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GEOTHERMICS--NEW MEXICO'S UNTAPPED RESOURCE

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INTRODUCTION

New Mexico is blessed with important ore deposits and mineral wealth. The State has established energy resources in the fossil fuels: petroleum, natural gas, and coal; it has abundant uranium, as well as the technology to develop atomic energy; it also has virtually untapped geothermal resources. What are they? Where are they? What are they worth?

From experience of other areas around the world and from preliminary work here at home we have learned some of the answers. For the questions that cannot be answered directly we have a sound basis for speculation. Here, then, is a look at geothermics.

DEFINITION

"Geothermal" refers to the natural heat of the earth. The earth radiates heat into space, but usually the amount of such heat released is so small--only about one one-thousandth of the daily solar radiation--that the effects of solar radiation totally mask it. In some areas, however, heat seems to be concentrated. If we drill a deep hole and measure temperatures carefully, we see that the effects of solar radiation in a "normal" thermal area are evident to depths of as much as 100 feet, but that from that depth downward the temperature increases about 1.8^{o} for each additional 100 feet.

The effects of concentrated heat range from the violent eruptions of volcanos to the spray and steam we see at geysers, fumaroles, and hot springs or to the modest little anomalies evidenced only by slightly warm water or extra-warm mine workings. Although a few schemes have been devised to tap the heat in "normal" thermal areas, only the heat pump has proved useful; and that, only in moderate climates.

For practical purposes geothermal resources are defined as the heat associated with the anomalous small areas, or more specifically, the concentration of that heat in ground water and the effects of this concentration. The California legislature defined geothermal resources as "the natural heat of the earth, the energy in whatever form below the surface of the earth, present in, resulting from, or created by, or which may be extracted from, such natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases, and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas or other hydrocarbon substances."

USES OF GEOTHERMAL RESOURCES

Geothermal resources have four distinct uses:

1. heat for heat's sake,
2. hot water for hot-water's sake,
3. heat for energy, and
4. hot water for minerals.

To appraise the New Mexico situation accurately, we must look at each of these aspects in some detail.

Space Heating

The most obvious use of the earth's natural heat is for domestic purposes for heating interiors and water. This use has been exploited in several parts of the world. In Iceland more than 45, 000 people live in houses heated by natural thermal waters, and the number is expected to increase to more than 100, 000 by 1970. In 1962 the Reykjavik Municipal District Heating Service piped hot water to about 4, 400 homes. The well-heat cost of the heat is from 5 to 12 cents per million Btus., a price that compares with a range of from 8 to 40 cents for an equivalent volume of natural gas at a well head in the United States.

Iceland has other uses and prospective uses for its natural heat: It sustains more than 100, 000 square yards of greenhouses, where the Islander's grow tomatoes, cucumbers, and flowers. The Icelanders also expect to utilize their heat resources to produce heavy water. The process calls for an outlay of about 6, 000 units of steam for each unit of product--a very expensive process, indeed, when the heat has to be generated by more conventional methods. The Icelanders are also studying the prospects of obtaining salt from sea water by using evaporators that take advantage of the natural heat.

In New Zealand geothermal heat has been used in various ways. A pig farm is heated throughout and cleaned regularly with the natural steam obtained from a well. The Rotorua General Hospital has both a space heater and a water heater serviced by a well that delivers water at 243°F, and one paper mill uses the heat in its production process.

Klamath Falls, Oregon, has more than 350 wells that tap natural hot water to heat schools, industrial buildings, apartments, and houses. In Kenya one poultry raiser hatches chickens, using the heat from natural thermal waters to warm the incubators. In many places throughout the world swimming pools are so heated. In Japan natural hot water has been used to evaporate sea water and so to produce salt; but the Japanese operations have been small--less than 3, 000 tons a year--because they are not economical, costing $25 a ton compared with market prices of from $16 to $22 a ton.

Other uses of natural heat under consideration include producing fresh water; drying grass, seaweed, peat, and diatomaceous earth; processing alumina and sugar; and operating refrigeration units.

