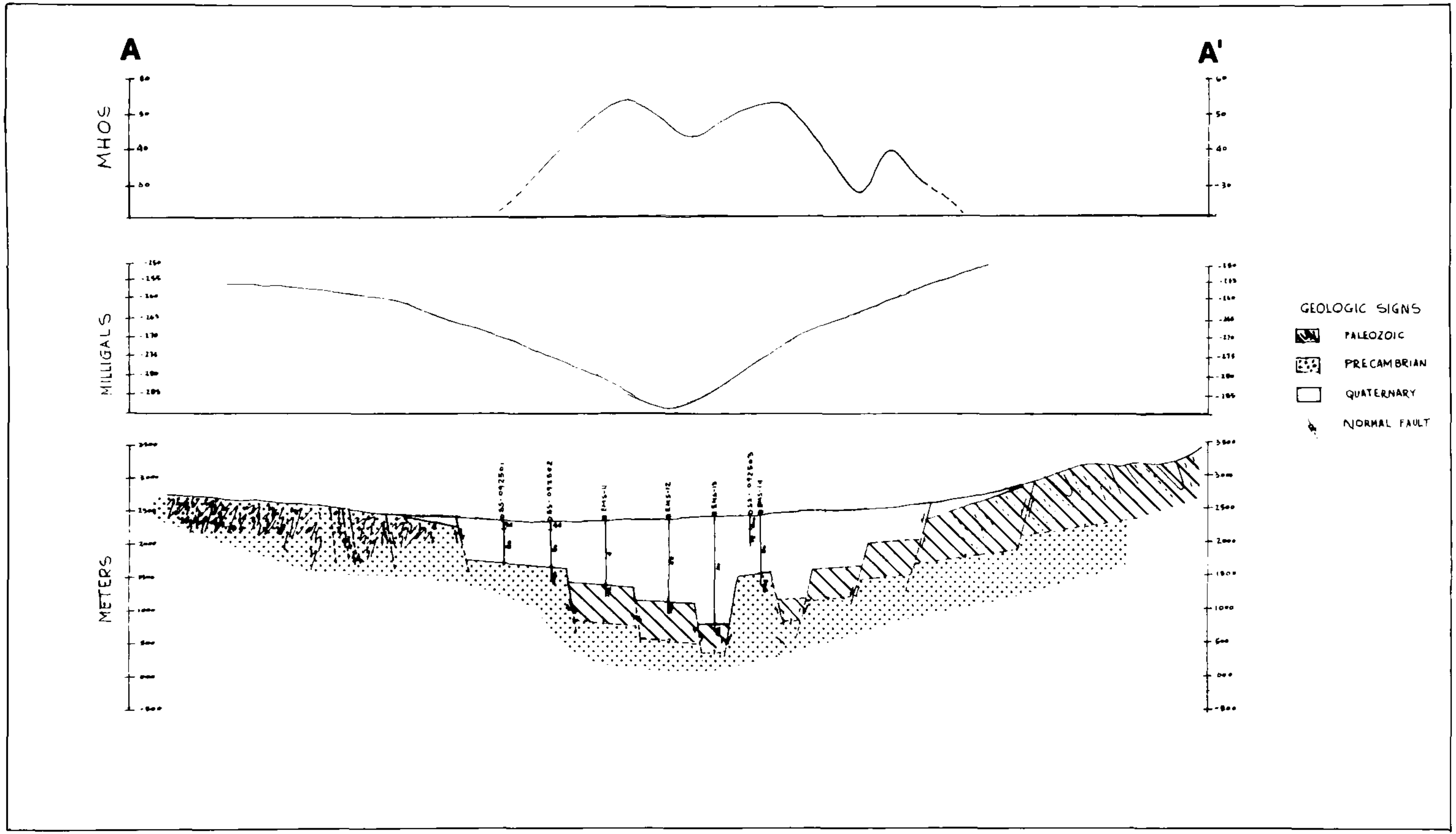

Figure 9. Geologic, gravity, and electrical conductance (N-S source) cross sections of Valley View-Mineral Hot Springs area, northern San Luis Valley, Colorado.

used. The direct-current sounding method is widely used (Keller and Frischknecht, 1966). It consists of measuring resistivity with a gradually expanding electrode array, so that resistivity is deter- to progressively greater depths. For the soundings done as part of the Valley View-Mineral Hot Springs survey, the electrode array was expanded from spacings of a few tens of feet to a maximum spacing of about 6,000 feet, presumably providing measurements of resistivity to corresponding depths.

For determination of resistivity at depths beyond 6,000 feet, the electromagnetic sounding method is somewhat easier to use (Keller, 1970). In this method, an electromagnetic pulse is generated by passing a current step through a grounded wire similar to the one used for dipole mapping. The magnetic field is then detected at a receiver station using a large induction loop laid on the ground and connected to a recorder. The early part of the magnetic pulse recorded with such a system yields information on the resistivity of rocks at shallow depths beneath the receiver loop, while the late part yields information on resistivity at greater depths.

The cross sections shown in Fig. 9 are based on depths to basement determined from both direct current sounding and electromagnetic sounding. The greatest depth to high resistivity basement rock was found to be about 5,000 ft. Near-surface resistivities were quite high, being approximately 100 ohm-meters. Only in the deeper parts of the graben were low resistivities detected, these being approximately 2 ohm-meters.

The relatively shallow depth to basement indicates that no large geothermal system can be present in the porous rocks above the basement. The low resistivities observed in the deeper parts of the graben could be attributed either to hot waters or saline waters. Resolution of this problem can be obtained only by drilling, but prior to drilling, it would be wise to carry out a careful seismicity survey to locate possible permeable zones where water movement maybe taking place.

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ECONOMIC CONSIDERATIONS FOR GEOTHERMAL EXPLORATION IN THE WESTERN UNITED STATES

Robert Greider[1]
San Francisco, Calif.

INTRODUCTION

Geothermal exploration in the United States, to date, has been conducted by industrial companies with experience in using geology and geophysics for the location and evaluation of oil, gas, and minerals. This experience, obtained over many years, has resulted in the building of data banks of basic geologic and geophysical information concerning geothermal resource areas. Table 1, "Characteristics of favorable geothermal areas", summarizes some of this basic information.

TABLE 1

CHARACTERISTICS OF FAVORABLE GEOTHERMAL AREAS

1. PROXIMITY TO COOLING IGNEOUS INTRUSIVE.
2. RESERVOIR WITH HIGH BASE TEMPERATURE AT REASONABLE DEPTH. 200° TO 300° C OPTIMUM.
3. RESERVOIR MUST BE PERMEABLE AND EXTENSIVE WITH IMPERMEABLE CAP.
4. RESERVOIR WATER IN A RECHARGEABLE SYSTEM. CONVECTION CIRCULATION.
5. WATER SHOULD NOT CONTAIN LARGE QUANTITIES OF DISSOLVED SOLIDS.
6. DISPOSAL SYSTEM FOR FLUIDS AFTER HEAT DISSIPATION.

Geological areas offering moderate risks for geothermal exploration have been examined in detail by natural resource development companies or well-financed individual investors. Exploration to locate a geothermal prospect will be the high risk part of the geothermal industry and, as such, requires management by groups experienced in assuming risks, such as the petroleum industry. Table 2 compares the exploration requirements of the petroleum industry and geothermal exploration requirements. This management group will be experienced in reducing the expected delays of four to five years before commencement of income from the development and production of geothermal heat. The sale of the geothermal heat to the electrical producing organization and the return of the cooled fluid that transported the heat from the subsurface geothermal reservoir completes the high risk phase of the geothermal industry. This high risk part will require a high rate of return on the risk capital invested (Table 3).

[1]Chevron Oil Company

TABLE 2

COMPARISON BETWEEN PETROLEUM AND GEOTHERMAL EXPLORATION AND PRODUCTION PROCEDURES

PETROLEUM	GEOTHERMAL
EXPLORATION	
GEOLOGY-GEOPHYSICS	
PREDICT AND DETERMINE RESERVOIR EXTENT, QUALITY, AND DEPTH. TRAP CONFIGURATION, PRESSURE AND NATURE OF RESERVOIR FLUIDS.	SAME - MINOR DIFFERENCES IN DATA GATHERING TECHNIQUES
LAND LEASE	
OBTAIN LEASES ON TERMS ESTABLISHED FROM ABOVE DATA	SAME
EXPLORATORY WELLS	
DESIGNED TO DETERMINE RESERVOIR FLUIDS, NATURE AND PRODUCTIVITY.	SAME
PRODUCTION	
DRILLING	
ROTARY MUD OR AIR	SAME
COMPLETION	
INCLUDES CASING AND TUBING, BOTTOM HOLE COMPLETION AND SURFACE SEPARATOR INSTALLATIONS FOR WIDE RANGE PRESSURES AND VOLUMES.	SAME - SAME PROBLEMS AS IN LOW PRESSURE, VOLUME WET GAS COMPLETIONS
FIELD DEVELOPMENT	
DESIGNS DEPEND UPON MARKET AND EFFICIENT RECOVERY.	SIMILAR BUT FIELD AREA WILL BE MORE COMPACT.

TABLE 3

GEOTHERMAL INDUSTRY

I. EXPLORATION - DEVELOPMENT - PRODUCTION

   A. HIGHER RISKS REQUIRE HIGHER RETURN.

   B. EXPERIENCE IN OIL & GAS TRANSFERABLE.

      1. MANAGEMENTS NORMALLY RISK ORIENTED.

      2. EXPLORATION DATA ACQUISITION & INTERPRETATION.

      3. DRILLING IN DIVERSE GEOLOGIC SECTIONS, WIDE CLIMATIC CONDITIONS & EXTENSIVE GOVERNMENTAL GUIDELINES.

      4. PRODUCTION AND DISPOSAL OF FLUIDS AT HIGH VOLUMES.

II. POWER PRODUCTION

   A. LOWER RISK - FIXED RATE OF RETURN.

   B. RECEIVING OF STEAM OR WATER IN 350° TO 400°F TEMPERATURE RANGE.

   C. GENERATING AND DISTRIBUTING ELECTRICITY.

III. RECOVERY OF CONSTITUENTS OTHER THAN ENERGY

   A. UNUSUAL CIRCUMSTANCES.

   B. BY EITHER I OR II.

The organization receiving the heat carrying fluid will probably design, build and operate the electrical generating equipment. Management of the power plants at The Geysers, California; Cerro Prieto, Mexico; Larderello, Italy; and Wairaki, New Zealand, has provided a background of power plant problems and design solutions to these factors, so that now the electrical generation phase is "low risk" (Table 3). A fixed rate of return, with consideration for research and development expenditures in fitting present technology into the peculiar characteristics of each producing area, probably will be established by the public utility commissions in each geothermal resource producing state.

Exploration programs to find geothermal resources must offer a potential return (for the risk taken) that is competitive with the return expected if the same funds could be used to explore for oil, gas, coal, or uranium (Table 4). To acquire geothermal exploration funds, the rate of return should be more attractive for the geothermal projects than for more familiar fuels. Figure 1 shows the magnitude of production being obtained at The Geysers Field in California. Competitive fuels are being sought by sophisticated exploration groups with knowledge and experience that provide the investor with a reasonable chance of success at calculable risk factors, technology and prescribed budget framework. The majority of exploration programs for geothermal resources will be required to use a similar economic evaluation format to obtain the extremely large funds required to develop a successful find.

TABLE 4

COMPETITION FOR CAPITAL

I. FUNDS FOR GEOTHERMAL EXPLORATION AND PRODUCTION PROVIDED FROM SOURCES THAT HAVE A WIDE INVESTMENT CHOICE.

II. OIL, GAS, COAL & URANIUM EXPLORATION MATURE.

- A. TECHNIQUE EFFECTIVENESS KNOWN.
- B. PREDICTABLE COSTS & TIME FRAMES.
- C. RISK FACTORS CONFIRMED BY STATISTICAL SUCCESS.
- D. SHORT FALL BETWEEN SUPPLY & PREDICTED DEMAND ASSURES RAPID DEVELOPMENT AND SALE.

III. GEOTHERMAL MUST MEET ECONOMIC CRITERIA OF

- A. EXPLORER & PRODUCER HIGH RETURN EARLY PAYOFF.
- B. POWER PRODUCING UTILITY LOWER RISK & RETURN REGULATORY RATES.

IV. PREDICTION OF PROFITABILITY FOR GEOTHERMAL INVESTMENT.

- A. AFFECTED BY EVOLVING REGULATIONS.
  1. LEASE SALES
  2. EXPLORATION PROCEDURE
  3. LOCATION OF AND THE MANNER OF DRILLING
  4. SPACING OF WELLS
  5. PLANT & LAND SITES
- B. TYPE OF OWNERSHIP.
- C. TREATMENT OF EXPLORATION & DEVELOPMENT EXPENDITURES FOR TAX ANALYSIS.
- D. TREATMENT OF PRODUCTION TAXES.

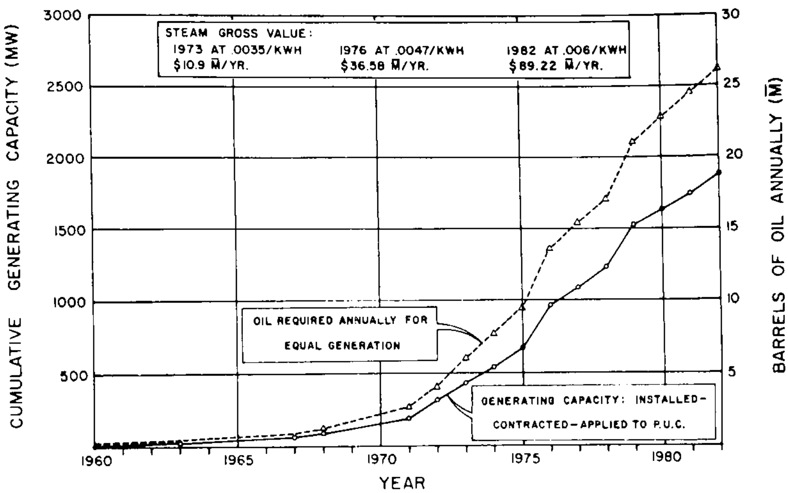

Figure I. GEYSERS GEOTHERMAL FIELD
MAGMA ANNUAL REPORT, 1972

The profitability of any geothermal exploration program in the western United States will be affected by:

1. Inclusion of total geological, geophysical and land costs of all exploration work leading to the completion of each successful field.
2. The length of time between program initiation and payout of all expenditures or until a positive cash flow is reached.
3. Location, terrain and geology of the development site as drilling and production costs are influenced by these factors. The value of an electrical generating plant at the anomaly's location determines the price the utility can afford to pay for the heat.
4. Price for competitive fuels in the market area.
5. Tax structure and treatment of all costs applicable to this depletable resource of heat.
6. Ecological expectations existing before and after development.

