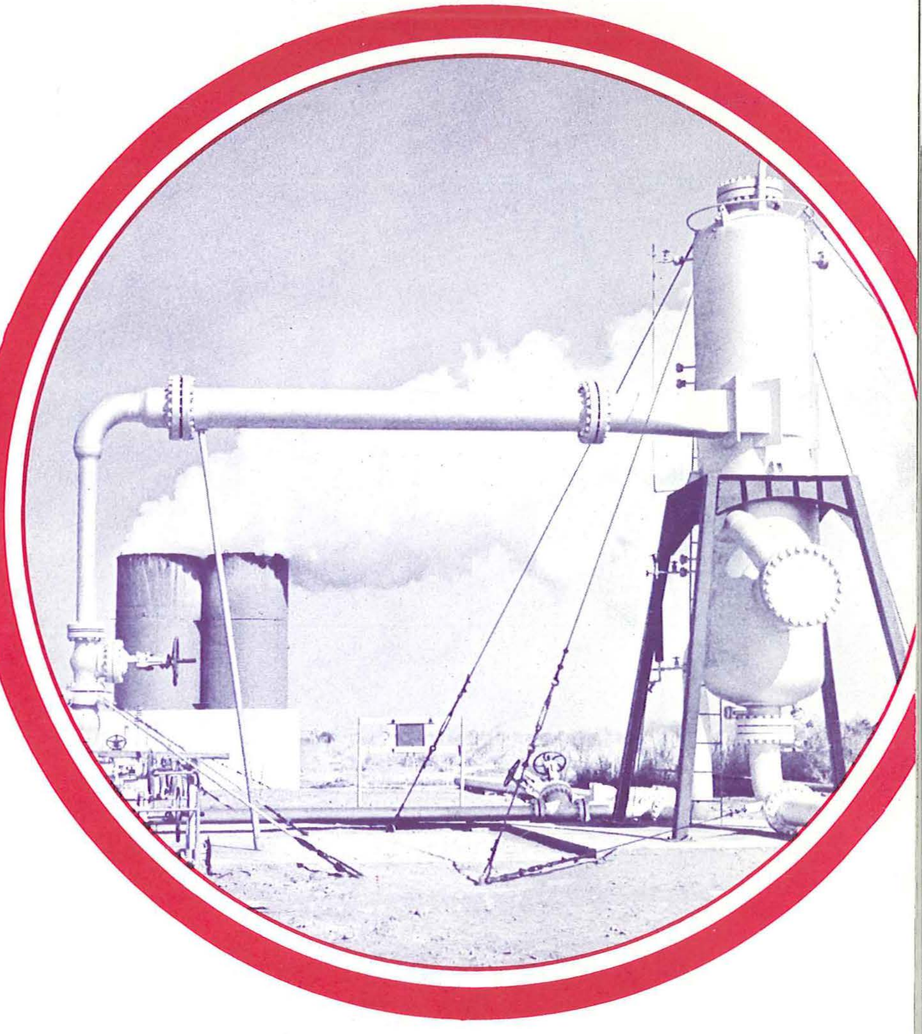
GEOTHERMAL RESOURCE INVESTIGATIONS

IMPERIAL VALLEY CALIFORNIA

STATUS REPORT

April 1971



UNITED STATES DEPARTMENT OF THE INTERIOR
ROGERS C. B. MORTON, SECRETARY
Bureau of Reclamation
Ellis L. Armstrong, Commissioner

GEOTHERMAL RESOURCE INVESTIGATIONS
Imperial Valley, California

STATUS REPORT

April 1971

Ellis L. Armstrong, Commissioner

E. A. Lundberg, Regional Director, Region 3

Bureau of Reclamation

Interior-Reclamation, B.C., Nev. 3-71

GEOTHERMAL RESOURCE INVESTIGATIONS
Imperial Valley, California

STATUS REPORT

Foreword

This report was prepared under the Authority of the Federal Reclamation Laws (Act of June 17, 1902, 32 Stat. 388, and Acts amendatory thereof or supplementary thereto) and the Colorado River Basin Project Act (Public Law 90-537, 82 Stat. 885, September 30, 1968).

Preliminary studies of geothermal resources in the Imperial Valley of California indicate that substantial quantities of low salinity water with a high heat content are stored in the ground-water basin. This water is an attractive source of irrigation and municipal and industrial water for augmentation of the Colorado River. Development of a supply of demineralized water would improve the water quality of the Lower Colorado River Basin and would help the United States in meeting its Mexican Treaty obligations. Successful geothermal development in this area would be a technological base for development of additional water supplies in other geothermal areas of the West.

The University of California at Riverside has performed geothermal investigations in the Imperial Valley under contracts with the Bureau of Reclamation for a total cost of $285,000. The research investigations were initiated to determine the feasibility of developing a water supply from geothermal resources.

GLOSSARY OF TERMS

Anticlinal Dome

Upfolded strata opening downward in all directions and thus taking the shape of a dome, usually elongate in form.

East Pacific Rise

A branch of the worldwide network of oceanic spreading centers. The East Pacific Rise has been traced as running along the axis of the Gulf of California, and entering the United States under the Imperial Valley. Its route after that is unknown as the trail is obscured by continental crustal formation.

Earth Resistivity Survey

Introducing electrical current into the ground and measuring the distribution of electric current below the surface. Surveys are performed in search for water-bearing formations, stratigraphic traps in oil fields, and conductive ore bodies.

Geothermal Resource

The heat generated from the interior of the earth and recoverable in some medium such as hot ground water or existing as steam.

Gravity Surveys

Measuring the changes in densities within the earth as well as about the surfaces that bound the region of differing densities. The information obtained is subject to certain ambiguities inherent in the Theory of Newtonian potential. Bodies in a geothermal environment having a density contrast may be created by metamorphism due to heat or cementation due to deposition of silica or calcium carbonate.

Heat Flow

The movement of heat through any given media. Heat flow rates vary with the conductivity of the media through which the heat is being transferred and the thermal gradient.

Spreading Centers

A geological feature usually in the form of a sea floor ridge thousands of miles in length. It is caused by the circulating pattern of the molten rock in the mantle just below the crust of the earth. The upwelling of molten rock causes spreading or rifting of the crust, thus creating movement of large masses of land. There is believed to be a network of spreading centers covering the entire earth but occurring mostly under the oceans.

Thermal Anomaly

An area of high heat flow as indicated by contouring thermal gradients.

Thermal Gradient

The rate of change in temperature with depth. It is normally expressed "degrees Fahrenheit per 100 feet."

Temperature Recovery

The return of a well to equilibrium with the various temperatures of the formations that were penetrated. Circulation of drilling mud cools the formations immediately adjacent to the well bore and in the Imperial Valley it requires from 10 to 20 days for a well or test hole to equilibrate.

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CHAPTER I

GEOTHERMAL RESOURCE INVESTIGATIONS
Imperial Valley, California

Summary

Exploration within the last few years indicates the presence of a large volume of water in the sediments of Imperial Valley, California. The water has been heated to high temperatures by abnormal heat flow in the earth's crust. Some of this superheated water will flash into steam which can be used to desalt the remaining mineralized water and to generate electric power.

This geothermal resource could supply usable water for augmentation of the Colorado River and for agricultural and municipal and industrial development in this arid section of the Nation. In addition, it could supply electric energy for the increasing demands of the Pacific Southwest power market area. The development of this resource could be accomplished without the environmental hazards of air and water pollution commonly associated with fossil fuel and nuclear powerplants.

Scientists have only recently verified the existence of a global network of spreading centers that largely traverse the floors of the three largest oceans. Heat flow from the molten mantle into the earth's crust is abnormally high along these spreading centers. The spreading center known as the East Pacific Rise passes under the floor of the Imperial Valley. Thus, much of the saturated sediments of the valley contains heated mineralized water which is estimated to have a volume of 2 to 5 billion acre-feet. A large part of this water is believed to be less saline than sea water.

Early prospectors, drilling in an area at the southeast end of the Salton Sea, discovered hot water with about 30 percent salt concentration, which was considered too mineralized to process for electric power. Later drilling showed that the high salt content of the Salton Sea area is unique, and in other parts of the valley, the water has a salt concentration of 1.5 to 2.5 percent. These discoveries rekindled the hope of processing the hot water not only for power, but also for a source of usable water.

The Bureau of Reclamation began long-range planning in developing the geothermal resource of Imperial Valley in 1968. It has supported the University of California at Riverside in its ongoing investigations. Studies were made in heat flow, geophysics, and geology. Thermal gradients were measured to depths of 500 feet in wells and test holes and supplemented with geophysical data. Areas of rapid increase in temperature with depth were identified as "Thermal Anomalies."

In January of 1971, the Bureau started a drilling program to explore temperature gradients to a depth of about 1,500 feet on Federal lands. Test wells were drilled on three different thermal anomalies to depths ranging from 375 feet at the Dunes anomaly to 1,463 feet at the Border anomaly. A temperature of 231 degrees Fahrenheit was measured at the Dunes anomaly at a depth of 375 feet. Additional test holes were drilled to determine the extent of the Dunes anomaly. Drilling is continuing on the East Mesa anomaly to determine its extent.

Future Work

Based on an analysis of work accomplished to date, it is concluded that geothermal investigations should continue at an accelerated rate. The next work to be accomplished pertains to locating an optimum site to drill a producing steam well. This work will include drilling an intermediate depth (2,500 feet) test hole to substantiate the linear projection of shallow thermal gradients.

Following this, the Bureau of Reclamation will determine the extent of the geothermal resources on Federally withdrawn lands in the Imperial Valley by additional shallow test drilling and detailed geophysical surveys. In the near future, the Bureau plans to drill a steam and water producing well field and construct a prototype desalting plant.

The Bureau of Reclamation will continue to cooperate with the UCR in the investigations of geothermal resources. It is anticipated that the Bureau will establish a staff of geothermal experts in the Regional Director's Office in Boulder City, Nevada. In addition, the Bureau will ask knowledgeable persons from other Government entities, universities, and the private sector to serve as an advisory panel.

It is proposed to complete a reconnaissance report in Fiscal Year 1972 and a feasibility report by 1977.

An orderly program leading to the development of a producing steam field and a prototype desalting plant will require the following annual funds:

Fiscal Year	Bureau of Reclamation	Office of Saline Water and Others*	Total
1972	$1,820,000	$1,130,000	$2,950,000
1973	1,780,000	1,230,000	3,010,000
1974	1,280,000	3,490,000	4,770,000
1975	1,080,000	890,000	1,970,000
1976	1,280,000	890,000	2,170,000

*Bureau of Reclamation funding.

CHAPTER II

THE SOURCE OF GEOTHERMAL HEAT

Heat Flow in the Earth's Crust

Temperatures below the earth's surface ordinarily increase continuously with depth reaching very high values near the liquid mantle. It is thought that the decay of radioactive elements over geological time and frictional forces caused by the circulation of hot liquids or plastic rocks in the earth's interior contribute to the generation of heat.

A relatively new hypothesis in global tectonics relates high crustal heat flow to the occurrence of a global network of spreading centers that largely traverse the ocean floors. Heat flow approaching the earth's surface along these spreading centers is often five to ten times the crustal average. The earth's crust is a series of continental and oceanic plates that are being rafted about on the liquid mantle of the interior. In areas of fluidic convergence or downsinking, buoyant crustal plates are plunged into the liquid mantle and resorbed. In areas of upwelling, the crustal plates are spread apart and oceanic ridges are formed. Geologists believe that oceanic ridges mark the alignments where continents split and began to drift. The mid-Atlantic ridge marks such a line of departure for the westward drift of North and South America and conversely the eastward drift of Europe and Africa. The Island of Iceland lies athwart the mid-Atlantic ridge.

