



Arid Lands Resource Information Paper No. 2

EXPLORATION AND EXPLOITATION OF
GEOHERMAL RESOURCES IN
ARID AND SEMIARID LANDS

University of Arizona
OFFICE OF ARID LANDS STUDIES
Tucson, Arizona 85719

1973

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EXPLORATION AND EXPLOITATION OF
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ARID AND SEMIARID LANDS

A Literature Review and Selected Bibliography

Prepared by the Staff of the
Office of Arid Lands Studies
University of Arizona

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FOREWORD

The Arid Lands Resource Information Paper presented here is the second of a series being prepared for the Water Resources Scientific Information Center of the U.S. Department of the Interior, Office of Water Resources Research, on Grant No. 14-31-0001-3729, to the University of Arizona, Office of Arid Lands Studies (OALS), Patricia Paylore, Principal Investigator. The first, issued in 1972, was entitled "Salinity Problems in Arid Lands Irrigation: A Literature Review and Selected Bibliography."

As pointed out in the Foreword to Number 1, "The historic role of the OALS has been the identification, evaluation, and computerized control of documentation relating to the world's arid lands. As our information services have expanded and become better known, certain contemporary topics emerge repeatedly as being of deepest concern to those who have sought our help."

The exploration and exploitation of geothermal resources in arid and semi-arid lands appears to be one of those topics whose time has come, tied as it is with the energy crisis that is already upon us. In this brief paper we have sought to isolate from the growing mass of reporting on geothermal power those citations that have the clearest bearing on techniques of exploration and that have addressed themselves to problems of environmental impact. We have tried further to include papers that deal with the potential of geothermal power as a positive economic force in arid and semiarid regions.

In such a fast-breaking area where public concern may collide with scientific investigation, there needs to be a mechanism for insuring that understanding prevails across the spectrum of conflicting interests, so that the ultimate decisions affecting a national resource are made on the basis of information and not speculation. To this end, we hope this modest paper will contribute.

Attention is called particularly to the bibliographical reference to Summers (1971) "Annotated and Indexed Bibliography of Geothermal Phenomena" which covers in depth information up through the late 1960s, and to the fact that our bibliography, displayed in this paper, has therefore been restricted generally to information appearing subsequently.

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16. Abstract Contemporary techniques for exploration of geothermal resources are outlined, with particular emphasis on the western U. S. as typical of problems encountered in arid and semiarid lands. These include field reconnaissance, infrared aerial reconnaissance, photogeologic mapping, drilling, geochemical analyses of groundwater, application of fluid dynamics to natural steam systems, electrical prospecting, seismic, gravity, and magnetic surveys. Environmental impacts, including noise, odors, subsidence, and legal problems involving developmental regulations, are reviewed. The advantages of cheap power, multiple use including greenhouse agricultural production and dilution of present saline irrigation water sources, power for cooling and heating are discussed. A 102-item computerized bibliography, most with full abstracts, is included, plus author index, and a detailed computerized keyword index constructed from terminology applied to each citation from the Water Resources Scientific Center's Water Resources Thesaurus, 2nd ed. Reference is made throughout the text to these citations. (Paylore-Arizona)			
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17b. Identifiers Geothermal Steam Act, 1970, Dry steam fields, Impurities, Geysers Field, California, Valle Caldera, Cerro Prieto Field, Imperial Valley, Salton Sea			
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Mr. Lynn Lybeck and Miss Julie Vance, working as a team, handled the computer program used in preparing the Bibliography and its keyword and author indexes. Mrs. Cecilia Gonzalez prepared the manuscript for printing.

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EXPLORATION AND EXPLOITATION OF GEOTHERMAL RESOURCES IN ARID AND SEMIARID LANDS

Evidence of geothermal resources was noted by man as early as two thousand years ago (Allen, 1972), but it was only by the beginning of the twentieth century that he began to realize fully the magnitude of this energy source that lay beneath the earth's surface. Electricity was first generated using natural steam at Larderello, Italy, in 1904 (Summers and Ross, 1971). More recently other countries around the world have taken up the search and begun to exploit their own geothermal resources.

Geothermal energy can be used for many purposes besides the production of electricity. In Iceland, hot groundwater is used for the heating of homes, factories, and greenhouses (Papin, 1971-1972). In California, tests are underway to see if a desalination plant can be built utilizing geothermal resources. (U.S. Bureau of Reclamation, Boulder City, Nevada, Region 3, 1971). Among the by-products of this new energy source are economically important minerals and a source of fresh water.

This paper emphasizes the economic impact, benefits, and disadvantages of the development and production of geothermal power in arid and semiarid lands. Exploration techniques and methods of exploiting geothermal power are reviewed. A comparison also is made of different power sources and their effects on the environment.