New Mexicans' make little use of the heat of thermal water, although one businessman uses the natural water of Gila Hot Springs to heat his trading post and ranch; and another family heats its ranch home with the water of Mimbres Hot Springs.

Many of the thermal waters in this state would provide sufficient heat for domestic purposes, if the occurrence of these waters were closer to human habitations. The few that might be so used have not been developed.

Hot Water

The uses mentioned in the preceding discussion sometimes include employing the water itself (aside from its heat) for cleaning purposes--from washing cars beside accessible springs and wells to scalding hogs and chickens.

Hundreds of spas around the world from Carlsbad, Germany, to Hot Springs, Arkansas, depend upon the presence of natural hot water. Developed decades ago, these spas long provided a form of hydrotherapy that could not be obtained in hospitals. With the advent of "miracle drugs" and the scientific practice of hydrotherapy the role of thermal-water spas has diminshed until now only few survive.

Even so, many of the hot and warm springs of the world are still visited annually by millions of people who enjoy bathing or swimming in them. In wilderness areas the use of hot springs is largely informal, but in Japan it is highly ritualistic. In the southwestern United States many Indian Pueblos, built near thermal waters, have "bathhouses" indicating that the Indians made special use of the soothing properties of the hot springs. At least one spring in New Mexico was the stopping place for cowhands and miners on their way into town on Saturday nights. Generally, however, New Mexicans have made only limited use of the hot water, despite the possibilities. The water supply of Socorro, for instance, is a warm (93°F) spring.

Five spas in New Mexico are currently operational--at Truth or Consequences in Sierra County, at Ojo Caliente in Rio Arriba County, at Warm Springs and Jemez Hot Springs in Sandoval County, and at Radium Hot Springs in Dona Ana County; but in years past spas were also operated at Socorro, Faywood Hot Springs, Mamby Warm Springs, Ponce de Leon Warm Springs, Montezuma Hot Springs, Sulphur Hot Springs and probably at several other places.

Geronimo frequently visited the spring that now bears his name at Truth or Consequences, to bathe in its soothing waters. A local-color incident involved an unnamed Apache who fared ill at Faywood Hot Spring. In the 1850s a detachment of cavalry was sent to the homestead there to wait for an Indian attack. When it came, one of the Apaches was wounded--the only casualty. A soldier reportedly threw the man into the 130-degree water (most people bathe in water at 105-110°F). The Indian was scalded, of course; but the soldier--though subjected to court martial-was declared innocent.

Thermal spas in New Mexico have three specific requirements for successful operation. One is a water temperature of at least 105°F. Another is a supply of at least 50 gallons of water a minute. The third is accessibility. We find that the surviving spas are all near well-traveled highways and have excellent roads leading to their front doors.

Energy

In 1904 Price Conti of Larderello, Italy, constructed a natural steam-driven generator that operated five electric lamps. After this first application of natural steam to generate electricity, other steam fields were tapped for the same purpose: electricity not only at Larderello (340 megawatts), but also in New Zealand (190 megawatts), in California (55 megawatts), in Russia (30 megawatts), and in Japan (20 megawatts). A 75-megawatt plant is under construction in Northwestern Mexico. Pilot plants to test the feasibility of producing electricity from other steam fields are being tested in Japan and California. Plans are also under way to build pilot plants in Russia, Venezuela, Mexico, Iceland, California, and Nevada. Experts believe that other geothermal steam fields can be developed in El Salvador, Costa Rica, Nicaragua, Burma, Kenya, Turkey, Taiwan, Chile, Cameroon, Philippines, Mali, Tunisia, Venezula, and the Western United States.

In general, the steam from thermal waters is available in one of two forms: "wet" or "dry." Wet steam has hot water associated with it, whereas "dry" steam does not. In the use of wet-steam wells water must first be separated from the steam. Techniques have not been developed by which these separations can be made easily, so that the main difference in utilizing wet as contrasted with dry steam is not so much the way in which it is used as in the disposal of waste, afterwards.