This report is concerned with a geothermal province in southern California that is directly tied in with crustal spreading involving a feature known as the East Pacific Rise. This feature angles northeasterly across the Pacific Ocean into the Gulf of California where spreading of two to three inches per year began about 4 million years ago. Baja California and the part of California that is west of the San Andreas Fault are drifting slowly to the northwest with respect to the North American Continent. This action has created a large structural feature in southern California called the Salton trough.

Figure 1 shows the phases of crustal breaching and heat flow under the Salton trough which also includes the Imperial Valley.

Geothermal Ground Water

As water flows underground through permeable hot rocks, it becomes heated. Temperatures may increase linearly with depth and can reach very high temperatures at relatively shallow depths. Recharge to most geothermal systems is, in overwhelming proportions, the local dominant meteoric water of each area. This water may percolate vertically to considerable depth at the edge of the heating system and then flow horizontally over the hot rocks where it is heated by contact. Its reduced density causes it to slowly rise through permeable formations or fracture zones. It may overflow above ground creating geysers or mud pools, or else it may flow horizontally below the surface and mix with cold ground water in which case there would be no surface indication.

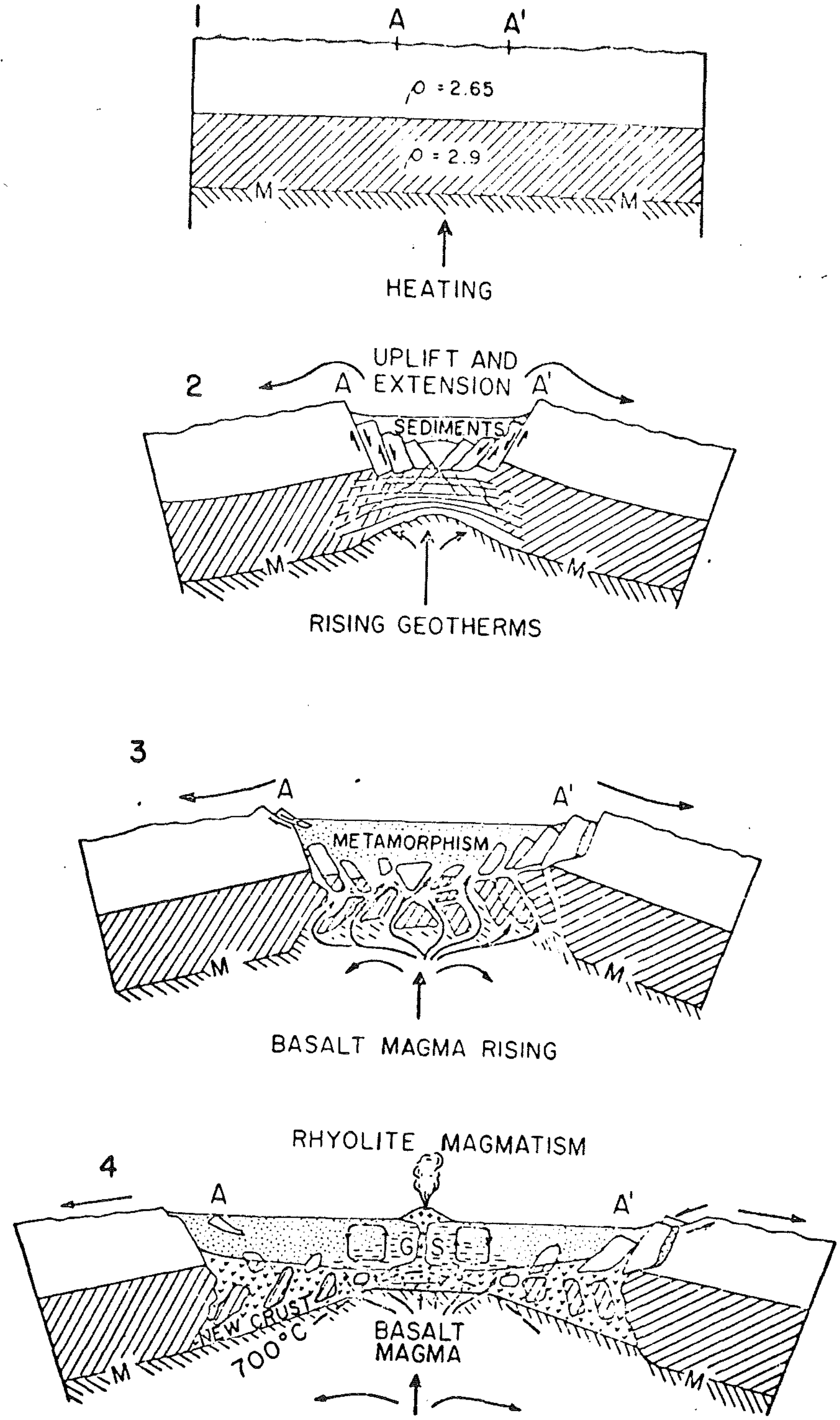


Figure 1. Model of rifting and magma generation during growth of a graben. Sections drawn parallel to strike-slip faults. Stage 1--sialic and simatic crust overlie a hot zone in the mantle. M--Moho, A and A' reference points for later movements. Stage 2--upward and lateral expansion, trough initiated, partly infilled by sediments. Stage 3--widening trough invaded by basaltic magma, metamorphism of sediments and gravity sliding of tilted walls. Stage 4--melting of basement produces rhyolitic magma. Ascending hot brines cause greenschist metamorphism (G.S.) at shallow depth.

(From "Crustal Spreading in Southern California," by Elders, Rex, Meidav and Robinson, 1970)

Geothermal systems may produce either dry steam, wet steam, or only hot water. The proportion of steam with reduction of pressure is related to initial liquid temperature. Wells in low permeability reservoirs may first erupt water and steam and then wet to dry steam, similar to the late eruption stages of many geysers. Wet steam producing wells are much more abundant than vapor-dominant systems (perhaps 20 to 1), judging from present worldwide geothermal developments.

Given an adequate source of water supply, there are essentially three factors which determine whether a geothermal well will become economically successful; temperature, permeability, and depth of the reservoir. The temperature must be high enough for steam development, the permeability must be great enough for adequate fluid flow, and the well should be as shallow as possible.

CHAPTER III

STATUS OF DEVELOPMENT OF GEOTHERMAL RESOURCES

General Statement

The development of geothermal resources provides a source of inexpensive heat, water, and power for man's needs in many parts of the world. Geothermal water and power must be able to compete successfully with alternate sources of water supply and energy such as natural gas, solid fuels, hydro power, and nuclear energy. In several areas of the world, geothermal sources are competing with conventional sources.

More attention is being given to multipurpose schemes which will utilize the maximum potential from each geothermal development. A significant use of geothermal fluids is the production of a usable water supply in arid areas. The typically brackish geothermal fluids can be demineralized by utilizing geothermal energy and modern desalting techniques. Separators at well sites are used effectively to provide steam for power and hot mineralized water for conversion to high quality water.

A major worldwide interest in geothermal energy appears to be its development as an alternative source of power. Power production from geothermal steam is rapidly gaining acceptance and many countries are planning major geothermal energy developments. Many geothermal fields produce only hot water with a limited amount of steam. The future utilization of geothermal energy on a large scale seems to depend on the possibility of competitive power generation by natural hot water. Successful experiments have been performed using hot water near the boiling temperature for power generation. Low boiling point heat carriers such as isobutane and freon show great promise and could create an economical source of electric energy from low enthalpy geothermal fluids.

Geothermal sources are presently being utilized for space heating, process drying, agricultural operations, and industry requirements. Hot water from geothermal fields has been used for other purposes such as fish breeding, poultry farms, and alligator farms. Extraction of chemicals from geothermal fluids may offer a profitable resource in some areas.

Techniques for exploitation of geothermal resources are being developed. Apparently no major technological problem has been revealed to date in the projects under operation at the present time.

Powerplant operators have not met with serious technological problems as apparent in atomic power generators. Steam producing wells are drilled routinely by qualified personnel. Geothermal reservoir engineering technology is still in its infancy. However, oil and gas reservoir engineering techniques can be applied to geothermal fields with some modifications based on thermodynamics. This technology provides a reasonable evaluation of the geothermal reservoir capacity and can provide guides for well spacing.

Worldwide Development

The utilization of water from hot springs and hot caves is probably as old as man. Early in their histories, Rome, Greece, and Japan used hot springs for thermal and space heating. A remarkable development in the use of geothermal resources is to be expected in many countries of the world in years to come. Many other countries, El Salvador, France, Turkey, Algeria, Colombia, Czechoslovakia, Yugoslavia, Indonesia, China, and the Philippines, are stepping up their activities in developing this vast natural resource. In 1961, about 420 megawatts of geothermal electric power were in production throughout the world. The figure is now over 675 mw and is likely to rise to about 860 mw by the end of 1971 and over 1,000 mw in the next few years.

Iceland. The development of geothermal househeating has continued rapidly in Iceland during the last decade, doubling from 1961 to 1969. Communities have been sited where thermal waters are available and heating systems are in operation covering whole towns. Within the next decade, it is estimated that 60 to 70 percent of the population will obtain heat for their houses from geothermal sources. A 3-mw pilot geothermal power station, the first in Iceland, has been developed.

A processing plant is now in operation using geothermal steam for drying diatomite from deposits on the bottom of Lake Myvatn in northern Iceland. The operation has been successful and the drying costs are about 1/6 of the costs of using fuel oil.

New Zealand. The main thermal area in New Zealand is in the North Island where there are abnormal earth temperature gradients producing hot springs, fumaroles, and geysers. The geothermal energy producing wells penetrate a hot water aquifer from which steam is produced during upward flow in the wells, giving a mixture of steam and water at the wellheads.

At the Wairakei field, a geothermal power station produces 192 mw of electric energy. At the Kawerau field, geothermal steam is used in processing pulp and paper and for producing a few megawatts of electric power. Utilization of geothermal energy at the Rotorua field is mainly for space heating.

Exploration in new fields has been carried out in New Zealand mainly for the purpose of developing electric energy sources. At one field, the Broadlands, an initial power station of 120 mw is programed to come into operation in 1976.

Italy. Italy has made the most extensive geothermal energy development for electric power production in the world. In 1969, the Italian geothermal powerplants totaled 384.1 mw of installed capacity and produced 2,764.8 million kilowatt-hours of electric energy. Most of the geothermal areas are located near the west coast of Italy, north and south of Rome.

In the last decade, power production from geothermal energy sources increased over 30 percent. Contributing to the increase was the modernization of generating plants and technological improvements.

Japan. Japan is one of the most famous volcanic countries in the world and has many hot springs and geothermal resources. The locations of the geothermal fields are spread throughout the Island of Japan. The depths of production wells range from 1,500 to 4,500 feet.

As a result of prospecting activities made for some 10 years, two geothermal fields have been discovered and developed. Power-plant capacities in these areas range from 10 mw to 20 mw. Geothermal potential in Japan is estimated to approach 10,000 mw and some believe this to be conservative.

In addition to power production, Japan now utilizes geothermal energy for recreation, agriculture, and industry.

Union of Soviet Socialist Republics. The development of geothermal energy in Russia has been impressive. Scientific investigations and engineering planning and experimenting are now developing on a large scale. Geothermal maps covering the entire territory have been prepared. It is estimated that 50 to 60 percent of the territory is occupied by thermal waters which are available for use.

Advanced engineering projects have been prepared and integrated systems of geothermal energy exploitation are in operation or programed such as space heating, heating greenhouses, and industrial cooling. Other more innovative Russian projects deal with mining in the Arctic regions and with the permafrost problem.

Mexico. The main activity of geothermal development in Mexico is at the Cerro Prieto field near Mexicali. It is located about 20 miles south of the United States Border. It is in the

Mexicali Valley which is a prolongation of the Imperial Valley of the United States. It contains a thick deltaic assemblage of successive horizons of sand, silt, and clay.