Geothermal energy utilizes the heat existing in certain parts of the earth's crust near the surface or at depths not exceeding the limit of economic utilization (United Nations, 1964). Three basic conditions are required for the existence of a geothermal field. First, there must be a source of heat, such as a shallow intrusion or an area of recent volcanic activity. Second, heat is radiated from its source to nearby strata, which have great enough thickness and permeability to allow the formation and the permanence of a system of convection currents in the interstitial water (Allen, 1972; Birdseye, 1971; and Rex, 1971). This layer is called the reservoir (Facca and Tonani, 1964). Third, overlying the reservoir there must be an impermeable rock layer to prohibit the escape of hot water from the reservoir. This impermeable stratum is known as a cap rock. If it is not present then permeable strata can develop their own impermeable capping by precipitating silica from circulating hot water (Facca and Tonani, 1967).

All geothermal sources in production today are found in regions of recent volcanic activity and are associated with major fault systems (Birdseye, 1969).

Heat generated by the heat source can be exploited only if a fluid is available to transmit it and be produced in sufficient quantity to generate energy (Facca and Tonani, 1964).

Usable sources of geothermal energy fall into three classes: dry steam fields, wet steam fields, and fields of lesser heat content characterized by water temperatures below 100° C (Barnea, 1972). Each of these types of geothermal energy has its own uses and capabilities.

Under some geological circumstances groundwater pressures may be low and temperatures high, resulting in underground boiling. If this continues for long periods of time the resultant steam can accumulate in rock fractures and in the natural porosity of subsurface rocks. This type of dry steam can be released directly by drilling wells similar to natural gas wells (Rex, 1971). Dry steam fields are relatively rare, but they have distinct economic advantages because the only pre-treatment needed is the removal of rock particles and grit. The steam is then fed into low pressure turbines to produce electricity. Because steam is piped directly from the well to the turbine with very little preparation, requirements for plant equipment can be simplified, and plant investment may be as low as \$100 per kilowatt (Barnea, 1972). Only five dry steam fields have been developed as of January 1972. These include the Larderello field in Italy, the Geysers field in California (Garrison, 1972), the Valle Caldera field in New Mexico (Birdseye, 1971), and two fields in Japan (Barnea, 1972).

Wet steam fields are approximately twenty times more common than dry steam fields. At depth, the temperature of the circulating fluids in a wet steam field ranges from 180° C to 370° C. Upon reaching the surface, this super-heated water is flashed to steam. Eighty to ninety percent of the discharge is water, the remaining portion is steam. The steam can be used for electrical power production. The hot water can be used for space heating and refrigeration, fresh water, and the production of electricity using intermediate low-boiling-point fluids. Unfortunately, most geothermal plants operating today discard the hot water, thus creating a source of thermal pollution, or use it to recharge the groundwater being removed.

Only recently have fields with low temperatures, ranging from 50° C to 82° C received serious attention. The hot water has been used effectively for heating houses, greenhouses, and industrial plants in Idaho, the USSR, and Iceland (Barnea, 1972). The utilization of hot water for the above uses is practical only if it can be used in proximity to the point from which it emanates. Magma Energy, Inc. is experimenting with the production of electricity from low temperature fields by evaporating iso-butane which has a boiling point lower than water. The iso-butane is then used to drive a turbine. Because iso-butane is flammable, special precautions

must be adopted if it is to be used. (*)

A fourth type of geothermal reservoir is being investigated. The Atomic Energy Commission and the American Oil Shale Corporation have suggested a method of extracting heat energy directly from heated rock material where no natural steam or hot water reservoir exists. They propose to create a hybrid type of geothermal reservoir by fracturing large quantities of hot rock with an underground nuclear explosion. Water would then be piped to the fractured region creating steam which would act as a medium for the extraction of heat energy from the rock body. The system would be closed to prevent radioactive pollution into surrounding water supplies and as a means of conserving water (Allen, 1972).

Until recently, geothermal fields had been discovered only by drilling in areas of thermal manifestations such as geysers, fumaroles, and hot springs. Unfortunately, surface phenomena do not readily depict subsurface conditions (McNitt, 1965). Many regions in which there are thermal manifestations are not amenable to geothermal development. Other regions lacking such thermal manifestations have been found to have subsurface conditions suitable for the development and exploitation of geothermal resources. Thus it has become necessary to utilize more sophisticated exploration techniques than simply surface expression.