Federal, state and county regulations are being developed now to provide control of lease sales, exploration procedures, location, manner of drilling, spacing of development wells, siting of steam transmission pipelines, generating plants and the electrical transmission lines. These controls can significantly affect the desirability of finding and developing geothermal resources. If the costs imposed by these regulations are such as to increase the price of geothermal heat to an amount that would not offer attractive savings over conventional fuels, the funds to explore for geothermal resources will be restricted and also associated activities. The recognition must be made that geothermal heat is a new commodity not envisioned during the time waters were considered simply surface or near surface water, potable, fit for agriculture, or deeper subsurface briny water not suitable for regulation or use, except in oil production. Thus, a sane approach should be made to determine the governmental agency responsible for regulation of geothermal activities. The mining of sand and gravels from a gold placer claim is regulated considerably differently, for example, than sand and gravel mining for concrete aggregate recovered under a lease. In the same way, brines producing steam or carrying heat under pressure are different from potable water.

ECONOMICS

The majority of published geothermal energy profitability reports have ignored treatment of exploration and development expenditures. The treatment of these items must be consistent with state and federal tax laws. For example, expensed items are those deducted from income in the year of expenditure. Capitalized items are those that have a tangible or salvageable value and are depreciated during the life of the project in a manner prescribed by Internal Revenue Service regulations.

Expenditures that are of a regional or of a reconnaissance nature, such as costs incurred in establishing the stratigraphy of a geologic province, are expensed. Expenditures that lead directly to the acquisition or retention of land in an area of interest are usually capitalized. Regional geophysical surveys, such as aerial magnetometer mapping, would be expensed. Geophysical surveys to detail the configuration of an anomaly to establish where to acquire leases would be capital in nature. Detailed temperature surveys on a leased prospect would be capitalized.

A payment to acquire a lease from the owner of the geothermal resources is treated as a lease bonus and is capitalized. Subsequent payments to maintain the lease in effect, if paid over certain definite uniform periods of time, are rentals and are expense in nature. Royalty payments prescribed in the lease or in the assignment of a lease to a third party are expensed.

Costs of unsuccessful exploratory wells may be expensed in the year incurred. Successful wells may be treated in a simple manner with all costs incurred considered to be capital in nature. If you elect to expense intangible costs incurred in drilling and completion of a successful well, this may be done. All wells must be treated consistently following such an election. The intangible expensed costs may normally account for 70% to 75% of the well's costs and do not have salvageable value at the completion of the project. These costs include: the location preparation, move in and move out of the rig, transportation of supplies and crew, drilling costs on a footage drilled basis or on a set day rate for the rig and crew, drilling fluids, cement, logging, testing and preparing the well for completion. All supplies used on the location are included in the expense category.

The tangible costs, comprising 25% to 30% of the well's costs, are usually for items having salvageable value. These include capital items such as all casing, tubing and well head equipment. Separators, gauges, valves and transmission lines are also capital in nature.

Revenue will usually be calculated on the basis of Btu's supplied, or for each kilowatt hour of electricity produced by the geothermal heat. Royalty is paid to the owner of the geothermal resource on the basis of heat supplied the electrical generating plant. At The Geysers Field, 0.5 mils per kilowatt hour of electricity produced is paid for reinjection of condensed fluid from the generating plant. This is not considered a payment subject to royalty computation. The expense for reinjection of fluids in a liquid-dominated system will be considerably larger than for a vapor-dominated system, such as The Geysers, due to the greater volumes of liquid to manage and the greater increase in corrosive material left after the steam has flashed from the liquid.

The precise amount of money generated by sales of the geothermal resource from fluid-flash systems and heat extraction systems cannot presently be determined as the tax treatment has not been tested in court. The extensive collection of data on geothermal systems from around the world now support the thesis that these systems are depletable in pressure, volume and temperature and will eventually be allowed depletion allowance for income tax computation. The flow of money generated by sales, less the expense items and the capitalized items' depreciation, will determine the amount of income subject to income tax.

Items subtracted from revenues include: exploration salaries, benefits, travel expenses, research management and administrative allocations, ad valorem taxes (county and state) and production or severance taxes. Indirect charges, such as depreciation on capitalized items and depletion allowances based on cost of a property or on a percentage of gross income, are deducted from revenue. Funds remaining <u>after</u> deducting income taxes are those remaining to pay out the investment which includes investments in previous failures. This deduction of income tax payments is frequently overlooked in geothermal economic discussions.

Now let us examine the framework of an exploration budget. The component costs of the various segments of the exploration program must fit within the magnitude of expenditures that can be allocated to the total budget. At this time, the exploration budget will probably include:

GEOLOGY	-Salary, office and field expenses average $3,000 to $4,000 per geologist per month - <u>Expense</u> all reconnaissance expenditures. (Table 5)
GEOCHEMISTRY	-Geologist and assistant with vehicle and analysis by commercial laboratory will cost $10,000 to $14,000 per month - <u>Expense</u>. (Table 5)
GEOPHYSICS	-Gravity $10,000 per month - <u>Expense</u>. Airborne magnetometer $5.00 to $10.00 per square mile - <u>Expense</u>. Electrical Resistivity or Micronoise $10,000 to $15,000 per project - <u>Expense</u>. Detailed surveys on or resulting in acquisition of leased prospects $10,000 to $14,000 - <u>Capitalize</u>.

Temperature surveys drilling costs $1.50 per foot for holes up to 500 feet deep. This results in the average prospects temperature surveys costing $10,000 to $15,000 per month, exclusive of geological interpretation. (Table 5)
Reconnaissance surveying costs are expensed. Detail temperature surveys on a close grid will be capitalized if leases are taken or retained.

LAND ACQUISITION -Lease bonus paid will be dependent on location of the nearest geothermal production, interest shown by academic or governmental research projects and degree of economic development. Wildcat areas will require $1.00 per acre bonus (capitalized) and $1.00 per acre per year rental (expensed). Competitive areas may require $5.00 to $10.00 per acre bonus after production has been established in the area. Broker or landmen will cost $65.00 to $130.00 per day during leasing activity. This sum is capitalized. It is anticipated that an average sized prospect should require $45,000 to $60,000 - Capitalize. Table 5 summarizes these costs.

DRILLING -Exploratory well costs in the United States will average $20.00 to $30.00 per foot down to 5,000 feet in most geothermal provinces located in sedimentary basins. In remote areas or those with igneous interbeds, costs will be $30-$60 per foot. To run casing and prepare for production will cost approximately $10.00 to $15.00 per foot down to 5,000 feet. Wells capable of production will be capitalized. Non-commercial wells that are abandoned will be expensed. When the lease or the failure is abandoned, all capital items charged to the site will be expensed. See Table 5 for a breakdown of these costs.

The above costs indicate that an average area of interest can cost approximately $75,000 to $95,000 before knowing that drilling is justified. If one out of four areas of interest is judged to be worthy of drilling for temperature and water quality data, the cost will be $300,000 to $380,000 per drillable prospect. Though most exploration programs will locate steaming water, we must assume one out of four of the prospects drilled for temperature and salinity data will have sufficient economic or technical encouragement to run pipe and complete for extensive testing. The three unsuccessful wells will cost $100,000 to $200,000 each, and the completed well $150,000 to $250,000, for a possible average total of $650,000 of exploratory drilling costs for each well worth extensive testing. If one out of four of these locate an anomaly large enough to be commercial, the program will be attractive. The cumulative exploration expenditures for all the prospects leading up to and including the sixteen prospects evaluated by drilling for each successful prospect comprise the "risk" money attributable to the success and must be paid out by that success. The cumulative expenditure average for the example given is $8,000,000. It is believed that an experienced geological-geophysical team can improve on these statistics in the next few years. There will probably be a more favorable success ratio in the early stages of geothermal energy exploration as the large, easily detected anomalies will be the first drilled. As the industry matures, higher risk projects will be explored and this 16:1 ratio will be approached.

Federal regulations prohibit the discharge of degrading effluent into a river system. Therefore, as liquid-dominated systems are the most likely system to be found, the development stage of prospect analysis should require plans for injection wells costing nearly $125,000 for a 5,000 foot deep well. As a result of the large volumes of liquid produced in a hot water geothermal field, the ratio of injection wells to producers will be nearly 1:2. Environmental concerns will dictate returning the cooled fluids to or near the original reservoir. Field operation costs will be approximately $30,000 per well, per year.

A review of case histories of geothermal energy developments indicates that a prospect located 75 to 100 miles from a market, to warrent development, should have the potential to support the generation and marketing of 250 to 275 megawatts in a base load situation. Any operation with a smaller goal than this cannot support the exploration risk, the field development investment and the charges for time value of capitol invested while waiting for revenue to be generated.

In a valid analysis of investment opportunity, one must assign a time value of money to all monies invested for "n" number of years prior to any revenue being received. A common value of money today is 12 1/2% if the venture phase is low risk, and 15% if moderate risk is expected. The value of money (VOM) for any period of time after the money is invested is calculated by the following formula:

$(\text{Value of money today})(1 + \text{interest rate})^n$ = Value of money after "n" years. In a similar manner, revenue expected in "n" years reduced to present value is calculated in the following formula: Value of money today = $\frac{(\text{Revenue expected})}{(1 + \text{Interest rate})^n}$

Figure 2 shows the value of money invested for any period of time up to twenty years at varying interest rates. For example, one million dollars of income eight years from now discounted at 15% is valued at $325,000. Thus it can be seen that the effect of several years' wait from exploration to initiation of sales of heat is disastrous in the rate of return; thereby, endangering the economic viability of a project (Figure 2).

The amount and time that money is invested with no revenue being received may be reduced, thus improving the economic viability of the project, by the acceptance of basic reservoir engineering data obtained from the carefully designed initial drilling and text programs. Studies by Dr. H. J. Ramey, of Stanford University, on reservoir performance and reserves forecast for the liquid-dominated geothermal system in

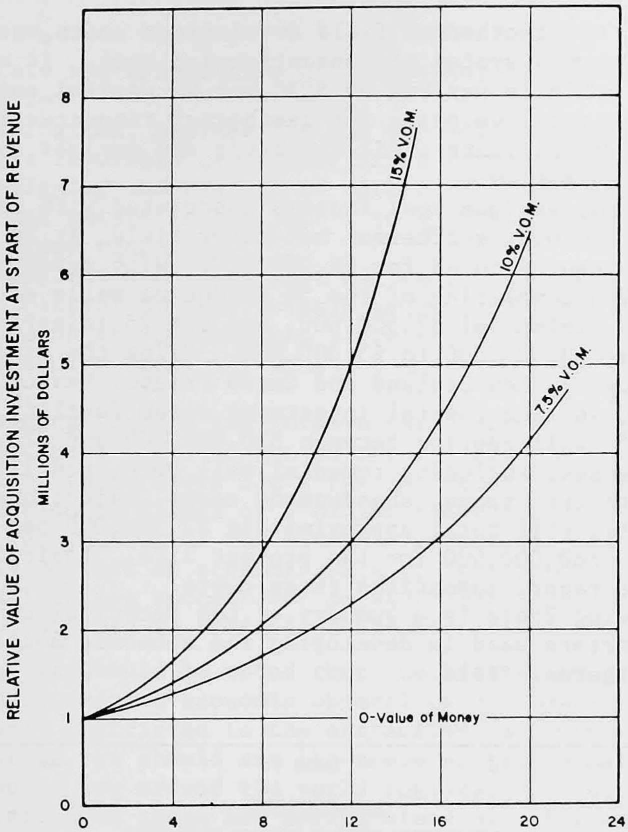

Figure 2. ELAPSED TIME BETWEEN INITAL INVESTMENT AND BEGINNING OF REVENUE

New Zealand and the vapor-dominated system at the Geysers, demonstrates that it is not necessary to completely develop a geothermal field before designing the electrical generating plant. Reliable predictions on field size can be made using material balance analysis of broadly spaced wells completed in a common reservoir.

The price for steam produced from the only producing steam field in the United States, the Geysers, is approximately 3 mils per kwh generated (Figure 1). This price is very cheap today compared to conventional electrical generating plants using the low sulfur fuels required by the Environmental Protection Agency. The sharply lower operating costs for geothermal plants compared to conventional plants using the low sulfur fuels results from elimination of boiler plant and auxiliary equipment investment and operating charges plus eliminating the \$ .40 to \$ .90 per million Btu low sulfur fuel used to fire the boiler plant.

A study done by Westinghouse in the Spring of 1973, equated operating and fuel costs for coal, oil, and nuclear generating systems.

In this study, the geothermal field development costs were substituted for the steam supply system of conventional plants. It was shown that approximately 6.3 mils per kwh or $250 per kw capital costs would be a reasonably competitive price for geothermal resources when nuclear fuel is priced at 21 cents a million Btu's and nuclear capital costs are held to $400 per kw.

Reviewing the various cost factors associated with exploring for a 250,000 kw (minimum) geothermal hot water field, it is estimated that the field can be found for $8,000,000. With careful planning, the drilling and completing of the 50 producing wells of the field will cost at a minimum of $7,500,000, and the 25 injection disposal wells will cost $3,500,000 to $5,000,000. Using the experience and knowledge gained in New Zealand and Cerro Prieto, Mexico, the total subsurface and surface capital investment steam facility over a 35-year field life will require between $20,000,000 and $24,000,000. Operating expenses, including remedial well work, redrills, overhead, mineral and property taxes, abandonment costs, injections costs and royalty paymets, will total approximately $2,300,000 per year or $75,000,000 to $80,000,000 for the project life. Table 6, located at the end of the paper, summarizes these costs.

The following Table is a summary of the technical conditions and economic parameters used in developing the economic model of a 275 MW hot water geothermal field.

TABLE 7

ECONOMIC MODEL

EXPLORATION PROGRAM THROUGH PRODUCTION
275 MW FUEL SUPPLY

INCLUDES ALL GEOLOGICAL, GEOPHYSICAL AND LAND EXPENDITURES REQUIRED FOR DRILLING SIXTEEN PROSPECTS TO DISCOVER ONE FIELD THAT CAN MEET THE REQUIREMENTS FOR THIS SIZE OF PRODUCTION.