Drilling in this area was initiated in 1959. Steam and water were obtained at 157 degrees Centigrade from a depth of about 1,600 feet. In the following years, geological, geochemical, and geophysical surveys were carried out to determine the structure of the basement rocks.

An exploratory well was drilled in 1964 about two miles southeast of the Cerro Prieto volcano. Commercial production of steam at 150 degrees Centrigrade has been obtained at 1,800 to 2,700 feet of depth. Figure 2 shows the temperature-depth relationship for a typical steam well in the Cerro Prieto field. In the following years, more than a score of additional deep productive wells have been drilled in an area of approximately 4 square miles. The producing formation contains hot water under pressure and the discharge from the wells consists of a mixture of steam and water, the rate being 4 to 8 parts of water to 1 part of steam. The cost of generating power from the Cerro Prieto field with a plant factor of 80 percent and a fixed charge of 11 percent is estimated to be 4.1 mills per kwh for a 150-mw powerplant and 4.9 mills per kwh for a 30-mw powerplant.

The Electrical Commission of Mexico has initiated a preliminary survey of all the important hot springs in Mexico, as well as a detailed study in the volcanic belt of central and northwest Mexico,

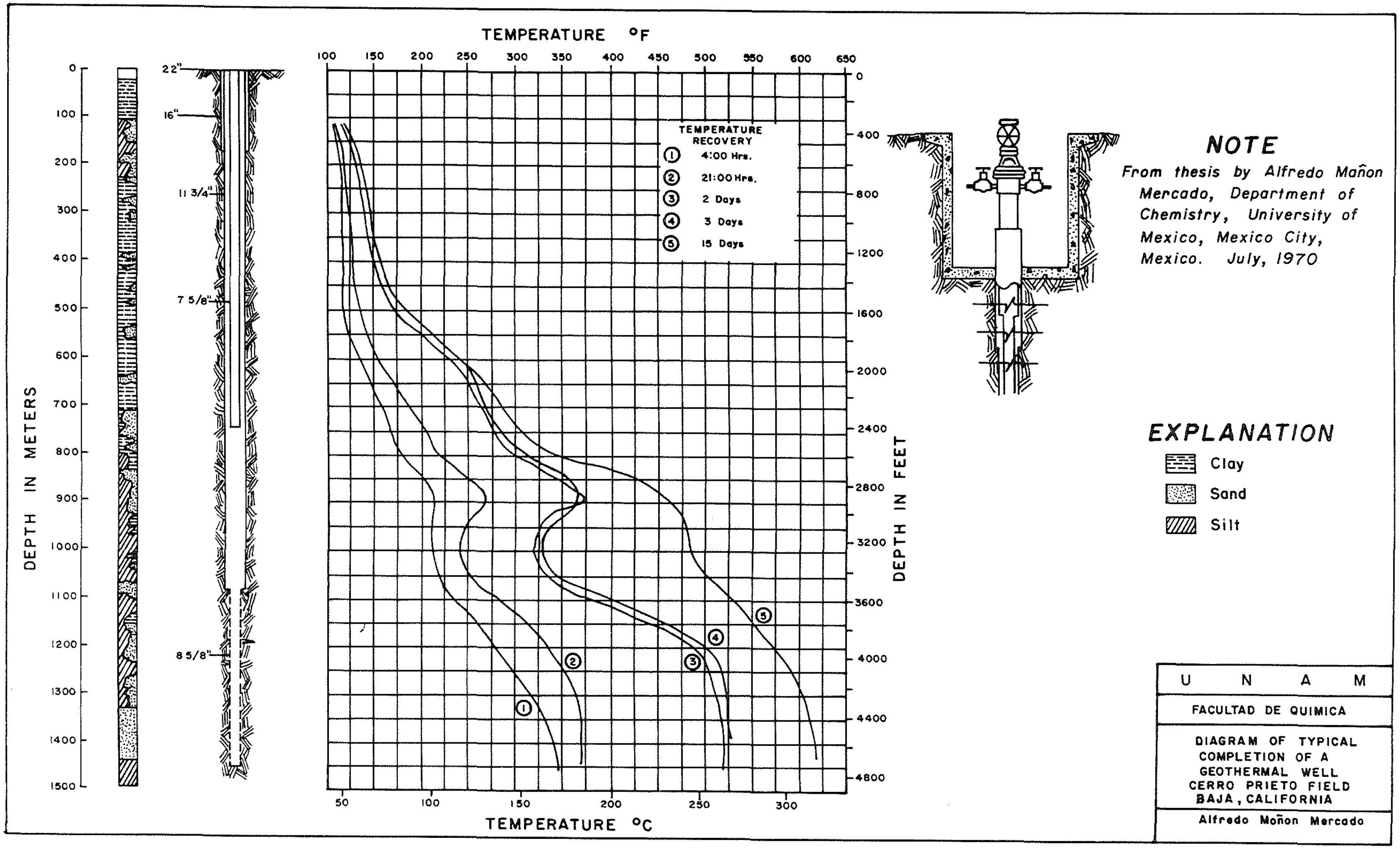


FIGURE 2

TEMPERATURE RECOVERY LOGS OF A STEAM WELL AT CERRO PRIETO, MEXICO

CURVES INDICATE TEMPERATURE CHANGE WITH DEPTH OF DRILL HOLE AFTER,

① 4:00 HOURS ③ 2 DAYS
② 21:00 HOURS ④ 3 DAYS
⑤ 15 DAYS

using 15 seismologic stations. It has been reported that 106 geothermal areas of possible commercial interest have been located and a feasibility study is underway for each of them.

The results of recent investigation and experimentation at the Cerro Prieto field were so encouraging that construction has been initiated for a geothermal powerplant of two generators with a total capacity of 75 mw. This plant is scheduled to be in operation in early 1972.

Photographs Nos. 1 and 2 show typical steam well installations at the Cerro Prieto field.

Development in the United States

Interest in geothermal energy is increasing and acceptance is gaining in the United States by the general public, investment firms, public utilities, and oil companies. The evolution is due mainly to the development of The Geysers field in California. At first, it was a geological curiosity, but now it is estimated that, with the wells already drilled, 300 mw of electric capacity can be generated. The proven capacity is 1,300 mw and the entire field may produce 3,000 mw. With the present generating capacity of 82 mw, the cost of producing energy in The Geysers is about 4 mills per kwh as compared to 7 mills average cost produced by conventional plants in California. Photographs Nos. 3, 4, and 5 show geothermal operations at The Geysers.

The existence of one very large geothermal field in the United States (The Geysers) has now been proved, and it is reasonable to believe that other similar fields exist and will be discovered.

Photo No. 1. Closeup of cyclone separator at Cerro Prieto well field, Baja, California, Mexico. Note silencer tanks and another cyclone separator in the background.
Bureau of Reclamation Photograph P-1215-300-11,122

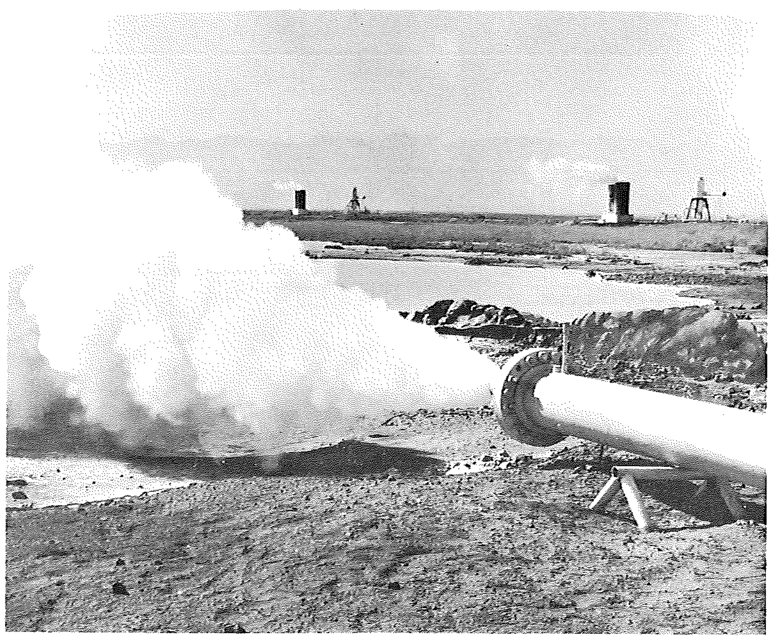


Photo No. 2. Blowoff from an idle production well in Cerro Prieto steam field, Baja, California, Mexico. This is done periodically to clear the well.
Bureau of Reclamation Photograph P-1215-300-11,121

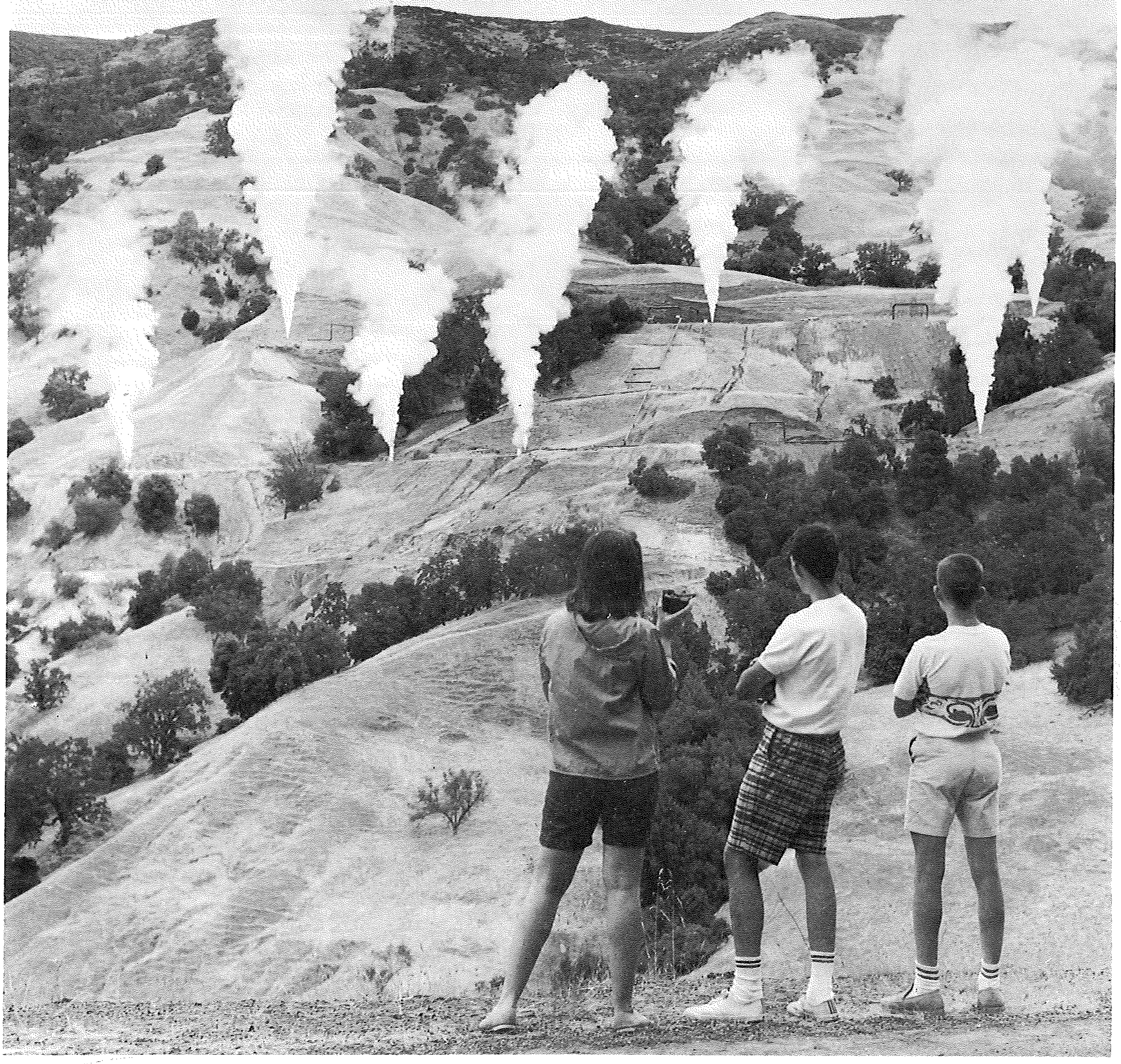


Photo No. 3. THOSE SMOKING HILLS--Tourists got a bonus display on the day of this big "blow out" at The Geysers. The eight wells in the Sulphur Bank area produce about 800,000 pounds of steam per hour. The blow out was conducted by Magma and Thermal Power Companies to remove accumulated subterranean debris prior to connecting five of the wells to piping which will carry 550,000 pounds of steam per hour to The Geysers Power Plant's generating Unit 3.
(Photo: Courtesy of Pacific Gas and Electric Company, San Francisco, California.)