The cost of developing a steam reservoir is prodigious. A natural steam well requires an expenditure of about $50 per foot to put into production--or from $100, 000 to $250, 000. However, at the Geysers in California, where field techniques are now routine, the cost per well is down to about $20, 000.

The net capitalization required to develop a natural steam field for electrical output is from $10 million to $100 million, an investment that must be returned before profit can be realized.

A big advantage of thermal-water exploitation is that the cost of operation of the natural steam field is remarkably low, and the production of electricity at the bus bar is extremely economical. Alvin Kaufman of the U.S. Bureau of Mines estimates that the annual costs per kilowatt-hour of variously powered, privately financed 600-megawatt plants are these: coal, $31.32; oil, $30.33; gas, $31.68; geothermal, $30.15. The cost of producing electricity ranges from 3.0 to 7.9 mills per kilowatt-hour when geothermal steam is used. In another significant comparison, we find that conventional thermoelectric energy costs range from 5.5 to 7.7 mills per kilowatt-hour; hydroelectric energy, from 5.0 to 11.4 mills per kilowatt hour; and nuclear energy, from 5.4 to 11.6 mills per kilowatt-hour. The net return on a steam well at the Geysers is $270 a day. There seems to be little doubt that, once the operation of a natural-steam facility begins (even though the Initial investments are large), the enterprise becomes competitive and profitable.

The Russians have experiments underway in Kamchatka that may result in even lower production costs. Their experiments involve the use of the gas freon in much the same way that it is used in a refrigerator. The gas is circulated under pressure into the bore of a natural steam well, where it is heated. The heated gas is used to power the pistons that drive the generators.

In New Mexico two steam wells in the Jemez Mountains on the west side of the Baca Location No. 1 attest to the presence of natural steam in this state. The wells are about a mile apart and about a mile from a discovery test that was plugged and abandoned. However, the capacity and future of this field are not known because little information has been released officially by the developer, the Baca and Land Cattle Company, James P. Dunigan, president.

Because geothermal heat has its origin in internal earth processes that operate over geologically long periods, the supply (from man's point of view) is inexhaustible. Nevertheless, steam fields have finite areas within which operations are economically feasible; that is, where wells discharge steam at optimum rates under optimum operating pressures. Fortunately, operating pressures of established fields have not declined, even though the fields have operated at maximum capacity for several years. Apparently, for practical purposes natural steam reservoirs tapped by wells are almost inexhaustible, though wells themselves are not.

The life of individual wells depends upon the chemical character of the steam. Kaufman in his evaluation of geothermal economics estimated that wells depreciate in 10 years, but experience indicates that he could have used 15 or 20 years in his estimate and still have been realistic.

The advantage of geothermal power lies primarily in the fact that it is a cheap base power that can be developed to meet the needs of the area in which it is found. Small plants seem to be as economical as large ones. Thus the initial 12.5-kilowatt-hour facility developed at the Geysers was both practical and profitable. The present development at the Geysers is 55,000 kilowatt-hours, but plans are already being made to double that output. The proved "reserves" are in the neighborhood of 600,000 kilowatt-hours.

Perhaps the most serious difficulty facing a would-be geothermal-power developer is the two-to-three-year delay between drilling the steam well and producing the electricity.

New Mexico currently exports electrical power --thanks to the development of coal resources on the Navajo reservation, but various projections of our own needs in 1957 or 1980 indicate that a power shortage will develop as the State grows. Inexpensive power, coupled with existing low-grade ore deposits could stimulate New Mexico's industrial development and suitable geothermal reserves, once established, would satisfy our needs for an inexpensive, easily available power supply.

Minerals

Although the search for natural steam fields is conducted primarily because of their possible use for electrical energy, the minerals and gases associated with natural steam may be sufficiently valuable in their own right to be exploited.

The first use of the thermal waters at Larderello was to recover boric acid. Now a chemical industry has developed there, based on the extraction not only of boric acid, but of carbon dioxide, sulphur, ammonium sulphate, and ammonium carbonate.