1. PRODUCTION RATE WILL BE THE AVERAGE OF COMPLETED WELLS AT CERRO PRIETO, MEXICO.
2. PRODUCING WELLS SPACED 10 ACRES APART. INJECTION WELLS ON FIELD PERIPHERY.
3. 10 PRODUCING WELLS AND FIVE INJECTION WELLS REQUIRED FOR EACH 55 MW TURBINE.
4. 80% PLANT FACTOR, 90% PRODUCING WELL FACTOR AND 20% STANDBY CAPACITY.
5. 10% MAXIMUM ROYALTY EXPENSE.
6. MINERAL AND PRODUCTION TAXES ARE 6% OF GROSS WORKING INTEREST INCOME.
7. 22% DEPLETION CREDIT.

DEVELOPMENT TO 275 MW	4.8 MIL PER KWH
INVESTMENT ($000)	$20,000 TO $24,000
OPERATING EXPENSE, TAXES & ROYALTY ($000)	$75,000 TO $80,000
YEARS TO COMPLETE PAYOUT	7.3 YEARS
RATE OF RETURN	13.7%
NET PROFIT PER YEAR AFTER PAYOUT ($000)	$3,820

THE PAYOUT TIME MAY BE DECREASED TO 6.4 YEARS, AND RATE OF RETURN INCREASED TO 17%, IF (1) THE PRICE OF FUEL IS INCREASED TO 5.6 MILS PER KWH GENERATED, (2) THE DRILLING SCHEDULE OF THE FIELD IS ADJUSTED TO ACTUAL MODULE GENERATING PLANT COMPLETION, AND (3) MINERAL AND PRODUCTION TAXES ARE HELD TO 5% OF INCOME.

SUMMARY

To accelerate the utilization of geothermal resources, more knowledge is needed in:

A. The geological, engineering and economical factors that characterize favorable geothermal areas for exploration.

B. The designing and testing of methods for generating electricity using hot waters in the 300° F to 400° F (150°C to 210°C) temperature range.

C. Well completion methods that can reduce corrosion, scale buildup and control of very friable sands that cause in-sand plugging and erosion at temperatures above 450°F (230°C).

D. Understanding reservoir behavior under drilled and production regimes.

E. Determining factors that create the large occurrence of 150°C to 210°C reservoirs of hot water, and how the very limited number of those above 230°C remain hot and will respond to reinjection of fluids of a cooler temperature.

F. Early recognition of the ultimate potential of a geothermal anomaly so that an economic rate of development may be planned.

G. The exploration success for conventional fuels and their being available in sufficient amounts during the next 15 years.

In summary, it should be noted that the future for geothermal energy presents attractive economic objectives and opportunities. These are not only restricted to the attractive California energy market. In the future, we should see the scope of geothermal exploration expanded, for up to now around the world regional geothermal prospecting has been limited to those hot spring areas offering exploration potential. This is the same as limiting oil exploration to areas of oil seeps. By analogy with the petroleum industry, it is therefore expected that there is a significantly greater amount of geothermal energy to be found in the future than that recognized by hot springs alone.

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TABLE 5

GENERAL GEOTHERMAL PROJECT BUDGET COSTS
EXPLORATION

GEOLOGY	SALARY, OFFICE AND FIELD-EXPENSE	$3,000 TO $4,000 PER MONTH
	REGIONAL EVALUATION - EXPENSE	PER GEOLOGIST
	SPECIFIC PROSPECT CONFIGURATION - CAPITALIZE	
GEOCHEMISTRY	GEOLOGIST, FIELD ASSISTANT VEHICLE	$10,000 TO $14,000 PER MONTH
	AND COMMERCIAL LAB. ANALYSIS	
	RECONNAISSANCE - EXPENSE	
	EVALUATION OF AREAS OF INTEREST - CAPITALIZE	
	BORE HOLE TEMPERATURE (WATERS) - EXPENSE	
GEOPHYSICS	GRAVITY	$10,000 PER MONTH
	BROAD COVERAGE - EXPENSE	
	CLOSE SPACED EVALUATION OF PROSPECT - CAPITALIZE	
	MAGNETICS - EXPENSE	$5,000 TO $10,000 PER MONTH
	MICRONOISE	$10,000 TO $15,000 PER MONTH
	RECONNAISSANCE - EXPENSE	
	DETAIL PROSPECT - CAPITALIZE	
	ELECTRICAL RESISTIVITY	$10,000 TO $15,000 PER MONTH
	RECONNAISSANCE - EXPENSE	
	DETAIL PROSPECT - CAPITALIZE	
	TEMPERATURE SURVEYS	$30,000 PER MONTH*
	200' DEPTH RECONNAISSANCE - EXPENSE	
	500' DEPTH PROSPECT EVALUATION - CAPITALIZE	

* ADD $10,000 PER MONTH FOR CALIFORNIA

TABLE 5
(cont.)

LAND ACQUISITION COSTS

THE FORM OF LEASE AND THE TERMS ARE DEPENDENT UPON THE STATE LAWS AND THE TYPE OF PREDOMINATE OWNERSHIP - FEE, STATE, FEDERAL, INDIAN, OR RAILROAD GRANT.

FEE	- SIMPLE OWNERSHIP: 10,000 TO 20,000 ACRES MUST BE OBTAINABLE IN A REASONABLY COMPACT BLOCK. ALLOWS EXPLORATIONS TO DEFINE THE CENTER OF HEAT AND CONTROL DEVELOPMENT.
STATE	- NORMAL AS FILL IN TO OTHER ACREAGE.
FEDERAL	- AT THIS TIME, ACQUISITION IS NOT ASSURED.
INDIAN LANDS	- WESTERN TRIBES PREFER TO NEGOTIATE INDIVIDUAL VENTURES.
RAILROAD GRANTS	- ALTERNATE SECTIONS USUALLY FEDERAL - THIS IS NOT AVAILABLE. ADDITIONAL COMPLICATIONS WHERE SURFACE AND SUBSURFACE RIGHTS HAVE BEEN SEPARATED.

ACQUISITION COSTS

BONUS	- WILDCAT AREAS, LITTLE DATA ON SUBSURFACE	$1.00 PER ACRE
	- SEMI-DEVELOPED AREAS WITH STRONG DATA AT DEPTH	$5.00 TO $10.00 PER ACRE
	- DEVELOPED AREAS WITH POWER PRODUCTION	$1,000 PER ACRE
PERSONNEL	- LANDMEN KNOWLEDGE OF GEOTHERMAL PRACTICES - $65.00 TO $130.00 PER DAY.	
	TOTAL LEASING COST	$2.00 TO $3.50 PER ACRE

TABLE 5
(cont.)
EXPLORATORY DRILLING COSTS

SEDIMENTARY SECTION

AREA REASONABLY NEAR DRILLING SERVICES: DOWN TO 5,000 FT., $20 TO $30/FT. FOR DRILLING & LOGGING, $1,200 TO $2,000 PER DAY	$125,000
COMPLETION WITH CASING & PERFORATIONS PLUS SURFACE VALUES - AVERAGE TO 5,000 FT., $10 TO $15/FT.	65,000
TOTAL	$190,000

IGNEOUS INTERBEDS & REMOTE AREAS

DRILLING COSTS TO DEPTHS OF 6,000 FT. FROM $30 TO $60 PER FOOT OR $3,000 TO $6,000 PER DAY	$250,000
COMPLETION WITH OPEN HOLE IN FRACTURED RESERVOIR, $8.00 TO $15.00 PER FOOT	60,000
TOTAL	$310,000

CAPITALIZE SUCCESSFUL TESTS (MAY EXPENSE INTANGIBLE)

INTANGIBLES: ACCOUNT FOR 70% TO 75% OF ALL COSTS, INCLUDING LOCATION PREPARATION, RIG MOVE IN & OUT, DRILLING AND DAY RATES DRILLING FLUIDS, CEMENT, LOGGING, TESTING, & PREPARING WELL FOR COMPLETION.

TANGIBLES: INCLUDE CASING, TUBING, WELLHEAD EQUIPMENT

TABLE 6

Estimated Costs for Exploring for and Developing a 250,000 kw Geothermal Hot Water Field

EXPLORATION	
GEOLOGY:	
SALARY, OFFICE AND FIELD EXPENSE	$3,000 TO $4,000 PER MONTH
GEOCHEMISTRY:	
GEOLOGIST, ASS'T., VEHICLE AND ANALYSIS	$10,000 TO $14,000 PER MONTH
GEOPHYSICS:	
GRAVITY	$10,000 PER MONTH
MAGNETICS	$5.00 TO $10.00 PER SQUARE MILE
MICRONOISE	$10,000 TO $15,000 PER MONTH
RESISTIVITY	$10,000 TO $20,000 PER MONTH
TEMPERATURE SURVEYS	$1.50 PER FOOT TO 500 FEET
LAND ACQUISITION:	$45,000 TO $60,000 PER PROSPECT
WILDCAT	$1.00 PER ACRE BONUS
SEMI-DEVELOPED AREA	$5.00 TO $10.00 PER ACRE
PERSONNEL	$65.00 TO $130.00 PER DAY
DRILLING:	
EXPLORATORY WELL TO 5,000 FEET	$20.00 TO $30.00 PER FOOT
COMPLETE WITH CASING	$10.00 TO $15.00 PER FOOT
SUMMARY OF COSTS:	
AREA OF INTEREST	$75,000 TO $95,000
FOR ONE DRILLABLE AREA FOUR AREAS WILL BE WORKED	$300,000 TO $380,000
ONE AREA OUT OF SIXTEEN DRILLED FINDS 250,000 KW FIELD	
TOTAL EXPLORATION COSTS	$8,000,000
DEVELOPMENT	
50 PRODUCING WELLS	$7,500,000 TO $10,000,000
25 INJECTION WELLS	$3,500,000 TO $ 5,000,000
TOTAL SURFACE AND SUBSURFACE CAPITOL INVESTMENT COSTS	$21,000,000 TO $24,000,000 (includes exploration Costs)
OPERATING	
ESTIMATED OPERATING EXPENSES, TAXES AND ROYALTY FOR 35 YEAR FIELD LIFE	
$2,300,000 per year	$75,000,000 TO $80,000,000

GEOTHERMAL ENERGY AND THE ENVIRONMENT

William L. Miller[1]
Washington, D. C.

INTRODUCTION

The future development of geothermal energy resources in the United States and throughout the rest of the world can be expected to affect the integrity of the surrounding environment in varying manners and to varying degrees. Before development can begin, proper considerations of all the environmental implications must be given.

LAND USES

Probably the single greatest environmental impact, resulting from any geothermal development, will be the disturbance of the land and resulting changes of its utilization. This impact has been of concern to many environmentalists for some time. Land in the vicinity of any geothermal development will be changed by the construction of roads, wells, pipelines, powerlines, power plants, and byproduct facilities. Depending upon the existing use of the land which may be agriculture, forestry, grazing, fish and wildlife habitats, recreation, or watersheds the impact of a geothermal development may be only temporary or permanent. Development of any geothermal resource, which by necessity must modify the existing terrain, may result in restricting the use of the land in the immediate vicinity of the development for other purposes.

For instance, a drill site generally involving an area of less than an acre may require clearing of vegetation and grading to a relatively flat surface. Because of the limited efficiencies involved in transporting high-temperature fluids under pressure, power plant sites are not located any further than a mile from the producing wells. At the Geysers field, in northern California, this distance is no greater than 1,200 feet (Figure 1). Steam is supplied to each plant by an optimum number of producing wells at spacings of approximately 40 acres per well. For this reason, too, power plants are limited in size, usually not greater than 100 Mw (Megawatts). Consequently, in a geothermal field, the landscape is covered with steam lines radiating out from power plants which are connected by high voltage power transmission lines (Figure 1). Any brush in the producing area is cleared to provide access and minimize the fire hazard.

Although land developed for its geothermal resources potential will be lost for other purposes, undeveloped or non-intensively used lands adjacent to the development site are expected to support multiple land uses. Creation of new access roads or improvement of existing ones can open new or previously inaccessible areas for multipurpose utilization, particularly recreation. In this regard, the opportunity to view first hand a "unique" power source in operation may cause an area to become a tourist attraction. This, of course, has both a positive and negative side.

[1] U. S. Bureau of Mines

Geothermal resources development on public land may result in land-use conflicts with adjacent private landowners. Similarly, development of geothermal resources on private lands can affect adjacent Federal lands and resources.

Since each prospective geothermal site may involve a number of different potential environmental factors, including geology, topography, soil, climate, vegetation, fish and wildlife, proximity to populated areas, adjacent land uses and values, and the type of geothermal evaluation will have to be made so that environmentally acceptable production facilities can be designed and built. Good design and engineering, proper construction techniques and controls, and adequate post-construction measures such as revegetation and soil stabilization, adequate drainage control, stabilizing cut banks and surfacing roads and areas subject to heavy traffic, will be required to prevent serious long-range environmental damage from occurring (Figure 2).

The development of a geothermal field, however, need not be incongruous with the surrounding environment. For example, prior to development, The Geysers area was a wilderness much of which supported the foraging of deer. Today, this use continues along with cattle grazing. The Larderello, Italy, field is situated in an intensive agriculture area (Figure 3). Within the field confine there are numerous farms, vineyards and orchards in close proximity to the producing wells, pipelines, and power plants.

SUBSIDENCE

The withdrawal of large volumes of fluids from hot-water geothermal reservoirs can cause subsidence of the land surface as a result of reduced fluid pressure. During full-scale operations, subsidence would reach a maximum rate unless adequate precautions are not taken to compensate for reduction of reservoir fluid pressure. Significant subsidence has resulted from the production of geothermal fluids at Cerro Prieto, Mexico; and Wairakei, New Zealand where the water is not returned to the reservoir. At Wairakei, the maximum subsidence between 1961 and 1968 was about 2.5 feet. The total subsidence areas of about 0.5 square miles in area. Based on changes in gravity, this subsidence represents about 3 percent of the fluid volume lost during the period. In some instances, limited subsidence may be tolerated if it is believed that there would be no serious land use or environmental consequences. However, subsidence of any appreciable magnitude could adversely affect the integrity of the geothermal wells, pipelines, and buildings as well as other structures and developments including irrigation canals and reservoirs in environmentally sensitive areas such as the Imperial Valley of California.