Photo No. 4. Pacific Gas and Electric Company engineers study the pressure and temperature of this geothermal steam well at PG&E's The Geysers Power Plant in Sonoma County, California. Wells to produce steam for the plant have been drilled to a depth of more than a mile and a half. Behind the steam wells can be seen Unit 3.
(Photo: Courtesy of Pacific Gas and Electric Company, San Francisco, California.)

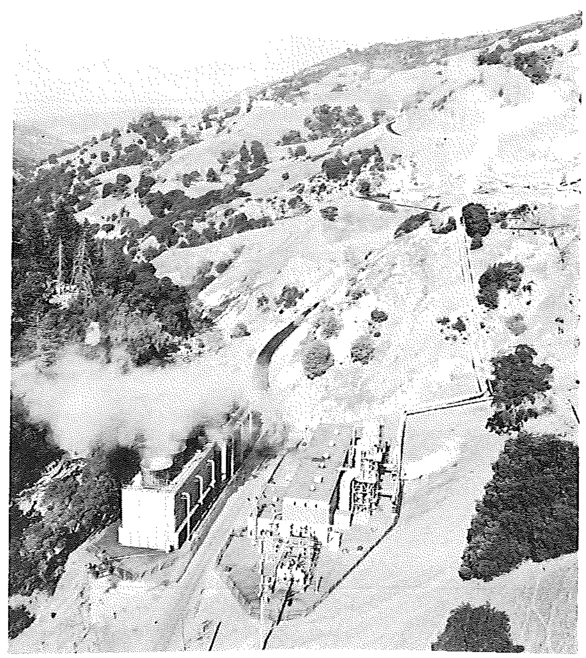


Photo No. 5. These are Units 1 and 2 of Pacific Gas and Electric Company's The Geysers Power Plant in Sonoma County, California. The plant is located about 90 miles north of San Francisco. These two units went into commercial operation in 1960 and 1963, respectively. On the knoll, upper left center, are Units 3 and 4. These latter two units went into operation in 1967 and 1968. Total capacity of the four units is 82,000 kilowatts.
(Photo: Courtesy of Pacific Gas and Electric Company, San Francisco, California.)

Space conditioning and other uses of geothermal energy have obtained little consideration in the United States because other sources of energy have been readily available and relatively inexpensive. However, one space heating project is in operation at Klamath Falls, Oregon. Approximately 400 buildings are heated by over 350 wells. In Boise, Idaho, 200 homes are heated by hot water from two 400-foot deep wells. At Calistoga, California, hotels, homes, and greenhouses are heated by geothermal water. Other small communities in Nevada, California, Oregon, and Idaho use geothermal water to a small extent as a supply of heat for homes and greenhouses.

It appears that areas warranting further exploration are the northern and western portions of the Basin and Range Province in Nevada and California, the high Cascade Range of California, Oregon, and Washington, the Aleutian Islands of Alaska, interior basins of Oregon, portions of the Island of Hawaii, and extensive areas of Idaho, Wyoming, Montana, Utah, and New Mexico. The Imperial Valley area of California has one of the greatest potentials for a successful source of geothermal steam and water.

CHAPTER IV

GEOTHERMAL ASPECTS OF IMPERIAL VALLEY, CALIFORNIA

History of Investigation

The first geothermal well drilled in the Imperial Valley was in 1927. A group of private investors drilled near existing fumaroles and mud pots in the area of the Salton Sea and encountered steam. The quantity and quality were insufficient for economical power production, but the discharge contained carbon dioxide gas. The gas was produced from 1934 to 1954 to operate a commercial dry ice plant on the site. This was the extent of commercial geothermal exploitation in the Imperial Valley for a period of 30 years.

In 1957, an exploratory oil well was drilled about five miles south of the exploration carried out in 1927. The well encountered a brine with a temperature of almost 600 degrees Fahrenheit at depths in excess of 4,700 feet. This discovery essentially discouraged further exploration for gas and oil reserves but rekindled the thoughts of continued geothermal exploration.

The Bureau of Reclamation began long-range planning in 1968 looking toward the development of geothermal resources. In June of that year, it began providing financial aid to the University of California at Riverside (UCR) which had been conducting geothermal studies in the Imperial Valley since 1964. Contracts covering this financial aid are shown below.

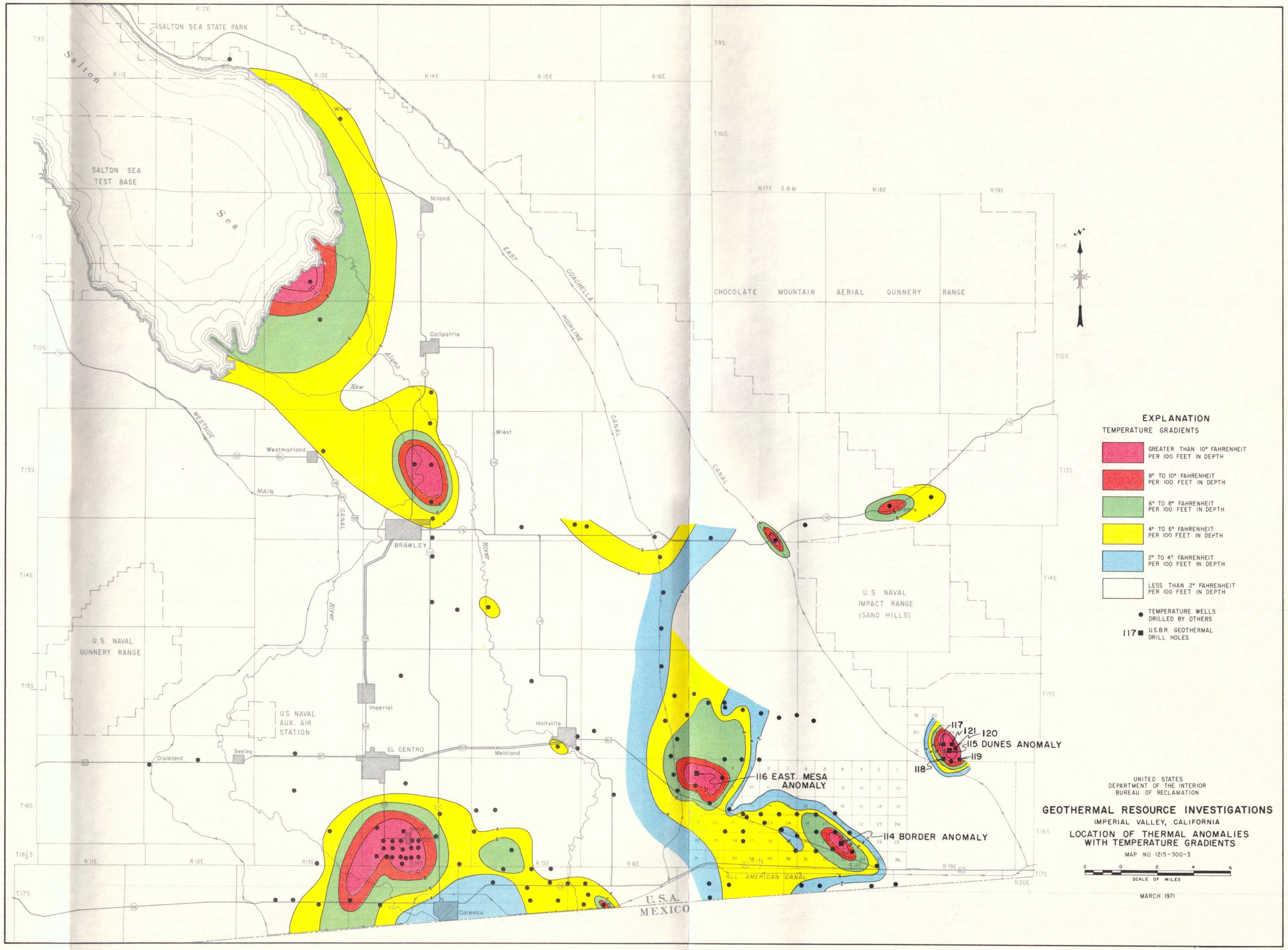
Fiscal Year	Contract Number	Amount
1968	14-06-300-2090	$ 15,000
1969	14-06-300-2090 (amended)	30,000
1970	14-06-300-2166	40,000
1971	14-06-300-2194	200,000

UCR investigations under the above contracts included geophysical surveys and measuring temperature gradients in wells and test holes. The temperature data were processed and correlated with available geophysical data from all sources. These studies led to the identification of important thermal anomalies (see Drawing 1215-300-3).

To compliment the work of UCR, the Bureau of Reclamation assigned geologists and drill crews to explore temperature gradients to a maximum depth of 1,500 feet. In Fiscal Year 1971, three sites were selected and drilled for further study on thermal anomalies in the East Mesa area on lands withdrawn for Reclamation purposes. Five additional holes were drilled on the anomaly that had the highest temperatures.

Geography.

In order to report the results of exploration in Imperial Valley, it is necessary to describe briefly its geographic and geologic setting. The geography includes the topography, drainage, economy, and landownership. The geology includes a regional structural feature, the Salton trough, the hydrogeology of the sediments in the trough, and the magnitude and distribution of heat flow.



Interior-Reclamation, B.C., Nev.

Topographically, the area is a deep trough trending northwest, floored with unconsolidated sediments and bordered by irregular mountains largely barren of vegetation.

Hydrologically, the dominant feature is the Salton Sea drainage basin, an area comprising about 8,360 square miles of drainage area (see Drawing 1169-326-7). There are three important valleys within the basin, namely, the Coachella, Imperial, and part of Mexicali. Imperial Valley lies between the Salton Sea and the Mexican Border.