The initial stage of any exploration program is a reconnaissance of the field geology and geologic mapping. Structural geology is of primary importance in determining geothermal anomalies. Steeply-dipping, normal, or strike-slip faults are common in thermal areas and probably aid in providing deep circulation of meteoric waters (Summers and Ross, 1971). Structural troughs, such as the Salton Sea area of California, or the Rio Grande trough in New Mexico, are favorable large-scale structures for the production of geothermal energy.

Photogeologic mapping, which facilitates rapid examination of a large area, is used to augment field mapping. Structural and lithologic information can be obtained readily from air photos, including the delineation of surface thermal phenomena (Miller, 1968; Moxham, 1969, 1970).

Closely associated with photogeologic mapping is infrared aerial reconnaissance (Moxham, 1969, 1970). Because infrared film is sensitive to heat, it is capable of detecting surface and near-surface areas of anomalous heat flow (Hase, 1971).

Recently, vegetative changes have been found to be useful criteria for locating geothermal phenomena (United Nations, 1964). Certain types of vegetation are

(*) Colorado River Association, Newsletter, September-October 1972.

modified in a characteristic way by variations in temperatures. A sudden change in vegetation may denote a change in the groundwater regime.

After the surface reconnaissance, the next step in an exploration program is a geochemical analysis of the groundwater, including sampling and testing of the steam emanations, as well as the condensed steam from the hot waters. Such a geochemical analysis should provide three important facts: temperature, age, and chloride content of the water. First, the maximum temperature the water has reached provides information concerning the potential of the location to produce geothermal energy. Second, the period of time the water has been in the system: "If the water is relatively old it may indicate that the reservoir is recharged slowly and therefore would be subject to depletion if developed unwisely" (Summers and Ross, 1971). Finally, White, Muffler, and Truesdell (1971) have proposed a method for distinguishing between dry steam areas and wet steam areas. Dry steam areas are characterized by acid-sulfate springs, with insignificant chloride content, but springs from wet steam fields have a high chloride content.

A new exploration approach presently being developed is the application of fluid dynamics to natural steam systems (Summers and Ross, 1971). This method describes quantitatively the movement of groundwater on a regional scale. A study of fluid dynamics also facilitates the determination of the life span of a particular geothermal field after it is developed. Other regional studies, such as temperature and heat flow analysis permit localization of favorable zones for the presence of super-heated fluids.

Electrical prospecting methods facilitate relatively rapid and complete reconnaissance programs. The resistivity of a formation is partially dependent on its temperature; an increase in groundwater temperature would appear as a decrease in resistivity. Variations in resistivity also denote changes in groundwater salinity or changes in geologic formation.

In New Zealand seismic methods have been incorporated into geothermal explorations. When groundwater comes in contact with a heat source, a seismic noise pattern is produced that can be used to determine the extent of a favorable geothermal aquifer (Summers and Ross, 1971). Refraction and reflection seismic methods have also been used to investigate the subsurface geologic structure of a region.

Gravity and magnetic surveys are two additional techniques used in the exploration for geothermal resources (Crosby, 1971; Griscom and Muffler, 1971). Because hydrogen sulfide near heat sources causes magnetite to change to non-magnetic pyrite, magnetic lows are often associated with hydrothermal activity. Gravity surveys can be utilized to study deep subsurface structure and help delineate feeder channels or reservoir characteristics.

The final and most important phase of the exploration is the actual drilling. No conclusion as to the productive capacity of a region can be formulated without drilling. Information derived from the drilling program should include the porosity and permeability of the rock strata and the nature of the permeating fluid.

In exploring for geothermal resources, it should always be kept in mind that different geologic settings require different exploration techniques. Because the expense involved in drilling can be prohibitive, a very diverse and intensive yet low-cost exploration program should be carried out prior to actual drilling.

Although the development of geothermal power is still in its infancy, many distinct advantages over fossil-fuel and nuclear power plants are already apparent. Economically, geothermal power appears to be competitive with other sources of power. Bowen and Groh (1971) estimate that a geothermal power plant would cost only two-thirds to three-fourths as much to build as a conventional fossil fuel power plant. The maximum capacity of a geothermal power plant need not be developed immediately. The plant can be enlarged as needed, lowering the initial capital investment for an extremely large plant before it is needed. A geothermal plant is also relatively simple to operate, another factor in reducing operating costs. The Geysers plant in northern California, for instance, operates throughout most of the day unattended, with a small crew monitoring the equipment for only eight hours daily (McMillan, 1970). Bradbury sounds a warning note (1971), however, in pointing out the need to compare high fixed charges and low variable costs in estimating exploration and development charges. Maintenance costs will vary from plant to plant and may become extraordinarily high if large concentrations of impurities must be separated from the steam and occasionally removed from pipes and turbines on which they may accumulate.