Because a great deal has been learned during the years of petroleum production about controlling subsidence it should be possible to manage effectively any subsidence that might occur resulting from geothermal development. To accomplish this reinjection of an equal or greater volume of fluids, than that withdrawn, is essential in order to compensate for the loss of fluid pressure and to stabilize the area. With the production of fresh water from a desalination plant, a greater net withdrawal would occur unless makeup waters, probably of similar composition, are reinjected. If shallow ground water is used for makeup water, some subsidence could result from the lowering of the water table. Because some geothermal areas may be subsiding from natural causes unrelated to geothermal fluid withdrawal, monitoring of these areas prior to geothermal exploration and development activities can provide the information needed to determine the general stability of the land. Subsequent monitoring of the operation would be required to assess the subsidence potential and its probable impact. Consequently, most developments, whether for power only, or for power and demineralized water, would have to include provisions for minimizing the extent and magnitude of subsidence should it pose a significant environmental problem.

SEISMIC ACTIVITY

An associated effect which may develop as a result of reinjection of geothermal fluids and from subsidence is an increase in seismic activity. Because geothermal systems throughout the world are located near areas of active tectonism, major fault zones, and Cenozoic volcanism, the association of seismic activity is not surprising. Consequently, the likelihood of some earthquakes occurring as a result of geothermal developemnt is very high. Changes in stress and lubrication of fault planes by reinjection fluids coupled with pressure buildup and related effects could result in movement along fault zones. The role that fluid pressure changes play in triggering seismic activity is not well understood, although a causative relationship has been established in many areas. Earthquakes caused by reinjection fluids generally have not been damaging although the potential for a macroseism cannot be ignored. It is quite conceivable that this sort of activity may relieve built-up stresses in the form of multiple minor slips and microseisms thereby mitigating the severity of a potential major earthquake as we presently experience and record it. Considerable monitoring and related research effort will be necessary to resolve the cause and effect relationships between fluid withdrawal and reinjection and increased subsidence and seismic activity. Additionally, an evaluation of a geothermal area's historical seismic record, together with monitoring seismicity of the field prior to development, will be required to establish a baseline of the natural seismic activity. In this regard, the U. S. Department of the Interior is cooperating with the State of California in establishing a monitoring network to establish a seismic baseline in the Imperial Valley (Figure 4). If monitoring of any geothermal area indicates a significant increase in seismicity, particularly in intensity of motion, remedial steps, including limiting the rate of withdrawal or reinjection, should be initiated to control the increased seismic activity.

BLOWOUTS

Well blowouts or uncontrolled, sudden and violent releases of steam or hot water into the atmosphere are major environmental problems

Figure 1. View showing relationship of power units, cooling towers and steam lines at the Geysers, California.

Figure 2. Modification of landscape due to construction of roads, well sites, and steam lines, Geysers, California.

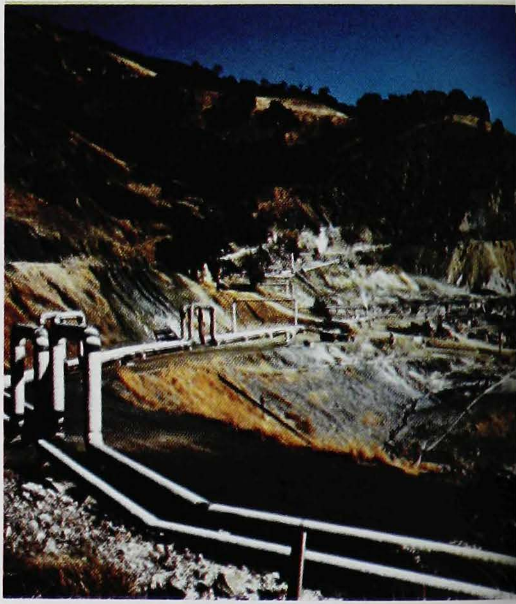
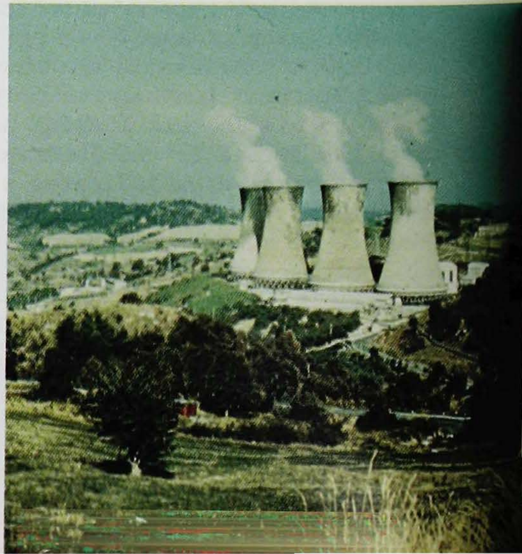


Figure 3. Lardarello, Italy, view showing possible harmony between geothermal developments and surrounding environment.



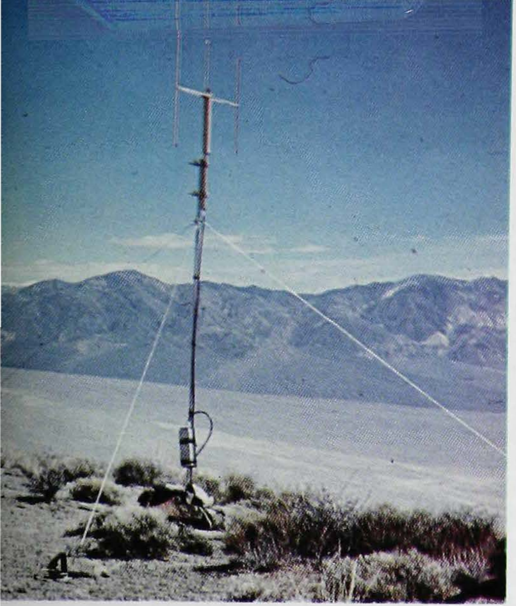


Figure 4. U.S. Geological Survey seismic telemetering station located in southeastern California.

Figure 5. Steam well blowout at the Geysers Field, California. Illustrates the need for precautions to prevent blowouts from occurring even at producing fields.

Figure 6. Venting of wells at the Geysers Field, California. Such practices allows for the escape of noxious gases and causes noise problems.

throughout geothermal operations. The potential adverse environmental impacts resulting from accidental well blowouts include: hazard to workmen safety, pollution of surface and ground water resources, air contamination, noise pollution, and partial loss of the resource. Although the probability of blowouts occurring is not particularly high, the chances are greater during the test drilling phase than in any subsequent development operation. This is true mainly because of inadequate knowledge about the subsurface geology and thermal conditions. As an indication of the relative magnitude of this problem and of the frequency of blowout occurrences, the following examples are cited.

At Larderello, blowouts are an important, localized drilling problem. Because production wells are brought in with controlled releases of steam, sudden, uncontrolled releases often are anticipated when circulation losses cause the hydrostatic head inside the well to fall below the steam pressure in the cavernous producing horizons. Consequently, blowouts are handled routinely as a noisy, bothersome part of regular operations which are not felt serious enough to cause any adverse environmental effects.

Of the more than 100 wells drilled in The Geysers field, as of January of this year, only three well blowouts have occurred (Figure 5). In all three instances, the casing ruptures were affected by landslides or slip surfaces, caused by heavy rains. Over the past 15 years since the first blowout occurred in this field, it is estimated that more than 9 million tons of steam and 4 thousand tons of hydrogen sulfide, in addition to significant quantities of other noncondensible gases, have been released to the atmosphere from this well.

The frequency of blowouts at The Geysers appears to be comparable to the occurence of blowouts in the Wairakei, New Zealand geothermal field. Over 175 wells have been drilled with only three blowouts, two of which occurred during drilling. At the Cerro Prieto, Mexico, field, over 40 wells have been drilled since 1960. Of this total, two blowouts have resulted.

From the experience gained at all of these geothermal fields, blowouts can be expected to occur, although the probability of a blowout occurring at any given location can be greatly reduced as a result of technological refinements, drilling control measures and increased operating experience.

NOISE POLLUTION

Another potentially hazardous and certainly annoying environmental problem associated with geothermal development is noise pollution. Generally speaking, a noise becomes objectionable whenever its level exceeds the background noise level by a certain value or when it attains a certain absolute level. The resultant noise level from geothermal development activities tends to increase with the progression of the various phases. Excessive noise levels are not only objectionable to persons in close proximity to the source, but they also could seriously affect the wildlife. The principle sources of noise are the drilling of the wells, racking of drill pipe, venting of compressed air and cuttings during drilling operations and the venting of steam from wells after drilling has ceased (Figure 6). Noise generated during the drilling operations can be harmful to the operators if adequate safety precautions are not taken.

As an example, noise measurements taken at one geothermal power facility show that the noise level at 25 feet from an unmuffled air drilling operation and from a muffled test well were 126 and 100dB (A) (decibels A scale) respectively. For a steam line vent at 50 feet, the noise level was 100dB (A). For comparison, the noise level for a jet aircraft taking off is 125dB (A) at 200 feet. However, of the principle noise sources, the roar of the steam issuing from an unmuffled production well is the most pronounced. Venting of a well upon completion is necessary to prevent condensation of the steam and flowback down the well which otherwise could result in its loss. In order to suppress the noise, prevent damage to the well, and conserve the geothermal resource, while at the same time insure continous venting, installation of a controlled venting device is usually required at the well head. Controlled venting normally continues until the power plant is placed on stream with the well. Attenuation of this objectional and particuarlly difficult noise spectrum can be accomplished through the use of properly designed muffling devices. At The Geysers, control-valve exhausts equipped with mufflers maintain the noise at an inaudible level during the production of steam. Also at Cerro Prieto, muffling devices have been successfully tested. Thus, the impact of noise on the environment can be maintained at safe levels to permit the continuation of established uses and activities with minimal effect on wildlife and man.

NOXIOUS GASES

Geothermal fluids normally contain dissolved gasses, including hydrogen sulfide, carbon dioxide, carbon monoxide, methane, ammonia, and mercury vapor in varying concentrations. The gases are released to the atmosphere with the steam when the fluid flashes at the surface during the bleeding and venting of the wells. Release of gases occurs also at the gas ejector vents on the condensers and at the cooling towers after the generation of power. In large amounts, many of these gases are not only corrosive but hazardous to the environment and to the health and safety of persons working near the power installation where the effect from such gases may become a serious problem.

Of the gases usually associated with the various types of geothermal systems, hydrogen sulfide occurs in sufficient quantity such that it is considered to be one of the greatest threats to the health and well-being of the workmen as well as the surrounding environment. During stagnant air and air inverson conditions, hydrogen sulfide could accumulate to the toxic level, causing shutdown of the power facility if precautionary measures have not been taken. Hydrogen sulfide removal technology has been developed by other industries, mainly the oil and gas industry. At The Geysers, effective measures are being taken to control hydrogen sulfide emissions.

Ammonia gas, on the basis of volume percent, appears to be the second greatest threat.

Mercury, on the other hand, found to occur near hot springs, mud volcanoes and in petroleum brines, is usually present in very low concentrations. However, in sufficient quantities, mercury vapor could pose a serious health hazard at some locations.

During steam production testing, extensive monitoring and analytical work will be required to determine the quantity of all potentially toxic vapors present in geothermal fluids at each field, to evaluate their potential threat, and to determine what control measures should be imposed to maintain environmental quality and health and safety. Effective means for removing or collecting these noxious gases safely have been or will be developed as the geothermal systems dictate. Geothermal steam not containing noxious gases in toxic concentrations generally can be exhausted to the atmosphere without causing significant environmental damage. If byproduct mineral recovery is not practiced and gases dissolved in the brines are not of value, they could be compressed and subsequently pumped down the injection wells.

MINERAL SALTS

The production of potentially valuable associated geothermal byproducts, demineralized water and mineral salts, could have far-reaching, beneficial environmental consequences. Certainly from a total resource point of view, their development is desirable and should be considered. However, when recovery and production of byproduct mineral salts from geothermal brines is not economically feasible, adequate and safe disposal methods must be developed. In the United States, the normal disposal practice is expected to be by reinjection. Deep-well injection of brines and other fluids, to horizons from which they were extracted, is a practice commonly used by the American oil and gas industry.

The major area for concern in the reinjection of brines is the use of proper and adequate engineering safeguards. Contamination of a fresh water aquifer could result if one horizon were not kept isolated from the other by properly cementing the casing of the reinjection wells as well as the production wells. Injection wells must be designed to assure that the brines are entering and remaining in the desired strata. Indiscriminate discharge of mineralized thermal fluids that could pollute surface streams, lakes, and watersheds, or cause other environmental damage, should not be allowed.

One example of a mineralized fluid discharge occurred at the Geysers when condensed steam containing boron and ammonia, found its way into Big Sulfur Creek. Although this situation was corrected, an adverse impact on the stream's aquatic life may have resulted. In a few cases, it is expected that geothermal byproduct fluids may be of satisfactory quality to be disposed of without treatment. Surface disposal, in these cases, may be allowed under controlled conditions. As an example, the thermal waters heating the homes of Boise, Idaho, are disposed of in the city's sanitary sewer system.

FISH AND WILDLIFE

The development of geothermal resources can be expected to have varied impacts upon fish and wildlife. These impacts would begin with the exploration phase and continue on through the operation and production phase. The magnitude of any impact would depend upon, among other factors, the extent and duration of development and operation activities as well as the effectiveness of control measures. The impact resulting from exploration, development, and construction would tend to be of a temporary nature so long as the activity continued. Impacts associated with the operation and production phase would tend to be more permanent in nature and would continue during the life of the plant. However, some wildlife accept intursion into their domain without serious consequences. The greatest impact would be localized and would be expected to occur on or adjacent to well sites and power plants, where displacement and alteration of some wildlife species and habitats are expected. Inadequate control and release of highly saline geothermal fluids into streams, ponds, and game management areas could have potentially far-reaching consequences to fish and wildlife alike. Due to the presence of rare or endangered species or of unique wildlife habitats, future geothermal development in certain areas may be precluded.

On the positive side, revegetated areas and roads, cleared during the development phases, could provide wildlife with additional habitat. Consequently, the degree and permanence of displacement or disturbance of wildlife would depend upon the scope, duration and phase of activity.

SUMMARY

In summary, any adverse environmental impacts resulting from the development of geothermal resources for the production of power, and byproduct water or minerals, generally will be localized at or near the production site. Modification of the land resulting from exploration through operation and production phases will preempt and restrict uses for grazing, forestry, mining, fish and wildlife habitats, outdoor recreation, and watersheds. Well blowouts, noise pollution, noxious gas emissions, and the release of mineralized thermal fluids could pose problems during testing and production. Other possible adverse effects include land subsidence and increased seismic activity caused by the production of geothermal fluids and their subsequent reinjection.