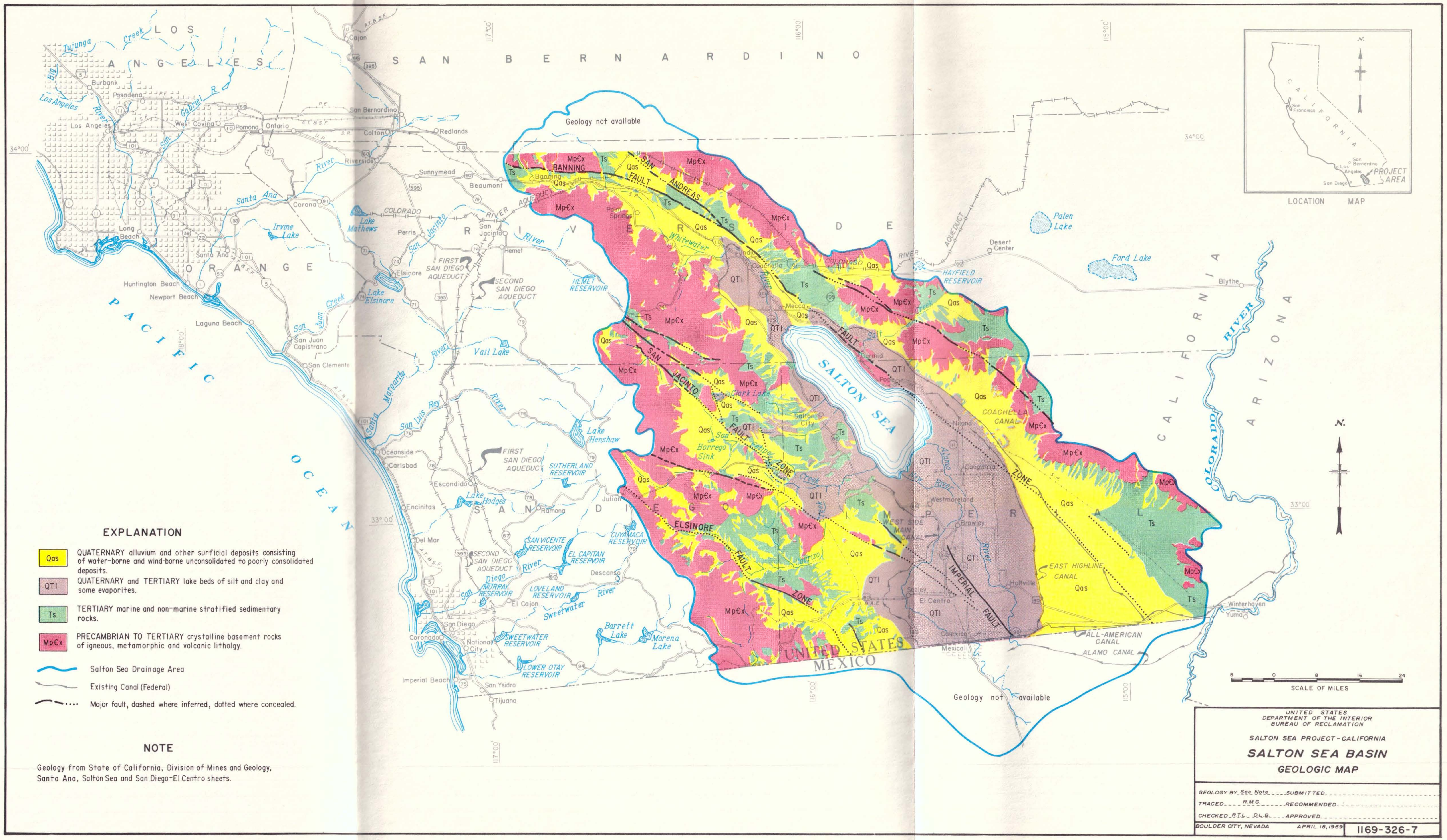
The major economic activities of the basin are agriculture, recreation, and light industry. About 500,000 acres of agricultural lands are under irrigation and are producing a wide variety of crops. The area has a long growing season which permits multiple planting of high value crops that are marketed during the off-season in most of the United States.

The industrial development is primarily related to agriculture, such as fruit and produce packing houses, food processing, cotton ginning, well drilling, concrete pipe, and cardboard box manufacturing. The Southern Pacific Railroad has the largest single payroll in the basin.

The tourist, resort, and vacation trade has recently gained in prominence, particularly near the Salton Sea.

Mining is primarily sand and gravel production and rock quarrying for the construction industry.

The land status is discussed herein from the standpoint of exploring geothermal resources. Landownership is shown on



INTERIOR-RECLAMATION, BOULDER CITY, NEVADA

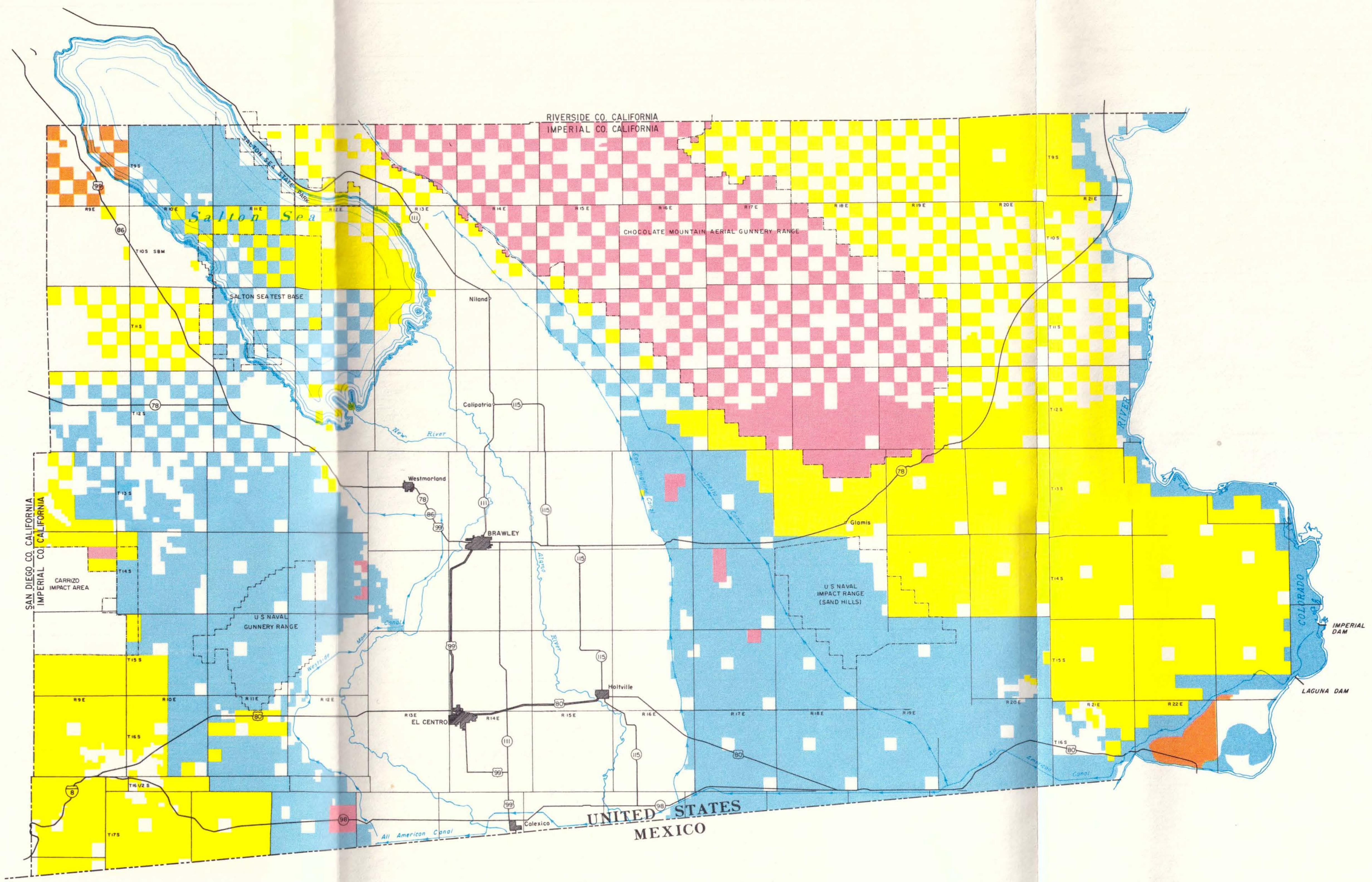
Drawing 1215-300-2. The map shows the distribution of patented lands, Reclamation withdrawn lands, Indian lands, military reservations, and public domain in Imperial County.

<u>Geology of the Salton Trough</u>

As previously stated, the concept of global tectonics involves relative movement of the oceanic and continental plates that comprise the earth's crust. The structural relationship of the two types of plates at any one area on the globe is important to an understanding of the regional structural geology and its control on the occurrence of hot water and steam.

The Salton trough of California is in the border zone between the continental crust comprising the western part of the United States and the oceanic crust of the eastern Pacific Ocean. Geologists believe that the Pacific plate is drifting by the North American plate. This action is responsible for a belt of weak crust that extends from the Gulf of California through southern and western California and is widely known by the all-inclusive term, the San Andreas Fault Zone. This belt is characterized by extreme crustal instability manifested in many hundreds of earth tremors annually. Occasionally a tremor will reach the magnitude of a damaging earthquake. Characteristic of this zone also is the high heat flow from the liquid mantle into the crust, along the alignment of the East Pacific Rise.

The Salton trough did not form as a single break in the earth's crust but rather a system of faults dominated by two important trends, the San Jacinto and San Andreas (see Drawing 1169-326-7). The



EXPLANATION

- RECLAMATION WITHDRAWAL
- PUBLIC DOMAIN
- MILITARY WITHDRAWL
- INDIAN RESERVATION
- PATENTED LANDS

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

GEOTHERMAL RESOURCE INVESTIGATIONS
IMPERIAL VALLEY, CALIFORNIA
LAND STATUS MAP

MAP NO. 1215-300-2

SCALE OF MILES: 5 0 5 10 15

MARCH 1971

Interior-Reclamation, B.C., Nev.

trough is bordered on the southwest by the San Jacinto with its main break and numerous progeny of branch faults and on the northeast by the San Andreas Fault and its many branch faults. The Imperial Fault, which cuts the Imperial Valley just west of Holtville, is one of the significant interior faults along which there was displacement in the April 1940 earthquake.

As the Salton trough rifted and spread, it received sediments from inflowing streams, largely on deltas and in lakes. The weight of the sediment load, together with crustal spreading, contributed to basin subsidence. The sediments consist largely of sand, silt, and clay with some gravel. The accumulated thickness under the Imperial Valley is estimated to be in the order of 20,000 feet, based upon seismic surveys. The sediments are saturated to within a hundred feet of land surface and constitute a vast storage of water underground. The water in storage, coupled with high heat flow, constitutes a significant geothermal potential.

Hydrogeology

The general dimensions of the ground-water reservoir are known. However, essential data about the thickness and porosity of the lithologic units are lacking. As stated, seismic data indicate a maximum aggregate thickness of sediments of 20,000 feet. Depending upon the overall width and depth of the saturated sediments and the average porosity one assigns to the lithologic makeup of this reservoir, there appears to be a substantial quantity of water stored there. Estimates by UCR run as high as 5 billion acre-feet.

Recharge to the ground-water reservoir over a substantial period of geologic time has been from floodflows of the Colorado River and ancestral streams and flood runoff from the barren ranges that border the valley. In historic time, seepage from the unlined All-American, Coachella, and East Highline Canals has been the principal source of recharge. In the early days of irrigation, deep percolation recharged the ground-water reservoir. Recharge has exceeded the discharge and substantial water has gone into storage, particularly in a triangular-shaped area bounded on the west by the East Highline Canal, on the northeast by the Coachella Canal, and on the south by the All-American Canal. This area is called East Mesa.

Ground-water movement from areas of recharge to areas of discharge is greatest in the upper few hundred feet of the reservoir where the sediments are less compacted, hence more permeable. It moves from large unconfined ground-water bodies such as the saturated sandy sediments underlying East Mesa and the alluvial fan deposits at the base of bordering ranges. These saturated deposits interfinger with the deeper strata consisting of fine-grained sand aquifers and interbedded confining layers of clay. Thus, the reservoir in the deeper part of the structural basin contains numerous confined aquifers. Present incomplete data suggest that these aquifers consist generally of very fine-grained sand deposited in ancient lakes and reworked by wind on shorelines as the lakes dried up. The Salton trough was occupied by lakes intermittently during its history accounting for a very thick section of interbedded fine-grained sand and clay.