Natural steam power plants have relatively little effect on the environment, when compared to other sources of power generation. Nuclear plants and coal-burning plants require the mining of fuel, land for processing plants and storage, and the development of a transportation system to a power plant. In comparison, the production of electricity from geothermal resources does not require excavation or mining, a refining stage, or any elaborate transportation system that can damage the environment. The Larderello field has been producing electrical power since 1904, yet intensive agriculture is carried on within the steam field, with vineyards and orchards growing among the pipelines and wells (United Nations, 1970).

Natural steam from the earth is low in atmospheric pollutants. At the Geysers operation, the average content of the steam is 99.5 percent steam and only 0.5 percent non-condensable gases. Of these gases, 90 percent is carbon dioxide and the remaining 10 percent methane, hydrogen sulfide, and trace elements of other gases (Bowen, 1971; O'Rourke, 1972). The percentage of non-condensable gases may be

as high as four percent at the Larderello fields. Hydrogen sulfide presents a problem in larger plants but it can be extracted chemically from the escaping gases (Bowen and Groh, 1971).

Geothermal resources also have the advantage of serving multiple purposes. Besides producing electricity, excess hot water can be used to heat homes, factories, or greenhouses (Head, 1970; Papin, 1971-1972). Hot water can be used in a desalination process to produce fresh water for municipal or agricultural purposes. Minerals can also be removed from hot brines in economically profitable quantities (Hammond, 1972; Murray, 1972).

Although geothermal power is apparently endowed with a multitude of assets, many members of the technical community have been hesitant about giving approval to this new source of power, justifying their beliefs by pointing out some of the shortcomings present in the arguments developed by the proponents of geothermal power (Laird, 1971).

Geothermal electrical production may not be as competitive as it was once believed, due to numerous hidden costs which may raise the estimate of the initial capital investment needed. Exploration costs will vary, easily becoming the most expensive aspect of geothermal power development. The expense of removing brines and non-condensable gases from the steam may raise cost estimates considerably. Because of the location of geothermal areas within active earthquake areas, power plants are susceptible to seismic damage.

Another critical problem is the accurate determination of the life expectancy of geothermal fields. Producing fields have a life expectancy of only 50-100 years according to Mount (1969), with individual wells lasting only as long as five to ten years. Geothermal fields may not be numerous enough or in locations where they can have maximum economic benefit. Fenner and Klarmann (1971) estimate a world potential of one million megawatts per year, while White (1969) estimates a potential of only 60,000 megawatts per year. Both estimates are low in relation to the potential for other energy sources and the projected demand estimates.

There may well be numerous environmental effects related to the development of a geothermal resource. Initially, the prospect of putting an industrial plant into a non-industrial area may create severe problems. Hydrogen sulfide may escape into the air, and boron and ammonia may pollute surface waters if not reinjected into the ground. Such reinjection of fluid into the ground may precipitate earthquakes in a fault zone (Fenner and Klarmann, 1971). While land subsidence may occur (Goldsmith, 1971; Hamn ~~ed~~, 1972) due to withdrawal of groundwater, proposed Department of Interior regulations requiring drillers to reinject all water removed from the ground as brine or hot water will minimize this objection. Likewise, noise

pollution, another problem of some magnitude because of the necessity for geothermal wells to vent steam constantly through a small diameter pipe, may be solved with only a slight increase in initial development costs as a result of Interior's proposed regulation requiring special mufflers that meet specific noise levels. (*)

Finally, the largest hurdle preventing the development of geothermal resources is the legal ambiguity of the control and ownership of this resource. Congress passed the Geothermal Steam Act of 1970 (Godwin, et al, 1971; U. S. Code Congressional and Administrative News, 1970), but the Act failed to settle two basic questions: ownership of the resource and the rules governing its exploitation (Allen, 1972). In the United States, geothermal development may be hampered by the horizontal acquisition practices of oil companies (Netschert, 1971). This would threaten interfuel competition and could delay the development of new power sources.

Semiarid and arid lands are faced with three critical problems: First, there is a scarcity of water; second, it has been economically unfeasible to supply power to sparsely populated arid areas; third, groundwater tends to be saline. The development of geothermal resources may go far toward alleviating problems in the arid and semiarid regions of the world.