Considered collectively, the environmental impact resulting from geothermal resources development appears to be less adverse than those of alternative fossil-fueled power sources. However, envronmental evaluations of potentially sensitive development areas must be made to identify those problems which could cause unacceptable environmental impacts. Since most of the impacts are easily identified, we believe that they can be managed effectively in an acceptable manner through the application of sound engineering principles and good housekeeping practices, thereby mitigating impact severity and permitting the development of the geothermal energy resources with the continued use of adjacent land in accord with multipurpose uses.

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GEOTHERMAL RESOURCES--LEGAL AND TAX CONSIDERATIONS

Willard A. Burton, Jr.[1]
Denver, Colorado

Some of you will remember the radio program "Twenty Questions" which was popular nearly thirty years ago. The "panel of experts" was allowed a maximum of twenty questions to identify an object which had been described only as animal, vegetable or mineral. The "mystery voice" had already identified the object to the radio audience.

With the ever increasing interest in exploration for geothermal resources, we are on the threshold of a twenty questions type "program" involving those resources. Are they mineral, water, heat or, as the Idaho legislature has described them, "sui generis, being neither a mineral resource nor a water resource",[1] and who owns them, the surface owner, the mineral owner or the state?

That there is a question as to the classification and ownership of geothermal resources has been evidenced in several ways. The United States Congress, in enacting the Geothermal Steam Act of 1970,[2] provided a procedure in Section 21(b)[3] for determining title to geothermal resources underlying lands which have been patented with a reservation of minerals to the United States.

The Utah State Land Board, in adopting Rule 30 pertaining to geothermal steam leases, provided in subparagraph (c), "Geothermal Steam leases will be issued only on lands where the State of Utah owns both the surface and mineral rights."[4]

The State of Idaho's declaration that geothermal resources are neither a mineral resource nor a water resource does not eliminate the uncertainty of ownership. This is recognized by the Idaho State Land Board in the latest draft of proposed regulations for leasing state lands. It is provided therein that there shall be two separate geothermal leases. One limitation applies to acreage covering lands in which the State of Idaho owns both the surface and subsurface. The second acreage limitation applies to lands which have been conveyed with a reservation of minerals to the state.

There are numerous Federal acts under which all minerals have been reserved to the United States. The act most familiar to us and which affects millions of acres in Colorado and the west is the Stock-Raising Homestead Act of December 29, 1916.[5] Section 9[6] requires that patents granted under the Act shall contain a reservation

[1]Chevron Oil Company

1. Idaho Geothermal Resources Act, Section 42-4001, Idaho Code.
2. 30 U.S.C.A. 1001-1025
3. Id. at 1020(b)
4. Rule 30(c), State of Utah Rules and Regulations governing the Issuance of Mineral Leases.
5. 43 U.S.C.A. 291-302
6. Id. at 299

to the United States of "all coal and other minerals."

At the time of Congressional consideration of the Geothermal Steam Act of 1970,[7] both the Senate and House Committees on Interior and Insular Affairs were advised that it was the position of the Department of Interior that the Stock-Raising Homestead Act reservation of coal and other minerals did not include "geothermal steam."[8] This position was based on an opinion of the Deputy Solicitor of the Department expressed in two letters dated December 16, 1965.[9] The Department recognized that while it was the prerogative of Congress to include Section 21(b)[10] in the Act, the provision was inconsistent with the Depararartment's position. The House made note of the inconsistency but, on the basis of a lack of unanimity of opinion and because the Department's opinion was not finally determinative of the legal question of ownership, reasoned that the subsection should remain in the Act; that "an authoritative judicial determination of the ownership of geothermal resources" under a mineral reservation was needed.[11]

Section 21(b)[12] provides that if development or production of geothermal resources occurs or is imminent on lands the surface of which has been conveyed with a reservation of minerals to the United States, the Secretary of Interior shall notify the Attorney General who shall institute proceedings to quiet title to such resources in the United States, and, if the title of the United States is upheld, to enjoin development and production of said resources except under the provisions of the Act. The subsection further provides that once an "authoritive judicial determination" is made that the mineral reservation does not include geothermal resources the duty of the Secretary to notify and of the Attorney General to institute proceedings shall cease. It was the intent of Congress that an early judicial determination of ownership is necessary,[13] and it seems obvious from the proviso excusing the Secretary and Attorney General from further action that Congress intended to minimize litigation.

In October of 1972, the Attorney General instituted a Section 21(b) proceeding in the United States District Court for the Northern District of California in a case styled United States v. Union Oil Company of California et al.[14] The Court entered judgment for the defendants on October 30, 1973

The land subject to the controversy is located at The Geysers in Sonoma County, California, some 90 miles north of San Francisco,

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7. N. 2 Supra
8. Senate Report 91-1160 at Page 14, House Report 91-1544 at Page 13
9. Id. at Page 15 et seq.
10. N. 3. Supra
11. House Report 91-1544 at Page 8
12. N. 3 Supra
13. N. 11 Supra
14. Civil No. C-72-1866, ____Fed. Supp.____(1973)

and was patented under the Stock-Raising Homestead Act[15] with the required reservation of coal and other minerals to the United States. The individual defendants are successors in interest to the patentees of the land. The corporate defendants, Union Oil Company of California, Magma Power Company and Thermal Power Company, are geothermal resources lessees of the individual defendants, and are producing geothermal steam from the land. In its complaint, the United States asked: (1) that its title to the geothermal resources be quieted; (2) that production of geothermal resources except under the Geothermal Steam Act of 1970[16] be enjoined; and, (3) for damages.

The Memorandum of Decision is lengthy (26 pages) and time does not allow for a detailed analysis. The basis for the decision can be summarized by the following quotation:

> "First, it is evident from the debates, reports and other legislative history that provision for the reservation of minerals played a minor role in Congressional consideration of the Act. (Stock-Raising Homestead Act[17]). Second, it was the intent of Congress that the homesteader receive title to land granted to him by patent under the Act, and that the full mineral estate, including all substances definable as minerals, be reserved to the United States. Third, Congress did not intend to reserve geothermal steam and associated resources because such fluids would not have come within the definitions of 'minerals' in force and usage at that time."

In reaching the third conclusion, the Court took the position that the main constituent of geothermal energy is superheated water (or steam) and that the strong weight of authority is that water was not a mineral either at the time the Stock-Raising Homestead Act[18] was enacted or at the time the patents to the land in question were granted, nor is water considered a mineral today.[19] In this connection, I pose these questions. Is the geothermal energy the water or the steam or is it the heat with the water or the steam being the carrier? If heat is the energy, is it likely that the same decision would have been reached? I would answer the second question in the affirmative.

I understand the United States is now considering appealing the decision. Because of the vast amount of acreage which will be affected and to eliminate further litigation, I would think an appeal would be taken and would suggest that the "authoritative judicial determination" probably will be rendered by the United States Supreme Court.

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15. Supra, Note 5
16. N. 2 Supra
17. N. 5 Supra
18. N. 5 Supra
19. See 148 A.L.R. 780 and 1 Williams and Meyers Oil and Gas Law 219.6 (1972) for a discussion of water as a mineral.

Another action commenced earlier this year is the case of Harry Pariani et al v. The State of California et al[20] filed in Superior Court of the State of California for the City and County of San Francisco. Here again the land in question is located at The Geysers. The plaintiffs are successors in interest to the grantees under three 1953 patents from the State of California. In each of the patents, the State reserved "all oil, gas, oil shale, coal, phosphate, sodium, gold, silver, and all other mineral deposits -- (excepting all unranium, thorium, or any other -- fissionable materials) --". Union Oil Company, Magma Power Company and Thermal Power Company, as lessees of the geothermal resources from both the plaintiffs and the State, are joined as defendants. Geothermal resources are being produced from the lands. The defendant-lessees have not been paying the plaintiff-lessors the 12-1/2 percent royalty as provided in the fee lease but rather have been paying them an overriding royalty of 2-1/2 percent which was provided for in the event it was determined that the plaintiffs did not own the geothermal resources. Ten percent royalties are being paid to the state under its lease and are being held in a special account. The plaintiffs seek a declaration that they are the owners as tenants in common of the geothermal resources under the land and are therefore entitled to the 12-1/2 percent royalty under the lease held by Union et al. This case has not yet come to trial.

To the best of my knowledge, no court proceeding in the State of Colorado has considered or is considering the classification of geothermal resources and the ownership thereof. I would anticipate some litigation in this field in the not too distant future, not only with respect to fee lands but also as to state lands where there has been a separation of the surface and mineral estates. I'll leave the prediction of the outcome of such litigation to your judgment, but I would like to quote from a recent decision of the Colorado Supreme Court in a case involving a reservation of "all mineral and mineral rights."[21] The Court was in turn quoting from an old English case.[22]

> ".....in deciding whether or not in a particular case exceptional substances are 'minerals' the true test is what the word means in the vernacular of the mining world, the commercial world and landowners at the time of the grant, and whether the particular substance was so regarded as a mineral...."

Perhaps the most complicated question which will have to be answered is: Who owns the minerals which are produced in association with and extracted from the geothermal fluid if it is finally

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20. Civil No. 657-291
21. Farrell V. Sayre et al, 129 Colo. 368, 270 p.2d 190 (1954)
    See also United States v. 1,253.14 Acres of Land, et al, 455 F. 2d 1177, 43 O&GR 487 (10th Cir, Colo., 1972)
22. Waring v. Foden, 1 Ch. 276, 86 A.L.R. 969

determined that geothermal resources are not mineral and there has been a severance of the surface and mineral estate?

In one of his letters of December 16, 1965, to which reference has previously been made, the Deputy Solicitor stated, "any minerals connected with the geothermal steam would, however, appear to be subject to the mineral reservation."[23] This statement would seem to present no particular difficulty if the owner of the minerals and the owner of the surface is one and the same. But when the owners are different, the matter becomes complex.

I submit that the final answer will come only with judicial determination or perhaps prospectively with proper legislation. In the meantime, it might be well to cover all bases and negotiate with both the surface owner and the mineral owner and his mineral lessee, if any, to make sure that the respective rights of all parties are under lease.

Mention has been made of the possibility of state ownership of geothermal resources. If such resources are declared to be water, this can be the effect in states where ground waters are declared to be the property of the public and subject to appropriation.[24] In those states it seems prudent to file applications for appropriation with the water authority having jurisdiction whether the land be fee, state or federal. The Utah Division of Water Rights is accepting such applications but is delaying any action until regulations pertaining to the drilling for and production of geothermal resources have been promulgated, that Division having been given jurisdiction over geothermal operations in the state.[25]

Perhaps future litigation, and/or legislation accompanied by appropriate regulations will provide more definite direction. There is not now such legislation in the State of Colorado. For the present, consideration should be given to the applicability of Article 18 of Chapter 128 of the Colorado Revised Statutes (1963), pertaining to underground water, to the drilling of geothermal resource wells.

The classification of geothermal resources (mineral, water or heat) will affect their treatment for tax purposes. Section 613(b) of the Internal Revenue Code lists percentage depletion rates for various minerals from 22% on oil and gas wells and certain specified minerals to 5% for common varieties of gravel, sand, etc. Section 613(b) (7) is a "catch-all" provision which includes "all other minerals." In that subsection, it is expressly stated that "all other minerals" does not include, among other things, "water."

In 1969, in a rather lengthy and detailed opinion in the case of

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23. Senate Report 91-1160 at Page 16
24. See for Example:
    Utah - Section 73-1-1, Utah Code Annotated
    New Mexico - McBee v. Reynolds, 74 N.M. 783, 399 P.2d 100
25. Section 73-1-20, Utah Code Annotated

Arthur E. Reich, et al v. Commissioner,[26] the U. S. Tax Court held that the producer of steam at The Geysers was entitled to an allowance for percentage depletion at the rate of 27-1/2 percent (now 22 percent). The court also found that the petitioners were entitled to a deduction for intangible drilling costs.

The petitioners were engaged in drilling for and producing steam at The Geysers. One of them, Thermal Power Company, had deducted 27-1/2 percent depletion from its gross income from steam production. All petitioners had deducted intangible drilling costs. The deductions were disallowed by the Commissioner and all petitioned for relief. The Tax Court decision, which was not unanimous, was affirmed by the Ninth Circuit Court of Appeals in 1972 without dissent.[27]

To reach its decision, the Tax Court made these findings. First, it decided that steam, not heat, was the product of the wells. Had the Court found that the product was heat, it probably could not have allowed percentage depletion, as heat is nowhere mentioned or implied in Section 613(b).

Second, steam was held to be gas. The majority concluded that terms used in the depletion statute must be construed in the light of common commercial usage and that within the geothermal industry it is understood that steam is gas.

Finally, the Court found that, "The Geysers is an exhaustible natural resource which has been depleted and is continuing to deplete."[28] Had the conclusion been that the supply of steam in the reservoir was inexhaustible, it was undisputed that percentage depletion could not be allowed.

The issue of the deductibility of intangible drilling costs incurred in drilling for and developing geothermal resources was decided with little discussion. The Commissioner of Internal Revenue had agreed in his original brief that if the issue of percentage depletion was decided in favor of Thermal Power Company, so also should the issue of the deduction of intangible costs be decided in favor of all petitioners.

The Internal Revenue Service has not yet acquiesced in the Reich decision.[29] In fact, the November 14, 1973, Pacific Coast Edition of the Wall Street Journal, in the Tax Report column, reported that the decision is being challenged in a circuit other than the Ninth. My investigation revealed that the IRS was prepared to make the challenge in the Second Circuit on the basis of a petition filed in the Tax Court in New York.[30] However, the matter was settled in advance of

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26. 52T.C. 700; See also George D. Rowan et al v. Commissioner, 28 T.C.M. 797 (1969) with respect to intangible drilling costs.
27. 454 F.2d 1157
28. N. 26 Supra
29. Samuel M. Eisenstat, Tax Treatment of Exploring and Developing Geothermal Resources, Vol. XXII, No. 1, Oil & Gas Quarterly(S.'73)
30. Charles J. Thornton, Docket 181-66

a Tax Court decision. Future challenges would seem to be a distinct probability.

Can the favorable tax treatment afforded by Reich[31] be extended to depleting hot water and dry rock reservoirs? I submit the answer is no. And I can see the possibility of Reich being overturned on the ground that the resource or product of the wells is the heat and that the steam is the carrier. This would seem to be particularly true of dry hot rock reservoirs.