The circulation of ground water through the reservoir is a function of the kinematic viscosity of the water, the hydraulic gradient, permeability, and cross sectional area of the rocks. Circulation through confined aquifers strictly because of head differences would be small. However, circulation of water deep within the reservoir is affected by temperature and pressure changes. The kinematic viscosity of water increases directly with temperature. Heat accumulations within the reservoir represent potential steam fields and because of the high kinematic viscosity of hot water, we anticipate large yields from the reservoir rocks even though they are fine-grained and have relatively low particle permeability.

The water quality within the saturated sediments ranges between wide limits. In the East Mesa area within the upper 1,000 feet, the total dissolved solids range from about 600 to 2,000 parts per million. It is anticipated that at a depth of about 5,000 feet in the East Mesa area the degree of mineralization will range between 10,000 and 20,000 ppm. Substantially more data on quality of water are needed from the ground-water reservoir above 6,000 feet of depth.

Deeper in the reservoir where circulation is somewhat less, the degree of mineralization is substantially greater. Between depths of 1,500 to 10,000 feet the total dissolved solids range between 3,000 and 45,000 ppm. There are exceptions where the mineralization is greater than 45,000 ppm. notably at the southeast end of the Salton Sea.

Subsurface Heat Flow

The Imperial Valley, occupying a part of the Salton structural trough, is in an area of high heat flow. Figure 1 shows the phases of crustal breaching and heat flow under the Salton trough. Measurements of heat flow involve a determination of the thermal gradient and the conductivity of the rock through which the heat is flowing. Temperature gradients in the upper 500 feet of the saturated sediments were measured in existing water wells and test holes. In addition, UCR drilled a number of test holes for the purpose of checking measurements of thermal gradients supplied to it by outside sources. It found all available data to be reliable and subsequently contoured the thermal gradients. Thus significant heat anomalies were located (see Drawing 1215-300-3).

The actual heat flow into the saturated sediments, while of a large order of magnitude, has not been measured directly because the conductivity of the sediments is unknown. For practical purposes, conductivity is assumed to be unity and variations in rock types have been ignored. It is now believed that in order to fully understand the variations in temperatures obtained in our exploration program, it will be necessary to make laboratory measurements of conductivity on cores of rock types that make up the sedimentary section.

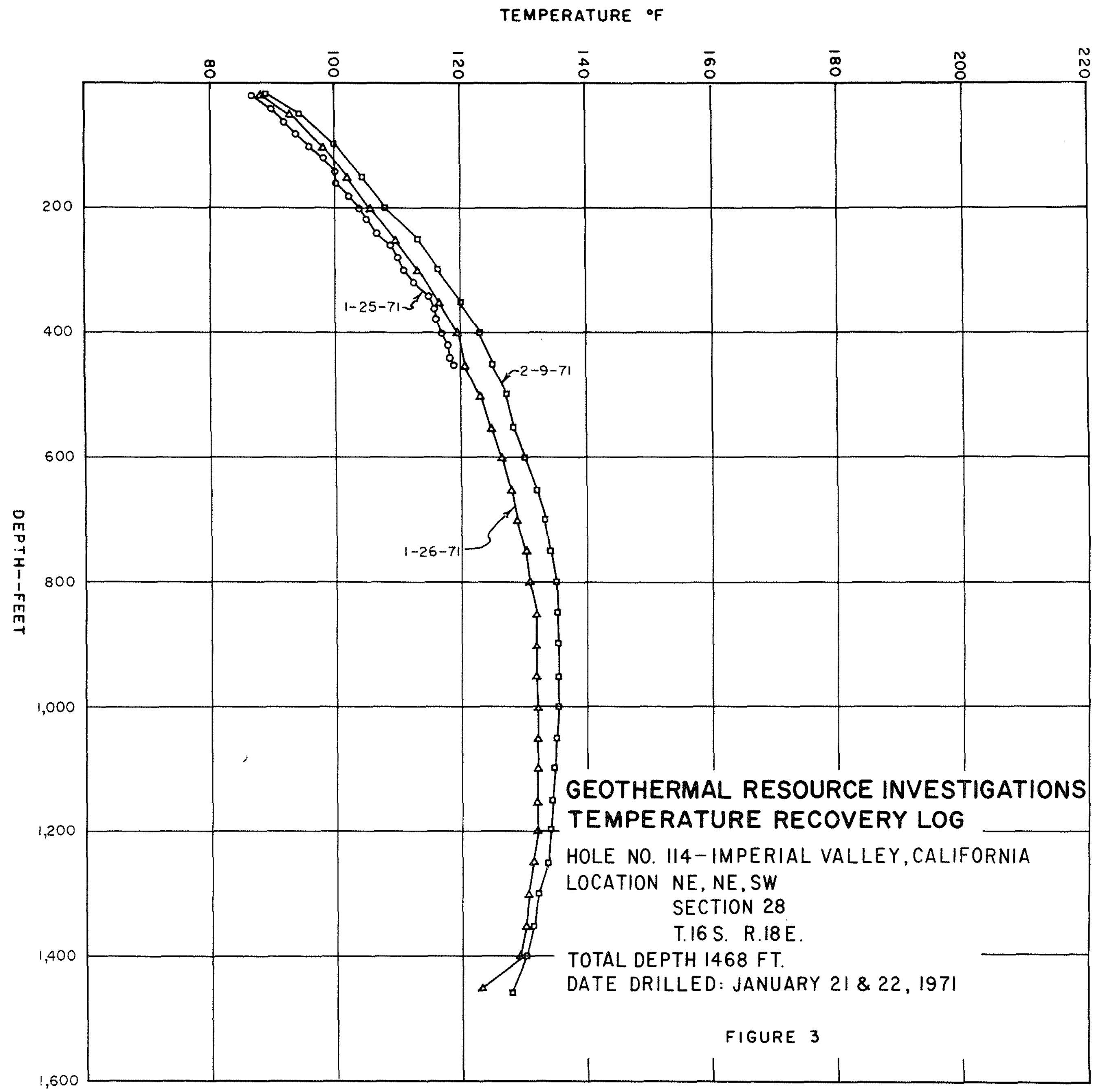
Maximum temperatures obtained from drilling on the three anomalies in the East Mesa area, namely Border, Dunes, and East Mesa, are given below.

Location	Hole No.	Total Depth (feet)	Maximum Temperature at Depth (degrees Fahrenheit at feet)
Border	114	1,468	135.4 @ 900 to 930
Dunes	115	375	231 @ 375
East Mesa	116	1,420	221 @ 1,365

Figures 3, 4, and 5 are temperature recovery logs showing the relationship between drill hole depth and temperature with time after drilling holes Nos. 114, 115, and 116, respectively. Photograph Nos. 6 and 7 show Bureau of Reclamation drilling and temperature logging operations.

The most promising of the three initial sites was at the Dunes anomaly where high temperatures were encountered in test hole No. 115. The hole penetrated a silica cemented sandstone from 206 to 375 feet. This sandstone apparently formed at the site of a hot spring that was discharging water with a high silica content. Five test holes, drilled around hole No. 115, did not encounter cemented sandstone nor did they encounter the maximum temperature recorded in hole No. 115. Temperature data obtained from the five periphery holes are shown below.

Hole No.	Total Depth (feet)	Maximum Temperature at Depth (degrees Fahrenheit at feet)
117	562	153 @ 130
118	542	117 @ 380
119	562	106 @ 562
120	562	192 @ 190
121	562	169 @ 90



GEOTHERMAL RESOURCE INVESTIGATIONS
TEMPERATURE RECOVERY LOG

HOLE NO. 114—IMPERIAL VALLEY, CALIFORNIA
LOCATION NE, NE, SW
SECTION 28
T.16 S. R.18 E.
TOTAL DEPTH 1468 FT.
DATE DRILLED: JANUARY 21 & 22, 1971

FIGURE 3

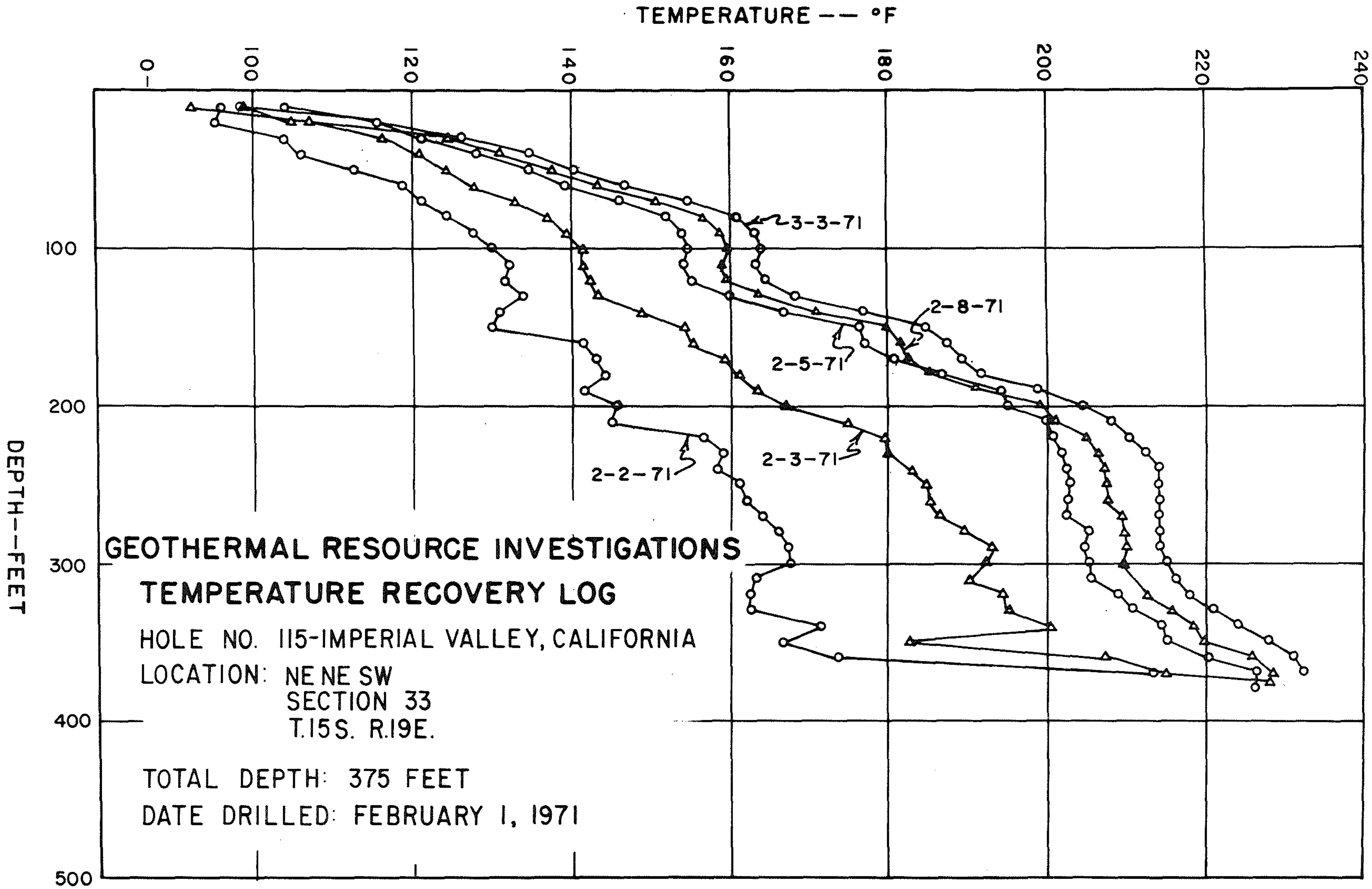

TEMPERATURE -- °F
0
100
120
140
160
180
200
220
240
DEPTH--FEET
100
200
300
400
500
3-3-71
2-8-71
2-5-71
2-3-71
2-2-71
GEOTHERMAL RESOURCE INVESTIGATIONS
TEMPERATURE RECOVERY LOG
HOLE NO. 115-IMPERIAL VALLEY, CALIFORNIA
LOCATION: NE NE SW
SECTION 33
T.15S. R.19E.
TOTAL DEPTH: 375 FEET
DATE DRILLED: FEBRUARY 1, 1971