The New Zealanders have considered extracting sodium chloride, potassium chloride, and lithium carbonate from the brines of their geothermal fields. Imperial Thermal Products, a division of Morton International, operates a pilot recovery plant near the Salton Sea in Southern California. According to testimony before the Senate Fact-Finding Committee on Natural Resources of the California Legislature, Imperial Thermal Products will spend from $20 million to $30 million, revovering minerals contained in thermal brines. One authority testified at these hearings that each well could, if the techniques were perfected, yield $40,000 per day. Another expert said that one well could produce all the potash the world could use.

Clearly, the mineral content of the thermal brines can be an important factor in their development; but it can also be a detriment. If the mineral content is too small for economical extraction, the used steam may be discharged as a brine too concentrated to be disgorged into local streams. State water-pollution laws prohibit such practices. The only place where a brine has become a particular problem is in the Casa Diablo area of California, where the Department of Fish and Game and the Lahontan Regional Water Quality Control Board imposed restrictions on the discharge of bitterns into the local drainage system. The problem has delayed development of this potentially profitable area. In New Mexico, we have no evidence to make us believe that the potential natural heat sources would provide commercial quantities of any mineral, but evidence exists that pollution may be a problem. However, until sufficient exploration has taken place we can not know what the fluid composition of any particular steam reservoir will be.

THE LEGAL PROBLEM

Before extensive development of a geothermal resource can begin, various legal problems must be resolved. The question "who owns the geothermal resource?" probably should be solved first. California and New Mexico already have laws governing the leasing of state-owned lands for geothermal development.

Unfortunately, existing federal law does not provide adequately for development of geothermal resources on the federal public domain. A geothermal leasing bill, passed by both houses of Congress late in 1966, was vetoed by President Johnson, apparently in direct response to the objection made by the Department of the Interior to a "grandfather" clause. Speculators had obtained leases of every sort on federal lands, hoping to convert them to geothermal leases when the law passed. Apparently, the Department of the Interior believes that the grandfather clause gives speculators an unfair advantage over prospective developers. In 1967, pending enactment of legislation, John O'Crow, Acting Director of the Bureau of Land Management, made a controversial "executive withdrawal" of 1,051,000 acres of land having potential geothermal value. In New Mexico, 140,180 acres in the Jemez Mountains were withdrawn.

The basic legal problem revolves around the question "Is the geothermal resource water or mineral?" If it is water, than the geothermal resource belongs to the surface owner of patented land. If it is mineral, the rights were reserved by the government when the land was patented. The failure of the government to legislate has resulted in at least one case in California where a lease has been obtained by one company from the holder of the surface rights and another lease has been obtained by a different company from the holder of the mineral rights. Such problems have restricted geothermal development in the United States to privately owned lands.

Owen Olpin, a Los Angeles attorney who has made a detailed study of geothermal law, points out that the "Rule of Capture" is as appropriate for geothermal resources as for oil and gas, but that new regulations are needed to deal with the delicate relationship between geothermal resources and water resources.

Mr. Olpin also points out that the geothermal operator's obligations and liabilities are only partly defined by existing laws and regulations. He raises two important questions: 1, "Is geothermal exploration and production an extra-hazardous activity which will make operators liable for damages rather than one in which ordinary negligence standards are applicable?" 2, "Does the possibility exist that operators will be liable for excessive noise and for water and air pollution?"

INTEREST IN U. S. GEOTHERMAL RESOURCES

1. State governments have expressed genuine interest in geothermal resources. California's concern is immediate, and the state has taken special steps to investigate prospects for developing its own. So have other states. Utah, Nevada, Oregon, Idaho, and New Mexico have sponsored preliminary studies.

Federal interest comes primarily from two divisions of the U.S. Department of the Interior, which have made studies of the subject. The Bureau of Mines has published Information Circular 8230, Geothermal power and economic evaluation, by Alvin Kaufman; and the Geological Survey has published Circular 519, Geothermal energy, by Donald E. White.

The United Nations is interested, also, though not directly in U.S. sources. The UN has sponsored many investigations of geothermal resources in underdeveloped countries and has arranged for the publication of much of the information thus produced.