To eliminate uncertainty, what is needed "is immediate and unambiguous legislation providing that the same tax consequences which flow from exploring and developing for oil and gas prospects will also apply to the exploring and developing for geothermal resources."[32]

So far, we have been talking about percentage depletion. What about cost depletion? In 1965, the Fifth Circuit Court of Appeals in the case of United States v. Shurbet et ux[33] affirmed a decision of the United States District Court for the Northern District of Texas[34] holding that under the existing special circumstances water used for irrigation in the Southern High Plains of Texas is subject to cost depletion.

The water bearing Ogallala Formation underlies the approximate 35,000 square mile Southern High Plains in Texas and New Mexico. The only source for new water in the reservoir is from precipitation upon the surface of the ground. Until the advent of drilling and producing wells for irrigation, the reservoir was in a state of dynamic equilibrium, a state in which the average annual natural recharge equalled the average annual natural discharge. With the drilling of thousands of wells and use of the water for irrigation, the reservoir is now being depleted. In addition to concluding that the reservoir was being depleted, the Court found that in Texas the owner of the soil is also the owner of the underlying Ogallala water and, more importantly, that water was a "natural deposit" within the meaning of Sections 611 and 612 of the Internal Revenue Code, which sections establish cost depletion.

The Court stated "the decision of this case is not meant to furnish a precedent as to the allowance of cost depletion for ground water, except under the peculiar conditions of the Southern High Plains."[35] Notwithstanding the assertion, I suggest that the case can be cited as authority to allow cost depletion for a depleting hot water or hot dry rock reservoir. While such a deduction would be of some advantage, it is obvious that one would prefer legislation to allow percentage depletion.

The Internal Revenue Service has ruled that it will follow the

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31. N. 26 Supra
32. N. 29 Supra at 81
33. 347 F.2d 103, 23 O&GR 491. (Texas 1965) For comment see Vol. No. 1, Oil & Gas Tax Quarterly 7 (October 1965)
34. 242 F. Supp. 736 (1963) 23 O&GR 475
35. N. 31 Supra

Shurbet case for the Southern High Plains of Texas and New Mexico.[36] The Service apparently doesn't place any weight on ownership of the water, for unlike Texas, all waters in New Mexico belong to the public.[37] The IRS has also established guidelines for computing cost depletion deductions under the doctrine of Shurbet.[38]

And so questions are being asked and answers are beginning to come. But many more answers must be forthcoming. Hopefully, these answers can come with a minimum of litigation and a maximum of effective legislation.

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36. Revenue Ruling 65-296. For Comment see Vol. XV. No. 2, Oil & Gas Tax Quarterly 83 (January 1966)
37. Article XVI, Section 2, Constitution of New Mexico (natural streams); McBee v. Reynolds, N. 24 Supra (under ground waters).
38. Rev. Proc. 66-11

UTILITY PARTICIPATION IN A GEOTHERMAL ENERGY SOURCE

William S. Landers[1]
Denver, Colorado

As you know, Public Service Company of Colorado and Petro-Lewis Corporation of Denver have entered into a contract to explore the possibilities of establishing a geothermal electric generating industry in Colorado. My remarks today will basically cover the approach to such a joint endeavor and means of resolving some of the problems that surfaced during the negotiations. PSCo's thinking was colored to a large extent by the history of the Geysers operation of Pacific Gas & Electric in California and that company's experience in this form of electric generation.

It is obvious that geothermal energy obtained from the ground can be used in a variety of ways. For example, it can be used to produce potable water, chemicals from the fluid, process or space heating and cooling, and the generation of electric power. Various combinations of these end uses can be conceived. However, I will consider the case where only the generation of electric power is involved.

Plans for adopting geothermal energy as a source of power generation vary from location to location and as a function of the time at which these installations are to be operative. Based on the single operating experience in this country, namely the Geysers, it is obviously impossible to establish specific parameters that can be applied to a new situation. We have to be prepared, therefore, to feel our way in order to understand the specific problems and advantages of each project as it is presented. Our participation in geothermal is confined to the use of steam. This permits development on a more rapid time scale than do hot rocks, hot brine, or hot water. There is a proven technique and commercially available equipment for one set of steam conditions that has proven viable as a means of generating electric power. To this extent the steam is ahead of the other technologies.

In attempting to develop the contract between our companies on our joint project, it was immediately apparent that there was a basic difference in philosophy between the electric generating company and the exploring, drilling, and producing company. The electric power industry by its nature is essentially conservative. It deals with large investments and is under the constraint of a legal obligation to serve its customers with electric power at all times. We tend to move relatively slow into new fields and techniques. On the other hand, our partners in this venture have a history of successful exploration, drilling, and producing followed by a rapid sale and utilization of their proven product whether it be oil or gas. One of the main difficulties is that in oil and gas all of the technologies

[1]Public Service Company of Colorado

involved are well established and well proven. While it is likely that a new oil or gas field will not be identical with any other field that the finder may have experience with, across the total industry experience it is likely that all of the problems that will be encountered have been encountered before and successfully solved. There is a definite lag, though, in the technology of utilizing steam for power generation. There is only one domestic installation and there is only one domestic reservoir to compare with the new one that might be found. It is highly unlikely that any new reservoir will be sufficiently like the Geysers in extent, quality of steam, or environment to permit a transfer on a one to one basis of Pacific Gas & Electric's experience into the new field. We consequently tend to move at a slower pace than our partners. This presents a real problem. We feel that in the case of the present venture that this was solved through a sincere desire to understand the problems of the other side and to accommodate as much as possible the desires of the partners. We frankly had a lot to learn about the exploration and drilling industry, and I am sure our partners had an equal education in the utility industry. Compromise was necessary on the part of both parties in order to develop a program and schedule that was mutually acceptable.

The specific requirements that must be met by a project are basically: (1) Economics, (2) Reliability, and (3) Environmental Acceptability. The economic approach of a utility to geothermal power varies as a function of the utilities resource situation. By this I mean if looking down the line a utility decides that presently used techniques of generation or sources of raw energy will not be available, it is incumbent upon the utility to direct its efforts immediately towards the finding and adoption of new sources or new techniques. If, however, present or soon to be available alternatives can be used for future generation, the utility is not under the constraint to move rapidly into the new energy source. This also has a distinct affect on the economics. In our particular situation we fall into the second category. In our area there are large reserves of coal available for long term contract. We feel that we have progressed far enough in our research and development and implementation of air quality control measures to believe that we can meet present and changing environmental requirements for burning fossil fuel. We are, therefore, in the position of looking at the economics as compared to viable alternatives and if geothermal or any other source of energy or technology is not reasonably competitive with these alternatives, it holds very little interest for us. We obviously feel that geothermal meets this requirement. We anticipate that our generating mix will consist of fossil fuel fired plants, hydro, nuclear, and, possibly, geothermal. Changes in fuel or generating techniques will continue to be made as they prove to be competitive

Because of the public utility nature of our industry and the requirement to serve our customers on demand, reliability and continuity of operation are of prime importance. Before we install geothermal generating capacity, we must decide how reliable this is going to be. If it is not as reliable as our normal generating equipment, we will have to back it up with other generating capacity using other forms of energy, such as nuclear, hydro, or fossil fuel. This obviously adds to our capital costs and reduces the attractiveness of geothermal. In considering reliability we, of course, take into account the type of service expected from a particular generating unit. It can be used for peaking, for intermediate service, or it can be base load. In this last mode, the units are operating at essentially constant capacity around the clock and every day of the year. It is our feeling that geothermal has its best application for base load. This, in turn, requires the highest reliability of all modes of operation in terms of energy supply and utilization.

Utility accounting practices dedicate long current life for generating facilities. When you consider that a 50 MW commercial geothermal generation plant may cost 8 to 10 million dollars, you realize the need for a long contract and, even more important, for a long physical life of the resource and reservoir.

The necessity for being environmentally acceptable is obvious and I am sure will be discussed in more detail by Mr. Miller. The problems that we anticipate will have to be defined and solved will be in the steam supply, electric generation, disposal of products from cooling towers and effluent, and transmission of the generated energy to load centers. We recognize that these problems are going to be very serious, but we cannot at this point in time define them precisely. It is obvious that the geothermal power industry must be acceptable from an environmental standpoint before it can be considered to be an integral part of the electric energy mix. These problems will have to be defined and solutions found, and this is one of the prime reasons for the apparently slow and pedestrian approach required for the development of this resource.

REQUIREMENTS FOR PRIVATE INDUSTRY IN DEVELOPING GEOTHERMAL ENERGY

Malcolm H. Mossman[1]
Denver, Colorado

The term "geothermal energy" as commonly used means, "that portion of the earth's natural heat that man can harness to improve his environment." The term "geothermal resources" includes not only the natural heat but the byproducts produced in the process of producing the heat, i.e. water, salts, gases, etc. The objective of private industry is to develop the geothermal resources of this State and Nation to the point where they become a reliable, inexpensive source of energy that contributes substantially to our economy and is in gear with our environment.

The basic technologies of exploration drilling, completion, development, production, and utilization are almost identical to those of the oil, gas, and electrical power industries. For this reason the oil industry will be the industry primarily responsible for the exploration and development of the geothermal resource while the utility industry will be primarily responsible for its market utilization.

The average successful geothermal prospect encompasses approximately 25,000 acres, requires an initial expenditure of $8,000,000 for drilling, completion, and collection systems; and $26,000,000 for generating plant construction. With existing lead times, the earliest possible cash flow would come in about 3 years, if everything went perfect. A reasonable time period would be 5 years. With current administrative, environmental, and judicial delays, some projects are now taking 10 years. The saving grace is that, once productive, the operating problems are few, the cash flow is steady, and the profit compares very favorably with competing forms of energy.

The state of the art of exploration, the capital needs, the unique market conditions, and the cash flow delays lead to the following requirements:

First: The explorer must overlease the prospect to make sure that he controls the resource he finds and can assure the power generating company that he not only owns and controls the resource but will have a large enough supply of energy to amortize the plant and provide a reasonable profit period after that amortization.

Second: The ownership of the geothermal resource has not been clearly defined and established by legislation and in the courts. Because of this, the responsible operator must lease both surface and mineral ownership where both exist. We must proceed to a clear definition as quickly as possible.

Third: The tax treatment was clearly defined at the Geysers geothermal field in California, but the Internal Revenue Service has

[1] The Anschutz Corporation

taken the position that that decision applies only to that field and is challenging depletion and intangible write offs in all other prospect areas. This policy serves to delay the development of new areas and postpone the time when electricity, working interest income, royalties, and taxes are generated from the prospects. The tax treatment should be the same as oil and gas. This should be established immediately.

Fourth: The industry is capitally intensive. Capital investors have a very limited track record to examine prior to the commitment of their monies. Since little is known about the life of a particular field, borrowers are unable to put up producing properties as collateral for production loans. Pete Sims of DeGolyer and MacNaughton tells his clients, "That in order to participate in geothermal energy, it will be necessary for them to have financial muscle sufficient to withstand the loss of earnings on their investment of $20,000,000 for a minimum period of five years." This is an area where government monies could be of great help. The government might participate as a partial guarantor for production and plant construction loans.

Fifth: The oil and gas exploration record has indicated that about 1 (one) in 10 (ten) exploration wells is a discovery and about 1 (one) in 25 (twenty-five) is commercial. We hope that the success ratio in these pioneering stages of the geothermal industry will be better, but our limited experience so far has shown no appreciable difference. Therefore, a prudent explorer hopes to drill at least 10 (ten) prospects and hopefully 25 (twenty-five). If an operator is fortunate enough to find 2 (two) or 3 (three) commercial discoveries in 10 (ten) to 25 (twenty-five) prospects, he can make the cash flow delays a one time proposition by paying for the development of the second prospect out of the cash flow from the first after it is paid off. As one rancher so aptly pointed out, "It's like the chicken business; you've got to have some laying, some hatching, and some growing, in order to stay in business."

Sixth: The Federal acreage limitation of 20,480 acres per state is unrealistic. With an average prospect size of 25,000 acres and a minimum of 10 (ten) exploration tests necessary, the minimum exploration program will include some 250,000 acres. In view of the estimation that the Federal lands contain 60% of the acreage potential for geothermal production, this low acreage limitation can serve only to delay the reasonable development of geothermal energy in this State and the Nation as a whole. The Federal acreage limitation should be the same as it is for oil and gas, i.e. 246,080 acres per person or corporation per state.

At this point, I would also like to point out that the present use of KGRAs (Known Geothermal Resource Areas) is destructive rather than constructive in nature. There is only one "known" geothermal resource area in the United States and that is the Geysers, California.

All the others are "potential" geothermal resource areas. The classification of an area as KGRA implies that it is a "known" resource with little or no risk involved. The other special provisions which call for increased royalties, rentals, competitive bidding, etc. also imply that there is little or no risk involved. This is not the case. Several of them have been drilled but only one, Geysers, is commercial. None of the others are even close to being commercial at this point. The increased front end and operational costs imposed upon KGRAs will make them the last areas to be developed. If the provision that, any Federal lease can be classified as being within a KGRA merely by competitive interest, is enforced fully, essentially all Federal leases will be classified as KGRAs. The provision for a KGRA should be repealed. Until this can be done, the U. S. Department of Interior can and should designate only those areas that have established commercial production as KGRA.

Seventh: At this stage of the game, we have not been at the business of exploring specifically for geothermal energy long enough to have developed the empirical data, experience, and art we now have in the oil, gas, and power industries. The factual information and experience from the few actual producing geothermal areas is very limited, but is the most valid information that we have. Risks are high, but the acquisition of this factual data and experience is a must. For this reason, the progress of the geothermal industry depends largely upon our ability to channel every possible dollar into the drilling of exploration and development test wells. The objectives are identical with the historical development of all our natural resources, including oil, gas, and coal. We must find and identify the natural resource first. Then, we can enter into meaningful research and development as to its specific utilization.

Eighth: Front end monies must be kept to a minimum so that the maximum percentage of the exploration and development dollar is spent on the drilling and completion of wells, and to encourage healthy competition among individuals and small and large companies. A major offender of this principle is the recent trend towards so called "competitive bidding". As the American public understands the term, it is designed to accomplish a task with the minimum cost. "Competitive bidding", as used in the Federal offshore sales and proposed for geothermal leasing, is designed to load up the front end with a maximum cost. Contrary to popular thought, this results in a net loss to the public. True, it frequently brings in more front end money to governmental agencies, but its built-in inflation and resultant loss in gross national product results in a net loss to the private citizen and governmental treasury as well. In 1971, for every eight dollars paid for offshore leases, there was only one dollar spent on drilling. This ratio should be just the reverse.