FIGURE 4

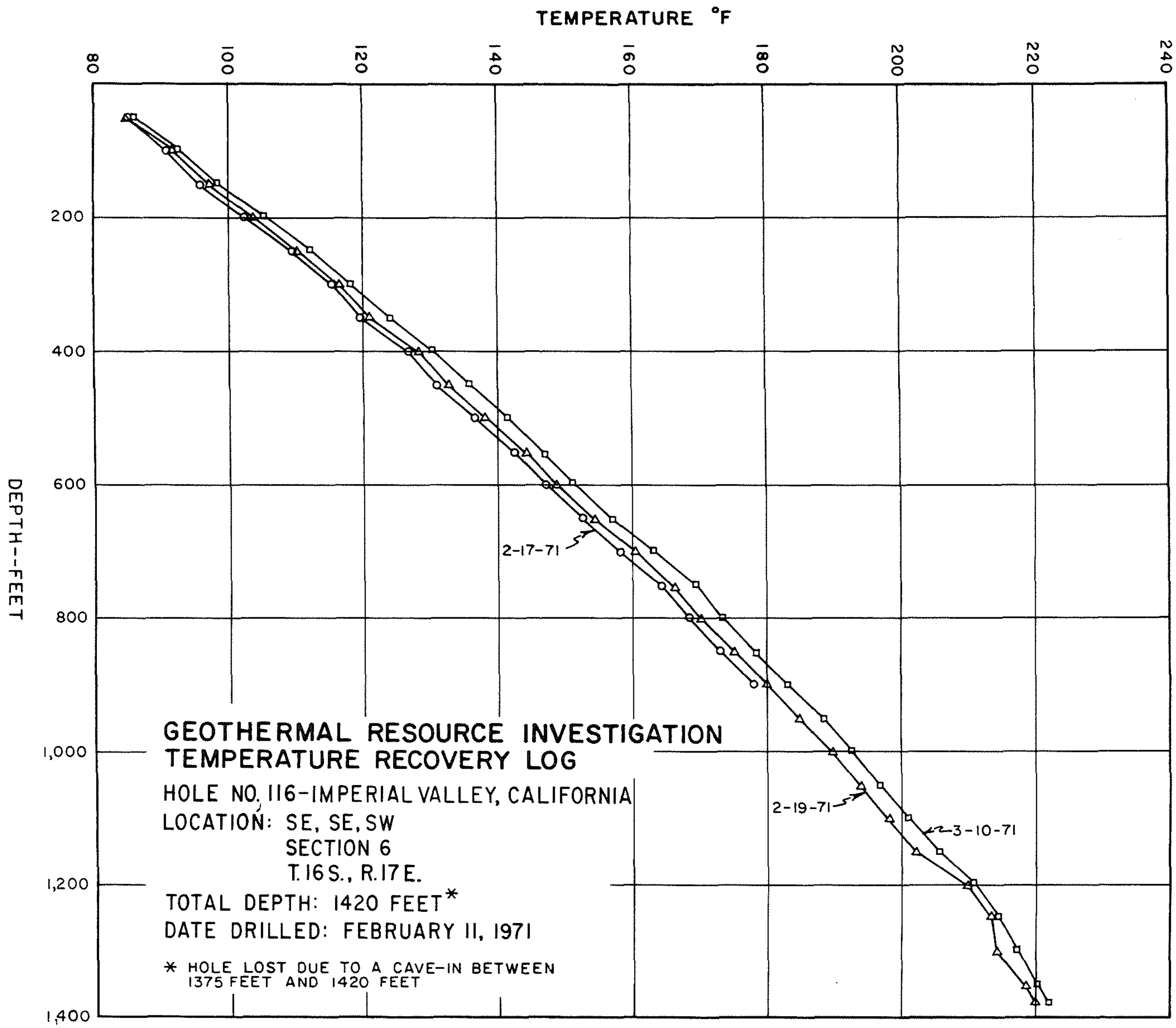

TEMPERATURE °F
80
100
120
140
160
180
200
220
240
DEPTH--FEET
200
400
600
800
1,000
1,200
1,400
2-17-71
2-19-71
3-10-71
GEOTHERMAL RESOURCE INVESTIGATION
TEMPERATURE RECOVERY LOG
HOLE NO. 116-IMPERIAL VALLEY, CALIFORNIA
LOCATION: SE, SE, SW
SECTION 6
T.16S., R.17E.
TOTAL DEPTH: 1420 FEET*
DATE DRILLED: FEBRUARY 11, 1971
* HOLE LOST DUE TO A CAVE-IN BETWEEN 1375 FEET AND 1420 FEET

FIGURE 5

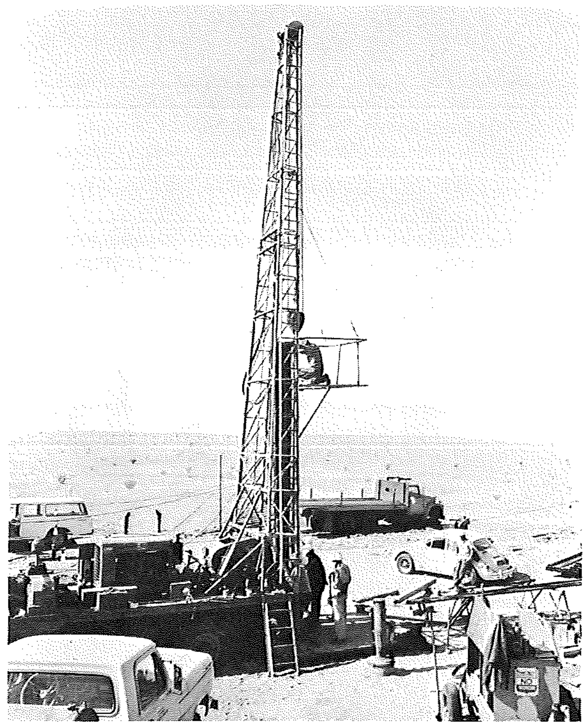


Photo No. 6. Bureau of Reclamation Failing 1500 rig on test hole 115, Dunes anomaly, Imperial County, California.
Bureau of Reclamation Photograph P-1215-300-11,119

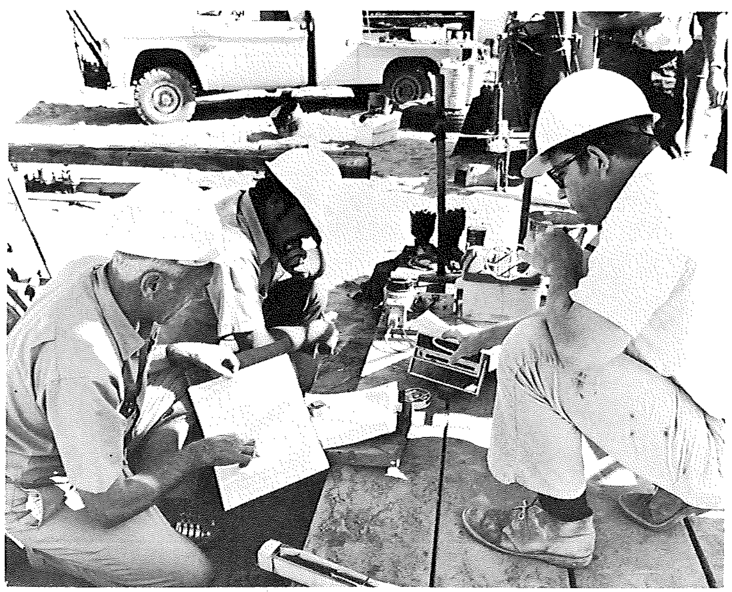


Photo No. 7. Bureau of Reclamation and University of California, Riverside, geologists logging the temperature of drill hole 115, using a deep well thermistor, Dunes anomaly, Imperial County, California.
Bureau of Reclamation Photograph P-1215-300-11,120

Seismic and gravity surveys are being conducted to further define subsurface conditions that may account for the high heat in this anomaly.

The Border anomaly was found to be relatively cold. However, the East Mesa anomaly indicated a uniform thermal gradient, within the range anticipated, to a depth of 1,365 feet (see Figure 5). Projection of the measured gradient in hole No. 116 indicates that high temperature zones capable of producing steam can be expected at depths ranging from 4,500 to 5,500 feet. Drilling is continuing this fiscal year to more accurately define the extent of the East Mesa anomaly. If funds are available, the drilling will be supplemented with seismic and resistivity surveys.

The Bureau has obtained sufficient information to program drilling a deep test hole to produce hot water and steam early in Fiscal Year 1972. Analyses would be made of the chemical and isotopic composition of the water. These data are needed to determine the feasibility of desalting the water and also to determine its origin. The quality of the steam with respect to temperature-pressure relationships will be determined. While the drilling techniques and well hardware developed by the Mexicans in their Cerro Prieto field are available, the Bureau of Reclamation would develop in-house expertise on these matters. A staff capable of handling the disciplines required in geologic exploration and reservoir engineering will be developed.

CHAPTER V

POTENTIAL GEOTHERMAL DEVELOPMENT IN IMPERIAL VALLEY

General Statement

Development of geothermal resources in the western United States was given a boost by the Geothermal Steam Act of 1970 signed into law by President Nixon. It is estimated that there are 1,350,000 acres of known geothermal resource areas on public domain in the western United States.

The population in the Pacific Southwest Region has increased steadily in the past 30 years. Colorado River water has been the key to its expanding agricultural and industrial development. Water surpluses no longer exist as all the water is being utilized. Prior to passage of the Geothermal Steam Act, the Bureau of Reclamation became interested in developing the geothermal potential in the Imperial Valley to produce a supplemental water supply for the Colorado River. As an adjunct to the production of usable water, electric power will be generated in steamplants.

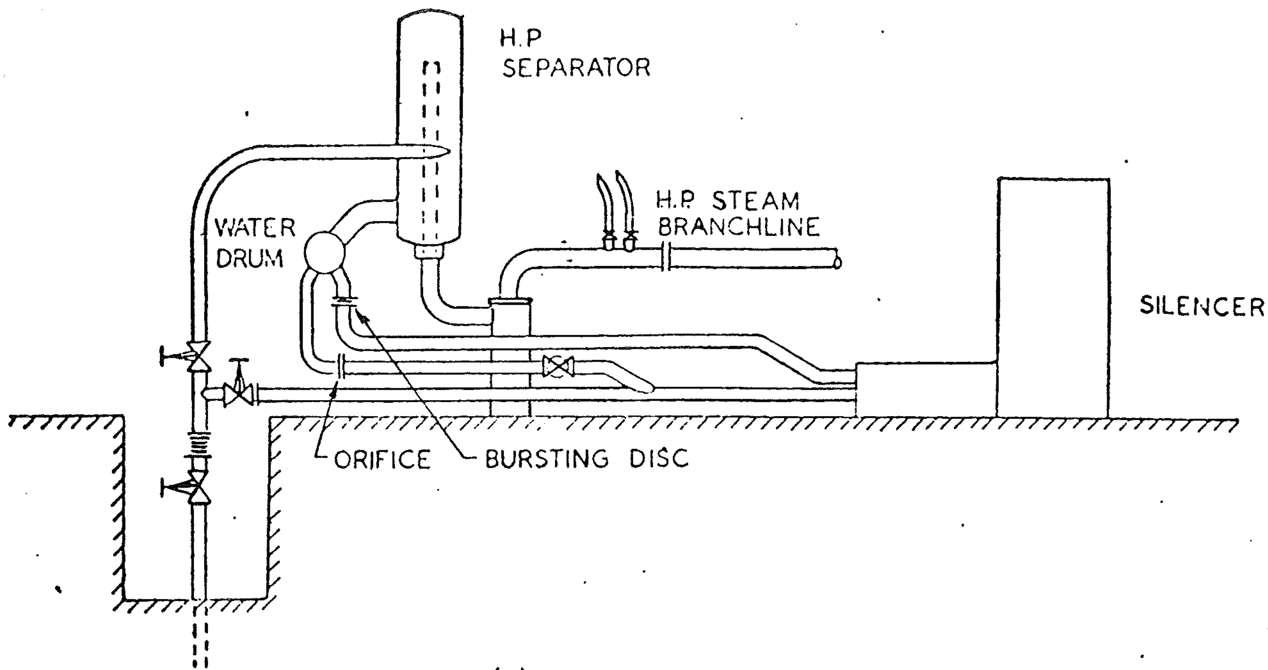
Information available shows that reservoirs capable of producing steam and mineralized water can be developed in the valley. Based upon data from the Cerro Prieto steam field in Mexico, about 20 miles south of the International Boundary, wells can be drilled to tap these reservoirs routinely. Much of the drilling technique and well hardware has been worked out by the Mexicans. The Mexicans space their wells less than 1,000 feet apart and, to date, have not experienced interference between wells. The geologic makeup of the fields apparently is quite simple. Sand and fractured sandstone form reservoirs for the hot water, and clay and shale beds confine the water under pressure. Figure 6 shows a typical wellhead assembly with interflash equipment. Figure 2, referred to earlier, shows the lithology penetrated, casing diameters, the wellhead assembly, and the blowout preventer cellar for a representative well.