In the United States private industry has assumed leadership in the development of geothermal resources. Indeed, the United States is the only country in which private industry has so asserted itself. Companies that have been active include these: Morton International, Imperial Thermal Products Division; Worldwide Geothermal Exploration Company; Occidental Petroleum Company; O'Neill Geothermal Company; The Fluor Company; S.I. Corporation; Pacific Gas and Electric Company; Geothermal Resources International, Inc.; Thermal Power Company; Southern Pacific Company; Magma Power Company; Earth Energy, Inc.; Lockheed Missile and Space Company; The Elliott Company; Geysers Team Company; Western Geothermal Company; Shell Oil Company; Union Oil Company; and Signal Oil and Gas Company. A few of these companies are service companies; of the remainder, some no longer explore for natural heat; but others are increasing their activity. As a result, competition for leases in some areas is keen. In New Mexico 2,900 acres have been leased under the State's geothermal-leasing Act.

THE GEOLOGIC SETTING

The natural-steam reservoirs that have been exploited and explored thus far may appear to the layman to differ vastly, but to the geologist they exhibit some remarkable similarities. (1) they all occur in areas of geologically young mountains; (2) they are found in regions where volcanoes have been active in the not too distant geologic past; and (3) they all occur in areas of major faults (fractures in the earth's crust) where the rocks on either side of the fracture have moved in opposite directions.

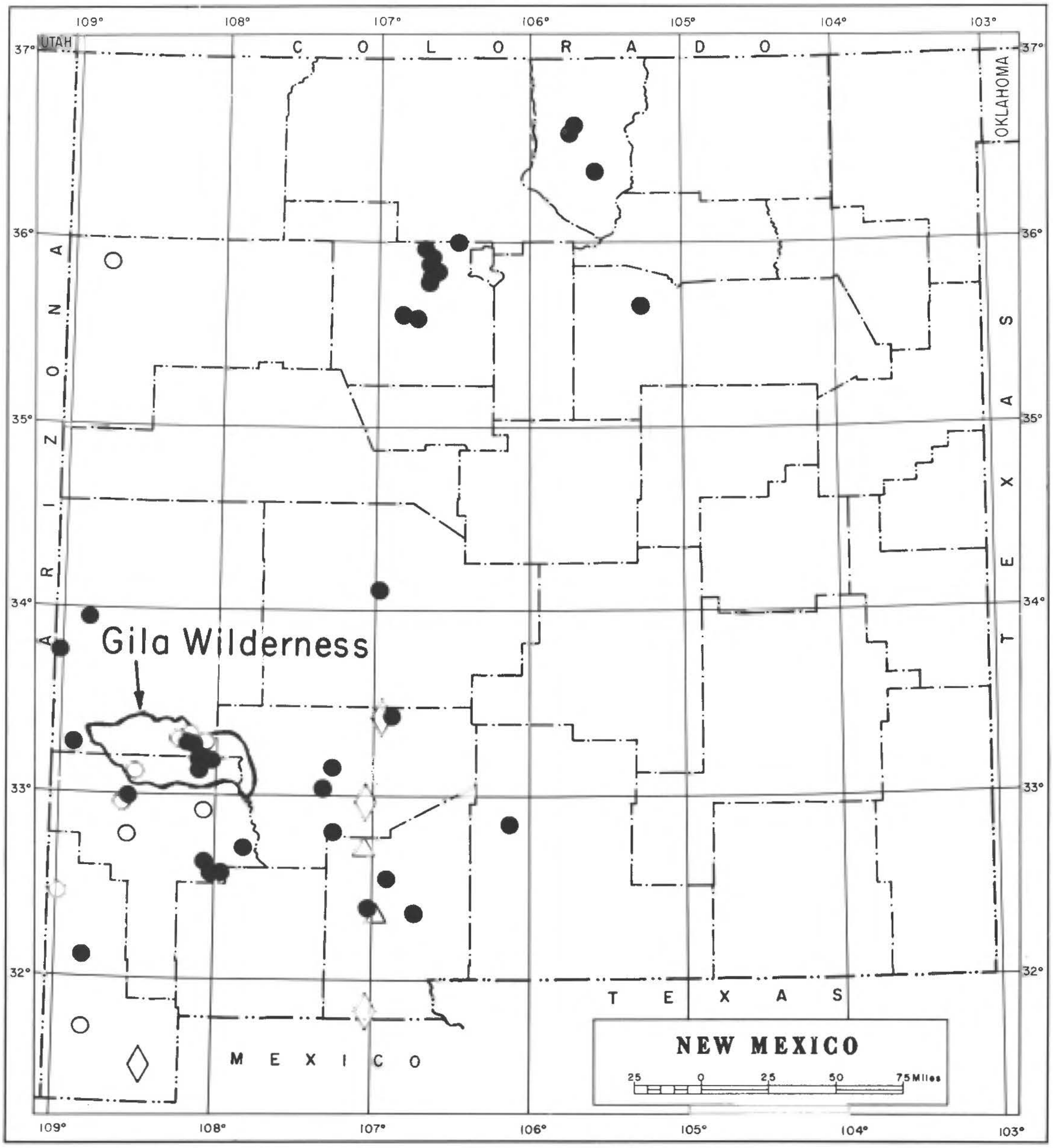
The relationship between these three geologic features is not clear cut. On one hand, many geologically "young" mountains, cut by faults and possessing associated volcanic rocks, show no evidence of any modern hydrothermal activity; on the other hand, at the Larderello steam field the nearest volcanic rocks are 15 miles north. Moreover, the rocks exposed in the "young" mountains are often geologically old--of Paleozoic or even Precambrian age.