"Competitive bidding", as it is currently practiced, has allowed the large companies and consortiums to virtually, "buy the game out". By paying high front end bonuses, they have effectively eliminated their competition. The rub comes in that they can and must, if they are to survive financially, pass on a multiple of these front end costs to the consumer raising his energy costs and thus contributing substantially to the inflation of our economy. That means that for every dollar collected by the government in front end bonuses from "competitive bidding", you and I, the consumers, are going to pay an additional 2 to 3 dollars, and I object to that. I don't wish to imply here that there are any grounds for "antitrust" action against the large companies and consortiums. I do wish to point out that they are caught up in a destructive type of competition from which I am sure they would enjoy relief. The relief must come through a change in the Governmental policy that created the problem. Geothermal leases should be issued on a "first come first served" basis where no competitive interest by simultaneous filing is established, and by "lottery" where a competitive interest is established by the multiple simultaneous filings.

Ninth: Unless the current trend of loading up the front end costs by such things as "competitive bidding", unreasonable environmental studies and requirements, judicial delays, and renegotiation of contracts after the fact is reversed, we will lose the constructive competitive input of the individuals and small independent companies that have traditionally found 75% of our natural resources. We are rapidly approaching the day when only two groups will be able to explore and develop our natural resources; i.e., the large integrated companies, who can afford to pay the front end loads because they can pass the costs on to the consumer; and the Federal agencies, who can ignore the restrictive and uneconomic aspects of the existing legislation, rules, and regulations. May I remind you that a small group of individuals are largely responsible for the Commercial Geothermal Industry in this Nation to date. Let's not negate their vital input under the guise of sound planning.

Many of the potential geothermal lands are currently owned by the Federal Government. The existing legislation, rules, and regulations for geothermal energy development on Federal lands make them noncompetitive with competing energy sources such as coal, oil, and gas. In addition to this, many of these lands have been proposed as wilderness areas which would preclude their development. The private lands that are in and adjacent to these lands are being condemned and purchased by the Federal Government to be included in these wilderness areas and other Federal projects. In the process, we are loosing another valuable natural resource, "private land". We should declare a moratorium on the acquisition of private land by the State and Federal Governments along with the establishment of maximum limits on public ownership of lands.

Tenth: The regulating agencies for geothermal resources and oil and gas should be the same. With the rapidly developing technologies, particularly in the field of heat exchangers, many producing oil fields will soon be producing electricity from the heat they are currently allowing to dissipate into the environment. Most exploration tests should now be evaluated for their potential to produce oil, gas, and geothermal resources. We now have a third energy source to explore for in an exploration test well. All these can and do occur frequently in the same environment. Let us take advantage of this fact and encourage exploration for, and development of, all three from the same bore hole. Bonds, forms, and environmental impact statements should be the same for all three. This will afford us the expertise of the current regulating personnel, while keeping the number of regulating agencies to a minimum.

In summary, geothermal energy will be a viable part of the energy source for this State, and the Nation as a whole. It is not a panacea nor is it something that requires a vast governmental agency to develop. It will become a reality as soon as we recognize it for what it is and fit it into its proper competitive position in our total energy economy and environment.

GOVERNMENTAL LEASING REGULATIONS

Reid T. Stone[1]
Washington, D. C.

Mr. Ten Eyck, Members of the Department of Natural Resources, Ladies and Gentlemen. It is a pleasure to be with you here today and to have the opportunity to discuss with you the regulations developed by the Department of the Interior to govern the leasing of geothermal resources on federal lands.

As many of you know, these regulations have been a long time in the making. Since the passage of the Geothermal Steam Act of 1970, proposed leasing regulations have been published three times in the Federal Register, with comments invited in each instance from federal agencies, state governments, private industry, and the general public.

In addition, publication of the Final Environmental Statement on October 23, 1973, provided the public additional information on which to base comments on our proposed regulations. In all, I believe that there has been unprecedented opportunity for public participation in the preparation of the geothermal leasing regulations.

To assure that all comments were fully considered, that the regulations were published in a timely manner, and that necessary forms and procedures were developed prior to the first competitive lease sales, a task force was formed within the Department. This group, composed of knowledgeable individuals from the concerned bureaus, offices, and the Office of the Secretary, has now completed its work. All the required actions are now before the Secretariat for review and submission to Secretary Morton for a final decision. In this regard, we anticipate that within the next week or two the Secretary will announce his decision. If his decision is to proceed with the leasing program, the first lease sale could be held the middle of January barring any unforeseen circumstances.

In this connection, I would like to review with you briefly some of the points in the proposed regulations which received the most public comment and which were studied closely by the task force in recommending action to the Secretariat.

1. OPERATION PLAN PRIOR TO LEASE. Many objected to the requirement for an operational plan prior to issuance of a lease on the grounds that it is usually impossible to write an adequate plan of operations prior to going upon the lands to explore for geothermal resources. Such plans, it was felt, would be inadequate and based on incomplete information.

2. DILIGENT PERFORMANCE REQUIREMENTS. Proposed regulations require that all leases include diligent performance obligations which require the expenditure of funds proportionate to an escalating rental

[1] U. S. Department of the Interior

scale after the first five years for exploration or development oper tions. Some reviewers felt that this requirement was too restrictive on operators and should be eliminated.

3. ENVIRONMENTAL STATEMENTS AND PUBLIC HEARINGS ON ALL LEASES. It was suggested that environmental statements and public hearings be added to the regulations to give additional assurances for environmental protection. All lands proposed for leasing must receive an environmental assessment to determine whether the leasing is a major federal action requiring an environmental statement under the National Environmental Policy Act. Environmental statements are also required for new geological areas and where unusual conditions are encountered. Public hearings are at the discretion of appropriate officials.

4. OPEN ONLY AREAS PROGRAMMED FOR LEASING UNDER LONG-RANGE LEASING PLANS. The ability to formulate a long-range plan from limited resource data was a principle consideration of the task force's review of this proposal.

The following listed proposals for change in the regulations were considered of less significance than the preceding. With the exception of the first, the task force recommended no change in the proposed regulations.

1. Change ownership interest limitations from 20% to 10%.
2. Limit or prohibit leasing in wilderness or recreational areas.
3. Develop environmental baseline data prior to leasing. (Present requirements are sufficient.)
4. Notice of intent for pre-leasing exploration activities.
5. Require explicit environmental standards.
6. Assign fish and wildlife responsibility to state or federal agencies.
7. Limit Supervisor's authority.
8. Provide additional protection for adjacent landowners.
9. Include specific inspection requirements.
10. Provide increased opportunities for non-competitive leasing.
11. Limit discretion of the Secretary of the Interior on "grandfather" applications.
12. Give KGRA "grandfather" applicants, with only applications filed, the right to match the high bid.
13. Eliminate separate permits required for power generation facilities. (The right to construct a power plant is assured to all lessees in the proposed regulations. However, the location and area are subject to permit from an authorized officer.)
14. Require environmental assessment before construction.
15. Make leases not subject to readjustment of terms.
16. Require compliance with state water laws.

RULES AND REGULATIONS RELATING TO GEOTHERMAL LEASES ON COLORADO STATE OWNED LANDS.

Thomas E. Bretz[1]
Denver, Colorado

Prior to Congressional ratification of the Constitution of the State of Colorado, legislation entitled "The Enabling Act" was adopted, granting to the State two sections in every township as a continuing source of income for the benefit of the State's schools and institutions. The Act specifies Sections 16 and 36, but, in those instances where these sections had been disposed of earlier, Colorado was, or will be, indemnified with other lands.

The Constitution of the State of Colorado, in Article IX, Sections 9 and 10, grants authority to the State Board of Land Commissioners to administer the State's lands. Further reference to the scope of the Board's authority is to be found in Chapter 112, Section 3, Colorado Revised Statutes, 1963. Later Congressional action forbids disposal of the mineral interests under most State lands (see USC 870-871, March 3, 1927). Though the surface rights may be sold, the mineral rights are a permanent source of revenue.

The State Board of Land Commissioners administers more than four million acres of state owned mineral lands, in addition to other state owned lands.

The following Regulations have been adopted by order of the Board, effective January, 1972. They are issued as a guide to the leasing and operating of State land. The Board reserves the right to make exceptions whenever it deems it advisable to do so, and these regulations are subject to change at any time at the discretion of the Board. However, these rules shall not supersede the provisions of any existing lease or laws relating thereto or in conflict therewith.

General Land Board Regulations relating to mineral procedures apply and will be adhered to.

1. Definitions

A. Geothermal Resources Lease -- is a lease agreement covering geothermal resources, issued by the Board of Land Commissioners at Denver, Colorado, on behalf of the State of Colorado.

B. Geothermal Resources -- means geothermal steam and associated geothermal resources, including, but not limited to, (1) indigenous steam, other gasses, hot water, hot brine and all other products of geothermal processes resulting from water, brine, (2) steam, air, gas or other substances artificially introduced into subsurface formations, (3) natural heat, steam energy and other energy in whatever form found in subsurface formations. Hydrocarbon

[1]Colorado State Board of Land Commissioners

substances are specifically excluded from the lease and must be dealt with under a separate contract with the Board.

C. By-products -- are the by-products derived from the production of geothermal resources. Including, but not limited to extractable salts, mineral products, chemical compounds, etc., recovered in the process of the demineralization of brines. Water suitable for irrigation or domestic use resulting from the demineralization of brines and water derived from condensation of geothermal steam are also considered a by-product.

2. Lease

A. How acquired -- A geothermal resources lease may be acquired by application to the Board. The Board reserves the right to issue leases on either a competitive or non-competitive basis. The Board reserves the right to deny a geothermal lease at any time for any reason it deems advisable. The Board will set the terms of any lease issued.

B. Primary term -- to be set by the Board.

C. Extension -- An additional term equal to the primary term at double the rent of the primary term may be applied for by Lessee in writing, and the granting of such extension will be at the option of the Baord. Terms of any extension granted will be fixed by the Board.

D. Annual rental -- $1.00 per acre or fraction thereof.

E. Minimum royalty -- The Board may require a minimum guaranteed royalty to be paid annually, whether or not products are being produced. Minimum royalties will be reviewed each five years of the term of the lease, and the amount will be set by the Board to be paid during the succeeding five-year period.

F. Production royalty -- to be set by the Board. Products must be accounted for each month by notarized production reports accompanied by full payment for royalty due the State.

G. Assignment -- Lessee may assign full interest in all or part of his lease according to established procedures of the Board. The Board may reject any assignment.

H. Surrender -- Lessee may surrender full interest in all or part of his lease according to established Land Board procedures.

I. Unit Agreements -- Pooling Agreements -- The Board will enter into unit or pooling agreements if requested to do so by Lessee, when in its opinion it is to the best interest of the State to do so. When only a portion of a lease is committed to a unit, the Board reserves the right to segregate that portion in the unit from the lands not committed.

3. Exploration

A. Notice of work to be done -- Lessee must notify the Board before commencing any exploration. The Board may require maps, plans and other information concerning the planned exploration to be done.

The Board may require changes or adjustments in any proposed exploration program.

B. Exploration bond -- Lessee must post an exploration bond with the Board on forms furnished by the Board in an amount set by the Board to guarantee compliance with the Board's requirements, restoration of the surface and settlement of all damages to surface owner's or surface lessee's property.

C. Drilling and plugging of exploration wells -- Restoration of surface -- All holes must be drilled and plugged in a manner that will insure no contamination of fresh waters of the area by well fluids. No drill holes are to be left in such a condition that they may be a hazard to persons or livestock at any time during drilling or after completion.

Protection of fresh waters of the area is vital, and the Land Board and State Engineer's office must be consulted and satisfied with the drilling, plugging, and completion or abandonment procedures of all wells before drilling is commenced.

The surface of each drill site must be restored to as near its original state as is practicable upon completion. If requested by the Board, roadways will be protected from erosion and all disturbed land reseeded. Final restoration must be done to the Board's satisfaction before Lessee will be released from his liability under his bond.

D. Reports -- Lessee shall furnish the Board a correct log of each well drilled on the leased premises, showing by name or description the formations passed through, the depth at which each formation was reached, the number of feet of each size casing set in each well, where set, and the total depth of each well drilled.

Lessee shall, upon the Board's request, make available to the Board or other proper State agencies any additional information Lessee may have that will contribute toward a complete record of all wells drilled. Such information shall include, but not be limited to, electronic, radio-active or sonic logs that are run, drillstem test results, core records, fluid analyses, fluid and formation temperatures, casing perforations, production tests, etc., that Lessee has in its files.

On or before the termination of the lease, or one year after the commencement of production under the lease, whichever is earlier, Lessee shall provide the Board with copies of all such information above referred to.

E. Pollution -- Lessee agrees to conduct his operations in a manner satisfactory to Federal and State agencies concerned with pollution of water and air. All waste, solid or liquid, must be disposed of in a manner satisfactory to the Land Board. None shall be stored in such a manner as may pollute the surface or subsurface fresh waters of the area.

4. Development and Production

A. Use of surface -- Lessee may use as much of the surface as is necessary to develop and produce geothermal resources. In no case will plants for utilization of products be allowed without special arrangements with the Board.

B. Development drilling -- Restoration of surface -- The Board must be kept fully informed of proposed development. Lessee agrees to abide by requirements set by the Board relative to developing and producing products from the leased premises.

All wells drilled for the production of geothermal resources must be located by survey made by a licensed surveyor. Surface pipe must be set and cemented in all such wells through all fresh water formations known or utilized in the area. No surface pipe is to be removed from any well.

All holes must be drilled and completed or plugged in a manner that will insure no contamination of fresh waters of the area by well fluids. The Land Board, prior to drilling of any well, must be consulted and satisfied with plans for the drilling, plugging or completion of all wells.

No well, whether capable of commercial production or not, will be allowed to remain unplugged unless Lessee satisfies the Board that it will be utilized within a reasonable time and that it will not contribute to pollution if left unplugged temporarily.

The surface of each drill site must be restored within a reasonable time to as near its original state as is practicable after completion or abandonment. If requested by the Board, locations and roadways will be protected from erosion and all disturbed land reseeded. Restoration must be done to the Board's satisfaction before Lessee will be released from his liability under his bond.

C. Reports -- Information to be furnished to the Board -- Lessee shall furnish the Board a correct log of each well drilled under the lease, showing location, elevation, description of the formations passed through, the depth at which each formation was reached, the number of feet of each size casing set in each well, where set, and the total depth of each well.

Lessee shall, upon the Board's request make available to the Board or other proper State agencies any additional information Lessee may have that will contribute toward a complete record on all wells drilled. Such information shall include, but not be limited to, electronic, radio-active or sonic logs that are run, drill-stem test results, core records, fluid analyses, fluid and formation temperatures, casing perforations, production tests, etc., that Lessee has in its files.