Water

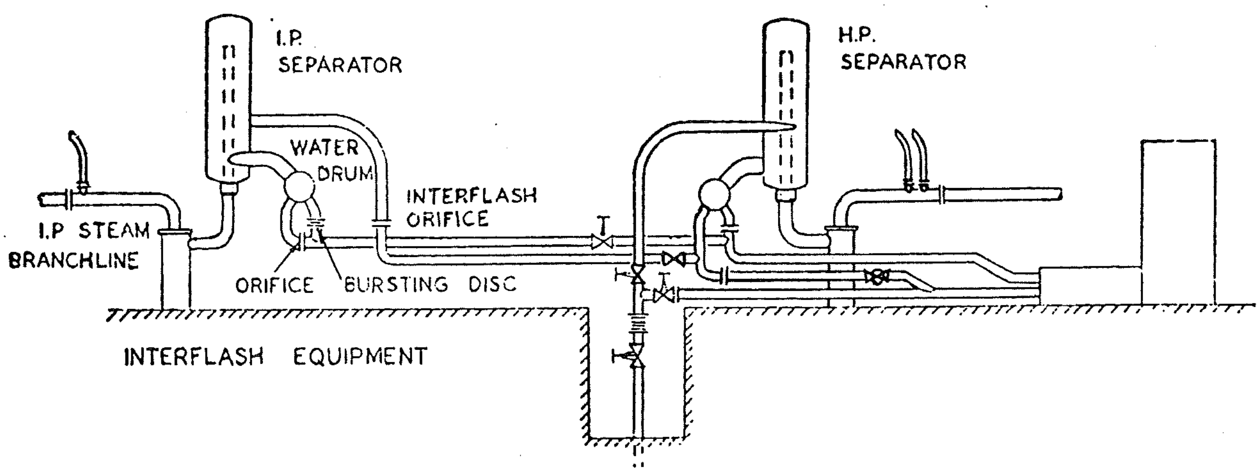
Good quality water for augmentation of the Colorado River supply can be extracted from mineralized water by modern desalting techniques. In addition, some water may be captured by condensing steam used for electric power production. The geothermal investigations program has not advanced to the point where a method of desalting can be chosen. The process will depend upon the degree of mineralization of the water, its temperature, and rate of flow. The proposed desalting plant will be unique as there is very little evidence of efforts to demineralize water from brine in other various geothermal developments around the world.

Electric Power

Electric power production from potential steam fields will require separating the steam from the water. The water in the reservoir will vary from 400 degrees to 600 degrees Fahrenheit, and will be under pressure. As the pressure is reduced on the liquid, approximately 20 percent of the mineralized water will flash to steam. Figure 6 shows two diagramatic layouts of separating steam from brine that are being used in wells on the Wairakei Project in New Zealand.



(a) Wellhead equipment.



(b) Wellhead and interflash equipment.

Figure 6: Diagramatic layout of wellhead separator equipment. (a) Wellhead equipment for separation of high pressure (H.P.) steam and brine. (b) Wellhead equipment for separation of high pressure steam and brine with interflash equipment for recovery and separation of intermediate pressure (I.P.) steam and brine.

(Taken from report: "Recovery of Flash Steam from Hot Bore Water," by D. M. Wigley, United Nations Symposium on the Development and Utilization of Geothermal Resources, Pisa, 1970.)

These separation systems are for high pressure and intermediate pressure wells. The powerplant is located some 7,000 feet from the wells. It was found to be more economical to locate the separator at the powerplant site and design it to handle several wells.

At Cerro Prieto, the Mexicans separate steam from mineralized water through a cyclone separator (see Photograph No. 1). The separator imparts a swirling motion to the steam and water. The steam collects in the center and the water collects at the outside of the swirl. A pipe inserted at the axis of the shaft collects the steam and routes it to the powerplant. The water issues from the shaft through side ports.

This report will not attempt to analyze the economics of electric power production from geothermal resources. Many of the variables which control the costs are still unknown, in particular, the thermodynamic quality of the steam. It is evident, however, that there is a source of energy for the production of electric power in an area of need and that further study on the matter is justified.

Other

Other possible developments from geothermal resources include the recovery of chemicals and minerals, as well as possible precious metals, from concentrated bitterns. Some private concerns have attempted recovery of mineral salts in the Salton Sea area. Methods of recovery are through open ponds using solar evaporation.

There are other related developments that may accompany the production of water and power. Hot water irrigation during periods of frost, hothouse agriculture, and central heating on a large scale are all distinct possibilities. The extent to which these developments could go can only be determined after more study.

CHAPTER VI

ENVIRONMENTAL CONSIDERATIONS

General Statement

Effects of geothermal development on the environment are important and must be thoroughly considered before any major development takes place. Experience from geothermal developments and active research projects indicates that extraction of steam and hot water from geothermal fields and disposal of waste fluids can be a pollution-free process. Solar energy, tidal flows, wind, and temperature gradients of sea water are other pollution-free processes, but as yet are uneconomical for large-scale enterprises. Modern technology has developed means of effectively eliminating deleterious waste products.

The layout of surface features for a geothermal plant shall be integrated into the landscape to minimize the disturbance of the natural features. For example, piping can be located underground and surface structures can be designed and painted to blend in with the terrain. There are no plans to locate any development on the Algodones sand dunes.

Waste Water Disposal

Disposal of residual geothermal fluids is one of the major problems of development.

Proposed development in the Imperial Valley would utilize the geothermal fluids as a water supply for irrigation and municipal and industrial purposes. By desalting, a supply of good quality water would be produced, leaving a small quantity of brine for disposal. There are several methods of disposing of the brine. The most feasible method, when developed in conjunction with a geothermal water and power development project, would be deep injection into peripheral zones of the producing reservoir.

Reinjection would prevent environmental pollution problems. The injection process would not require pumping because the high density effluent would flow by gravity into the geothermal reservoir. This would be an economical method of brine disposal and would alleviate some of the reservoir pressure reduction and subsidence that may accompany fluid withdrawal. The only cost would be for the injection wells and pipelines, pumping for surface transportation, and any conditioning required to prepare the brine for injection.

Gas Emissions

Air pollution could be a problem in a geothermal development if gases such as hydrogen sulphide are present in the steam and released into the atmosphere. Noxious gas emissions can be trapped and chemically removed.

Subsidence

Large-scale geothermal fluid withdrawal in the Imperial Valley may exceed the natural recharge rate and reservoir pressures may be reduced and, eventually, ground subsidence may occur.

Brine water from desalting plants and other waste water such as excess Salton Sea water could be injected into the reservoir for pressure maintenance. This would be an ideal pollution-free method of brine disposal from desalting plants and could be a possible solution for stabilizing the Salton Sea by pumping water from the Sea and injecting into geothermal reservoirs. Utilizing Salton Sea water for pressure maintenance will stabilize the surface elevation, salinity, and nutrient balance of the Sea without the need for costly features recommended by other proposals.

Ground subsidence monitoring systems would provide an early warning detection system for the need for increased pressure maintenance by water injection. Experience in other areas throughout the world indicates that ground subsidence can be controlled by water injection pressure maintenance programs.

The Imperial Valley has a natural subsidence rate of about one foot per century. It is widening at a rate of about three inches each year by crustal spreading. Future spreading of the valley floor could possibly have some effect on geothermal activity, but indications are that changes would be minor.

Seismology

The Salton trough is one of the most seismically active areas in the world. It is cut by many faults, most of which are presently active. However, the majority of resulting tremors are of a very low order of magnitude. It is not known if the seismic activity would be affected by geothermal development. Further studies are required to determine such effects. Therefore, seismic monitoring stations would be placed at strategic locations throughout the valley before geothermal fields are developed.

Some geophysicists believe high heat flow along fault planes promotes continuous creep and thus precludes stick-slip motion responsible for damaging earthquakes.

CHAPTER VII

PROPOSED PLAN FOR DEVELOPMENT

Bureau of Reclamation Responsibility

The Bureau of Reclamation is committed to develop a supplemental water supply for the Lower Colorado River Basin under Public Law 90-537. This supply of water could be developed from geothermal resources within the basin. The greatest potential for immediate development lies within the Imperial Valley.

Immediate Program

Exploratory drilling will continue at known anomaly sites on Reclamation withdrawn lands. The drilling will be concentrated on the East Mesa anomaly to determine its extent. This work will be supplemented with detailed seismic and resistivity surveys.

On the basis of the data obtained from test hole No. 116, an intermediate depth test hole (2,500-3,000 foot) should be drilled on the East Mesa anomaly. The temperature gradient would be monitored at depth to substantiate shallow findings. In addition, flow tests would be run in the lower most prominent sand if temperatures permit. Water samples would be obtained for chemical and isotopic analyses.

This work would be preliminary to drilling a steam producing well. The steam well would be 4,500 to 5,500 feet deep, based upon a projection of earlier findings. The well would be fully equipped to handle high temperatures and pressures. Blowout prevention equipment would be installed and appropriate casing strings would be set and cemented.

The well would be put on production and samples of the water and steam would be obtained for laboratory analyses.

Concurrent with the actual production of steam, a continuing program of shallow test drilling supplemented by geophysical surveys would be programed to explore the occurrence of thermal anomalies in all areas of the valley covered by lands withdrawn for reclamation purposes. It is anticipated that the University of California at Riverside would continue to give technical support in the above phases of work.

A pilot disposal well would be drilled on the periphery of a potential steam producing field.

A reconnaissance report will be prepared in Fiscal Year 1972.

Long-Range Program

The continuation of an orderly investigations program could ultimately result in the development of an entire geothermal field. It would involve drilling production wells on a spacing pattern and equipping them with the surface hardware required for safety and separation of steam and brine. This includes cyclone separators and silencer tanks. It would also require the drilling of injection wells around the periphery of the field to handle the disposal of residual geothermal fluid.

The Bureau of Reclamation will provide the Office of Saline Water with the necessary data for the design of a desalting plant.

Protection and enhancement of the environment will be primary considerations in the long-range program. Good design and construction practices will be followed in the drilling program and the layout of surface features to maximize harmony with the natural environment.

A feasibility report will be prepared by 1977.

ACKNOWLEDGMENTS

Some of the information contained in this report was obtained from geothermal reports prepared by the University of California at Riverside, and from the United Nations Symposium on the Development and Utilization of Geothermal Resources held in Pisa, Italy, in 1970.