Faults are common in the earth's crust; and where they occur thermal phenomena may sometimes be found, though infrequently. Where geothermal phenomena do occur, they may be found near, rather than at the fault--and even then only in limited areas.

Many, but by no means all, geothermal areas of the world occur in "graben-horst" structures. These structures are belts in which elongate, continuous blocks of rock have dropped downward (grabens) and the adjacent blocks (horsts) have risen. The Rio Grande trough and the basin and range mountains of New Mexico are graben-horst features, as are the Imperial Valley (Salton Sea area) of California and the Red Sea.

In all probability, many undetected geothermal areas occur in grabens but remain undetected because grabens tend to fill with detritus--sand, gravel, and clay--derived from the adjacent horst blocks. Ground water moves through these deposits, sweeps over the geothermal seeps, and removes and absorbs the heat. Thus, anomalies, which otherwise might be very strong go un-

New Mexico's Geothermal Areas



● Thermal area, field checked and sampled
△ Thermal area, field checked not sampled
◇ Oil test reporting thermal anomaly, plugged and abandonded
○ Thermal area not field checked, but reports believed reliable

tected at the surface. Many geothermal developments such as those of Larderello and New Zealand, are on horst blocks.

Some geothermal developments are in areas of active volcanism, but volcanic locations do not necessarily insure the presence of geothermal energy. Hawaii, for example, has active volcanos with recently erupted, cooling lava at the surface; yet that state's potential for geothermal energy seems to be minimal, largely because the rainfall on the rocks is so great. The excessive rainfall produces large amounts of ground water, which moves through the rocks with such speed and efficiency that the energy has no opportunity to concentrate and produce steam.

THE SOURCE OF HEAT

Although the source of geothermal heat has been the subject of much speculation, whenever detailed studies of thermal areas are made, the conclusion usually reached is that the heat must be related to steam and other gases released from a cooling intrusive igneous body--that is, from a mass of cooling magma (molten rock). Evidence indicates that the magma occurs at fairly shallow depths.

Magma is a complex, high-temperature solution of silicates, water, and gases under high pressures. As it cools, the silicates crystalize, releasing heat. The water (as steam) and the gases (principally carbon dioxide) escape, traveling up fracture zones to mix with ground water in the overlying rocks. If the ground water moves rapidly through the rocks, the escaping steam and gases are removed completely; and their presence is totally masked by dilution. However, if the ground water moves slowly, heat builds up; and even part of the ground water becomes steam. Thus, a natural-steam system owes its existence to a cooling magma chamber.