On or before the termination of the lease, or one year after the completion of each well on the lease, whichever is earlier, Lessee shall provide the Board with copies of all such records requested by the Board.

D. Pollution -- Lessee agrees to conduct his operations in a manner satisfactory to Federal and State agencies concerned with pollution of water and air. All waste, solid or liquid, must be disposed of in a manner satisfactory to the Land Board. None shall be stored in such a manner as may pollute the surface or subsurface fresh waters of the area.

E. Measurement of Production -- Commingling Production -- The Board must be satisfied that the method of measuring production from State land is accurate. All production must be accounted for before removal from the leased premises unless otherwise agreed to in writing by the Board.

Production from State land may be commingled with production from other lands, but only after the Board is satisfied as to the quantity as well as the quality of the production from State land. The Board may stop such commingling at any time the measuring system ceases to be satisfactory.

F. Market value in captive market -- If production from the leased premises is utilized in a plant wholly or partly owned or controlled by Lessee or his agent, the market value for royalty purposes must not be less than the prevailing price that would be paid for products of like character and quality in the same general area, and the Lessee must satisfy the Board that the price is reasonable and fair.

G. Compliance with laws -- Rules and regulations -- Pollution is of real concern in most areas, and Lessee must comply with all laws, rules, and regulations now in force as well as those that may be established during the period the lease remains in effect.

H. Offset drainage -- Lessee agrees to protect State lands against offset drainage by drilling the required offsetting wells on State land or by other means satisfactory to the Board. Failure to do so may subject the lease to cancellation of all undeveloped lands thereunder.

I. Development Bond -- Lessee must post a bond with the Board on forms furnished by the Board in an amount set by the Board before commencing the drilling of a well for production of geothermal resources to guarantee compliance with all terms of the lease and rules and regulations issued by the Board or other proper agencies, for payment for damages to the land surface and improvements thereon. Lessee's liability includes payment for loss to personal property of surface owner or lessee, proper abandonment of drill holes, and restoration of premises to the satisfaction of the Board.

The Board may require Lessee to maintain a bond in effect with the Board for the duration of the operation and completion of plugging and restoration upon abandonment of production. The Board may adjust the amount of the bond at any time it sees fit to do so.

J. Water rights -- Lessee shall have the right to produce water for exploration and development purposes under the lease.

Lessee shall not have the right to appropriate any water produced from the leased premises under the State's water laws without permission in writing from the surface owner and on terms agreeable to the surface owner. On the termination of the lease, all wells on the leased premises capable of producing water suitable for irrigation or domestic use not previously appropriated by the Lessee shall be offered to the surface owner for the salvage value of the equipment and material in the well. State laws pertaining to water and administered by the Office of the State Engineer must be complied with.

K. Inspection of premises and reports -- Lessee agrees to allow authorized personnel of all proper State and Federal agencies to inspect the property at any time during regular office hours.

Lessee agrees to file required reports to the proper government agencies and to keep the Board informed concerning exploration, development and production on the leased premises.

L. Rule changes -- Geothermal resources exploration and development are activities which are new to Colorado and rule changes will of necessity occur. The Board reserves the right to alter any of the foregoing rules and regulations or issue additional rules and regulations when it deems it advisable to do so.

GEOTHERMAL ENERGY AND THE ENERGY CRISIS: BANQUET SPEECH

William L. Rogers[1]
Denver, Colorado

Mr. Ten Eyck, Senator Schiefflin, President McBride, Mr. Pearl, Ladies and Gentlemen:

It is a rare privilege to be here with you tonight, not only to talk about my favorite subject -- energy -- but also to meet so many competent workers in a particularly important branch of science and engineering, which two fields of activity have been an integral part of my work throughout my career.

In this month of December, 1973, you are to be congratulated for scheduling a seminar on such a timely topic; but I doubt, even so, that you knew quite how much energy matters would be in the spotlight at this time. We find ourselves as a Nation coming rapidly to the realization that we face a real, honest-to-goodness, bonafide shortage in energy. If we don't turn to, lots of us will be cold and/or walking or riding buses before the winter is over.

Lots of people don't seem to have the message yet -- like those that pass me on 6th Avenue in the mornings and evenings as I drive at 50 mph on my way to and from the Federal Center, and those who keep their homes and offices at about 80 - 85 degrees. It is gratifying to notice, however, that more and more people <u>are</u> getting the message. I think I see an increasing number of us in the ranks of those

1. Driving at 50 mph,
2. Doing no unnecessary travel,
3. Living in cool houses, and
4. Driving to work with 3 - 4 people in each car.

Now we need more people to set the example. The Denver Federal Executive Board announced today the establishment of an Energy Conservation Committee, which I'm sure will help. I invite each of you to help spread the conservation message.

On the bright side, we are very lucky it's happening to us now. The Arabs did us a favor. The breakneck pace at which our consumption of energy has been increasing, together with the failing availability of sources of supply to keep up would have meant real hardship, had several more years passed by before our plight was brought home to us.

The present crisis stems from the simple fact that America, with only 6 percent of the world's people, expends over 30 percent of all the energy in the world. Our use of energy, particularly since World

[1]U. S. Dept. of Interior, Special Assistant to the Secretary, Missouri Basin Region

War II, has increased dramatically. Two-car families seem to be the rule, not the exception; air conditioning is the rule in public buildings and is becoming common in private dwellings; recreational use of energy in power boats, snowmobiles and campers continues to increase; and the industry which has made us the greatest Nation in the world uses huge amounts of energy. Basically, our energy problem stems not merely from curtailment of oil shipments to this country, but from the affluence and abundance we have come to accept as the rights of all our people.

There are two main approaches to solving the problem of providing sufficient energy for present and future needs; either the supply of energy can be increased or the demand for energy can be reduced. In the short run, to meet the crisis this winter, we must take the latter approach. Emergency measures in this direction have begun, and more will be taken. President Nixon just this week (December 4) announced the latest steps he is taking to combat this crisis. He has requested legislation, calling for the establishment of a new agency, the Federal Energy Administration, which will consolidate energy resource management activities and provide a basis for rapid expansion of those activities dealing with the energy emergency.

In anticipation of Congressional action, he issued an Executive Order, creating a Federal Energy Office, moving to the extent possible within his existing authorities to create a framework for the new agency, and to provide a basis for improved management and coordination immediately of Federal energy resource activities. He has selected Mr. William E. Simon to head the Federal Energy Office, and has designated John C. Sawhill as his Deputy.

Units now operating under the direction of the Federal Energy Office are the following:

1. From the Department of the Interior

   Office of Petroleum Allocation
   Office of Oil & Gas
   Office of Energy Conservation
   Office of Data & Analysis

2. From the Cost of Living Council

   Energy Division

The strategy for managing the currect situation is:

1. Minimize impact of energy shortages on economy
2. Maintain production and employment to maximum extent possible
3. Spread impact of shortages over less essential energy-consuming activities.

State Governments are taking emergency actions and all Americans have been asked to voluntarily limit their use of energy resources, particularly petroleum products, as much as possible.

But such measures, although necessary, are not the answer unless we wish to revert to the levels of energy use prior to World War II with serious consequences to our economy. An increasing supply of energy must be developed, and it must be developed in ways that meet legitimate environmental concerns.

In 1971, recognizing the urgency of the situation, President Nixon sent to the Congress the first message on energy policies ever submitted by an American President. In that message, a number of specific actions to increase the Nation's supply of clean energy were recommended. Some actions have been taken, but these are only a beginning. In view of this, the President in April of this year submitted to the Congress a new energy message, outlining the first important steps toward an integrated National Energy Policy.

The President indicated that the United States has plenty of energy resources. What is lacking is development -- and time. Within the limits of appropriate environmental protection, our vast coal resources, the oil shale which is so abundant in Colorado, solar energy, nuclear energy, and geothermal energy must be developed -- and the time for appropriate action is now.

One of the least developed sources of energy in the United States is geothermal energy -- the natural heat of the earth. Most of this heat is at depths too great (in light of present technology) to be tapped by man. But geothermal energy does have potential economic significance where heat is concentrated into restricted volumes in the earth's crust, in a manner comparable to the concentration of valuable metals into ore deposits or of oil into commercial petroleum reservoirs.

Most geothermal reservoirs are localized in regions of high heat flow from the depths of the earth. Such regions in the United States commonly occur in the western one-third of the country. From the standpoint of geothermally generated electric power, the eastern two-thirds of our country, excluding the Gulf Coast area, appears to hold little or no promise. There is some disagreement, but present evidence weighs heavily against geothermal energy development anywhere in the eastern two-thirds of the United States.

The western one-third of the United States, plus Alaska and Hawaii, offer the principle opportunity for the development of geothermal energy for the country. Here there is an abundance of hot springs, ample evidence of young volcanic activity, and - most importantly - high heat flow values. It is here that geothermal resources can be developed and here that they will be used. Unlike large producing fossil-fueled plants that generate electricity in one place for use in another, geothermal sites can generate relatively small quantities of electricity which will, in most cases, be used locally.

Presently, the only power generated from geothermal energy is at The Geysers, in northern California. This field has 11 generating units with a total present generating capacity of 300 megawatts, and an estimated potential of 1000 to 3000 megawatts. This is the largest geothermal facility in the world, and one of only nine that have been developed world-wide in the last 15 years. The small size of these facilities is emphasized by the fact that, in total, they will produce less than one medium-sized nuclear power plant.

The Geysers field is favorably located about 80 miles north of San Francisco. The Imperial Valley geothermal area has the attractive feature of being near densely populated areas in Southern California. Although based on limited knowledge, estimates indicate that electric power generated from these geothermal resources could supply a substantial portion of southern California's requirements.

With these exceptions, known geothermal resource areas are far from large load centers and any large blocks of electric power generated from geothermal energy would have to be transmitted over considerable distances.

Present estimates indicate that geothermal energy will constitute 1 to 2 percent of predicted national energy needs for the year 2000. However, this could mean up to 10 percent or more of the total energy requirements forecast for the Western States by that time. Estimates for total geothermal energy production by the year 2000 vary from 40,000 to 395,000 megawatts. The low figures tend to be based on continuation of present technology and the development of relatively few new fields, while the high figures are based on significant breakthroughs in technology and optimistic assumptions concerning total resources. Future geothermal capacity above the minimum estimates is contingent both on resource development and technological breakthroughs.

Cost estimates for geothermal power production compare favorably with those for power production from other energy sources. Cost at The Geysers, a dry-steam or vapor-dominated system is about 5.25 mills per kilowatt hour compared with 8.2 mills per kilowatt hour from a coal-fired power plant, 9.6 mills per kilowatt hour from a hydroelectric plant and 9.7 mills per kilowatt hour estimated from the much more common geothermal hot water systems.

Because of the relative isolation of most known and prospective geothermal resource areas, transmission costs tend to be high. For this reason, it is expected that the competitive output for geothermal plants will be highest in the Mountain States, and that most long-term development should occur there.

The Geothermal Steam Act of 1970 authorized the Secretary of the Interior to establish a program for the leasing of Federal lands for geothermal resource development. Under this legislation, about 1.8 million acres of land have been classified as "Known Geothermal Resource Areas" -- areas in which prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant spending money for that purpose. Over half of this area, more than a million acres, is in California. The remainder is in eight other Pacific and Mountain States. In addition, nearly 96 million acres have been identified as having "prospective value" for geothermal resources. Although Colorado presently has no classified Known Geothermal Resources Areas, over 1 million acres in Colorado are considered prospectively valuable for geothermal resources. It is significant also that about 1 million acres of the Known Geothermal Resources Areas, and 58 million acres of the prospectively valuable area, are on Federal lands and are thus covered by the Geothermal Steam Act of 1970.

You have heard today from Mr. Stone and Mr. Miller about the Department of the Interior's progress and current status regarding implementation of the Geothermal Leasing Act. Secretarial action on the leasing regulations, so carefully and thoroughly prepared by Mr. Stone and his colleagues, is imminent.

I mentioned earlier the wide discrepancies in the estimates of geothermal energy potential. The smaller estimates are based on existing technology -- the larger on significant technological improvement. How soon, in fact, can technology now in experimental stages be expected to evolve into major expansions of a budding geothermal industry? There is no clear answer, but we must recognize the magnitude of technological development needs. We must also recognize our present inability to evaluate all problems accurately and to foresee all difficulties.

Consider, for example, the evolution of nuclear power technology. Early predictions concerning industrial development were much more optimistic than subsequent results justified. The research and development effort was enormous. Still, about two decades were required for development and testing, plus design and construction of the currently operating plants. At present, the total nuclear generating capacity is about 22,000 megawatts -- not all of it operating at full potential. In the future, capacity is expected to grow rapidly. The time/effort relationship for geothermal development may not duplicate that for nuclear development, but the nuclear experience should caution us against expecting too much too soon.

Clearly, the amount and intensity of future research and development efforts will have an important bearing on the rate at which geothermal resources become a significant source of energy. Known technology and technology under development can be expected to result in a few thousand megawatts from geothermal energy in the next 10 to 12 years. Depending on the intensity of research and development efforts, totally new undeveloped technology may come into commercial use on a significant scale in 10 or 20 years. From the standpoint of such anticipated geothermal energy production technology, rapid growth of the industry could be expected to be significant during the rest of this century.

How then can we sum up geothermal energy and the energy crisis? First, there seems no way in which any kind of crash program could result in geothermal energy having any effect on our short-run problems. If our homes and offices are cold, and our cars idle this winter, there is nothing geothermal energy can do about it.

Second, geothermal resources do not at present seem to be a major potential source of energy on a National basis. The eastern two-thirds of the country requires more than two-thirds of our energy, and in this area known geothermal resources are virtually non-existent.

Third, geothermal energy offers a potentially significant and attractive source of energy for the Mountain and Pacific States, including Alaska and Hawaii. Here research and development may result in major technological breakthroughs and greatly increased production.

Fourth, locally, geothermal energy production has even more promise. Many small cities in Colorado and the other Mountain States may one day have local, economical sources of environmentally-acceptably produced local power. Or they may heat their businesses and homes with geothermal heat. Moreover, associated benefits including vitally needed additional water may result.

In conclusion, I fully believe that all economically feasible potential energy sources should be developed, consistent with appropriate environmental safeguards. It seems clear that, although limited in its total prospective impact, geothermal energy offers significant promise regionally and locally. Although geothermal resources may not help us in the present energy crisis, they may be of significance in assuring an adequate total energy supply into the next century.

Thank you very much.