But what is the source of the magma? Of the many answers suggested, the most acceptable one now is that the earth below the mantle is plastic. Convection currents circulate in this plastic material, causing hot rock to rise to from 22 to 35 miles below the surface. The movement produces two effects: first, it causes a drag, which generates mountains; second, it releases heat in such a way that pockets of magma are generated, then melt and force their way upward, producing the magma-holding chambers. Some of these chambers give rise to volcanos.

The convection cells seem to affect the surface in the East Pacific, the Mid-Pacific, the West Pacific, East Africa and the Middle East, and the Mid-Atlantic Ridge. For the most part, the world's volcanos occur in these areas.

According to geophysical measurements, the holding chambers for the magma (that discharges as lava) are at shallow depths: The holding chambers for one Japanese volcano may be only 2,500 feet down; the chambers for Hawaiian volcanos are less deep than the sea floor upon which the islands rest--25,000 feet--but much farther down than the Japanese example.

Geologists believe that the shallow magma chambers that did not generate volcanos are the source of heat for areas like Larderello and the Geysers. The source of heat in areas abounding in young volcanic rocks may be the magma chamber from which the lava for these rocks came; or it may be an entirely new feature that had its source in the same deep-seated reservoir.

NEW MEXICO'S THERMAL WATERS

The following discussion of New Mexico's thermal waters is based upon a study I have made that will be published by the New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology. This study was financed in part by funds supplied by the U.S. Department of the Interior, or authorized under the Water Resources Act of 1964, Public Law 88-379.

During this study I visited 49 of the State's 57 thermal areas. I collected water samples, drew maps ranging from sketches to detailed planetable surveys, measured water temperatures and discharge, and recorded other pertinent data. In addition, I made a painstaking search for written information. References not available in the library at New Mexico Institute of Mining and Technology, I borrowed from libraries across the United States--from the U.S. Geological Survey Library in Washington, D.C., to the Stanford University Library at Palo Alto. The following summary constitutes not only a comprehensive survey of previous studies, but, also, a review of my first-hand observations.

A difficulty arises in counting natural thermal anomalies in New Mexico. Obviously, the several thermal springs and wells at Truth or Consequences tap only one occurrence of such water. But are the springs in the Jemez Mountains individual or collective? That is, do they reflect one anomaly or several anomalies?

Arbitrarily, I decided to designate more or less contiguous areas as one anomaly; but those hot springs a mile or more apart, occurring under apparently dissimilar geologic and hydrologic conditions, I considered as separate. Thus, T or C, Socorro, and the Cliff-Gila-Riverside areas, which cover considerable acreage, constitute single anomalies, whereas the eight hot springs in the Jemez Mountains count as seven. Perhaps later investigation will show that some anomalies now considered individual, are, in fact, part of a large system and should have been labeled as units of a widespread occurrence.

New Mexico's Geothermal Anomalies

In the 57 anomalous areas mines may be abnormally warm. For example, in Socorro Mountain air temperatures in the old shafts range upward to about 95°F at relatively shallow depths. These temperatures are at least 15 degrees warmer than we expect in nonthermal areas.

In addition to the 57 areas in New Mexico that discharge ground water with temperatures of at least 90°F, more than 100 others discharge ground water having temperatures higher than "normal" but less than 90°F. The 57 occur in 12 counties: Bernalillo, Catron, Dona Ana, Grant, Hidalgo, Otero, Sandoval, San Juan, San Miguel, Sierra, Socorro, and Taos. No thermal waters are likely to be discovered in Chaves, Colfax, Curry, De Baca, Eddy, Guadalupe, Harding, Lea, Quay, Roosevelt, or Union Counties. The prospects for discovering thermal water in the remaining nine counties range from slight (where no warm springs occur) to excellent (where warm springs are numerous). For example, Valencia County has along the margin of the Rio Grande trough about 20 springs that range from "slightly warm" to "warm."

Thirty-six anomalies occur in the Rio Grande drainage basin; 18, in the Gila River Basin; and one each, in the Pecos River Basin, the Tularosa Basin, and the San Juan River Basin.

The age of the rock from which the water discharges seems relatively unimportant. The rocks are Precambrian exclusively in two areas, and Cenozoic exclusively in 35 others. The remainder discharge water from rocks of two or more ages.

Eleven thermal anomalies occur where consolidated sedimentary rocks are the only rocks in evidence. Fifteen are found in unconsolidated sedimentary rocks; eight, in massive igneous or metamorphic rocks; 10, in extrusive igneous rock; and the remainder, where both extrusive igneous rocks and sedimentary rocks are in evidence.

Thermal waters discharge from several distinct outlets:

	Number of Occurrences
Fractures in rocks	12
Talus slope	4
Interstitial porosity of particulate rocks	5
Calcareous tufa	2
Some combination of the above	8
Wells	7

Of the 49 thermal areas I visited, only five were primarily faults in structure. Twenty-one were associated with volcanic structures (including faults), and 23 occurred in situations where distinct structure was lacking or hidden beneath alluvium or pediment gravels.

Local structure, however, may be misleading. For example, the Jemez Caldera borders the Rio Grande trough. From a regional point of view, the Caldera appears to have developed where two deep intersecting faults provided a convenient conduit for magma from a relatively shallow magma chamber. Yet the individual occurrences of thermal water are not specifically related to the intersecting faults and can be classified in several of the categories listed above.

New Mexico's most fascinating thermal anomaly is the "Hot Spot" in the Animas Valley, Hidalgo County. In 1948 a water-well driller, seeking an irrigation well in a sand-gravel-clay aquifer, hit a fractured rhyolite at 87 feet; and water was discharged as steam, with an initial temperature of 240°F.

The wonder is that this "hot spot" went undetected for so long. Since its discovery it has been studied by many individuals and companies and has been the target for many tests of equipment designed to identify thermal prospects--especially infrared imagery. So far, three scientific papers have been written about the area and more are in the offing.

But perhaps the most significant feature of the "Hot Spot" is that it supplies a relatively complete picture of a New Mexican geothermal anomoly in a relatively simple geologic and hydrologic setting: Natural steam is injected into a relatively thin bed of saturated sand and gravel. Ground water moves through the sand and gravel from south to north, carrying the steam with it. The heat dissipates gradually into the moving ground water, so that only a mile and a half away there is no indication of the extraordinary heat. The injected steam may come from a holding chamber, or it may be leaking from a natural-steam reservoir at an economically exploitable depth.

The isotopic composition of the steam from established geothermal fields indicates that the water involved is at least 95 per cent of meteoric origin; i.e., it fell as precipitation, recharged the ground-water reservoir, and then moved through the heat source. Data from some explored but rejected anomalies suggest that they have too much water. Established fields exist that show the eccentric distribution of temperature, suggesting the sweeping of ground water through a heat source.

Several New Mexico thermal areas have temperature patterns suggesting that they, too, are the product of a natural-steam injection into a typical ground-water system. We must, therefore, consider not only the geologic setting but also the hydrodynamic and thermodynamic conditions if we are to explore and exploit properly a natural-steam reservoir in New Mexico.

Presently, the state of the "art" of geothermal prospecting is analogous to that of the petroleum industry in the late 1800s. Developers are drilling isolated tests at the seeps. If the test is not immediately successful--releasing quality steam at a satisfactory temperature (400°F) and pressure (150 psi)--the exploration is considered unsatisfactory. But undoubtedly, many rejected areas will eventually be developed, when exploration and exploitation techniques have improved. Although the New Mexico anomalies are less spectacular than those of California or Nevada, the geologic-hydrologic conditions in New Mexico are not only "right" but also similar to those in areas of established geothermal resources.

The time required to develop an established geothermal resource is at least three years. In New Mexico we need to establish more precisely the character and the extent of such resources and to prospect with enthusiasm while advancing our technology. We have a long way to go, but the future is bright. Although a fearless forecaster might speculate that our first commercial development of natural steam will be operational within five years, a more conservative prediction is that at least a decade will pass before we benefit from our geothermal resources.