As a power source, geothermal power may be the cheapest means of bringing electricity to desert areas. Initially, such power plants can be small, saving the expense of building a large capacity power plant for an undeveloped area with a small production. Many arid and semiarid regions are known to possess, or at least have the potential to utilize, geothermal power. Such regions include the western United States, specifically California, Nevada, New Mexico, Idaho, Utah, and Oregon (Birdseye, 1971; Bowen, 1972a; California, State Department of Water Resources, 1970; Heylman, 1966; McNitt, 1965; Summers and Ross, 1971), northern Mexico (Koenig, 1967; Mercado, 1969; Lear, 1970; Mooser, 1965; United Nations, 1964), the USSR (Fotiadi, et al, 1970), Argentina, Chile, Japan, Kenya, Uganda, Tanzania, Ethiopia, Algeria, Turkey, and India (Fenner and Klarmann, 1971; Noguchi, 1970; Uyeda and Watanabe, 1970).

The cost of geothermal electrical power may be kept low through the multiple use aspects of geothermal energy. Most thermal power plants require vast amounts of water to cool condensers. Geothermal plants that utilize dry steam, however, do not require a supplementary source of cooling water. Natural steam, after passing through the turbine, is condensed within the cooling water, thus providing additional water to the cooling towers. Increasing competition for diminishing supplies of water is probably the single most important reason for the development of geothermal resources (Bowen, 1971).

(*) Washington Star-News, January 9, 1973

The Chilean government in cooperation with the United Nations is developing a facility that will generate three products: electricity, distilled water, and a mineral-rich brine from which valuable minerals will be extracted in evaporating ponds. Thus one plant solves three problems: scarcity of water, desalinization of needed groundwater, and an economically important by-product which will help keep overall production costs relatively low. The water produced as a product of geothermal power can be used for agricultural purposes, with some reservations, as well as for municipal and industrial purposes. Whether enough water for irrigation can be produced in arid regions as a by-product of electrical production and/or desalination is not known yet, but it is a positive step forward in the solution of the problem (United Nations, 1964) if we see the major agricultural application of cheap geothermal power as irrigation water production. While we await the evidence that geothermal processes can produce the abundant quantities of water as a by-product needed for this purpose, we also need to know that geothermal power can be produced cheaply enough to justify desalination as an economically viable source of irrigation water.

The United States and Mexico are currently involved in a dispute over the salinity level of Colorado River water entering Mexico under treaty. It is almost certain that this dispute can be resolved only by the United States. A way must be found to lower the salinity of the River before its water is delivered below the border. It has been suggested (Lear, 1970; Rex, 1971; U.S. Bureau of Reclamation, 1971) that this might be accomplished by pumping geothermally-heated water to the surface of the Imperial Valley, using the steam to generate power and the heat of the water for evaporation, followed by injection of the distilled water into the River and thus achieving lower salinity levels by dilution. The multiple usage of the geothermal resource could reduce desalination costs.

A new 8,000-foot test well, pumping salty brine from beneath the Imperial Valley desert seven miles east of Holtville, California, has been described by Bureau of Reclamation officials (*) as part of a \$16 million test project expected to run through 1978, with early results being very encouraging. Should it be successful in accomplishing this potential of harnessing steam to power a desalting plant that would convert the brine into high-quality drinking water, it could serve as a model for other arid regions with similar geothermal resources, thus pointing the way for a combination of industry and agriculture interacting to lower unit power costs to each.

Many maintain that the most promising avenue of agricultural production in arid regions is through greenhouses rather than vast, heavily capitalized irrigation schemes. The heated water is one of the highest costs in greenhouse agricul-

(*) Associated Press, November 5, 1972; February 27, 1973.

ture but with a source of geothermal good quality water or a low cost method of distillation, a significant impetus could be given to greenhouse agriculture in deserts. It is felt that this is a particularly promising avenue of research. Near Lakeview, in the Oregon high desert where winters are very cold, geothermal power is being tapped 440 feet below the ground to maintain a constant greenhouse temperature for a year-round commercial tomato-growing operation (Head, 1970). Promising precedents, therefore, do exist.

Geothermal resources provide still other benefits to the entire world as well as arid and semiarid regions. Hot water can be used for heating houses in winter and air conditioning in summer. Already in use in a New Zealand resort hotel is such a joint setup, lowering its operational costs significantly. In Japan, high temperature waters are being tested for new techniques of fish breeding. Within the next decade 60 to 70 percent of Iceland's population will be heating their homes with geothermal resources (Barnea, 1972).

Geothermal power may never become a predominant source of energy for man but it has the potential to play an important role in augmenting the currently over-taxed facilities of power production. In arid and semiarid regions of the world where electric power is expensive because of transmission distance and low per capita distribution, geothermal power development would aid in lowering these costs as well as providing an incentive for industrial development. The water produced as a by-product of electrical production could be used for industrial or municipal purposes.

Nevertheless, problems do remain that will hinder the development of geothermal power resources. Although geothermal power is comparatively pollution free, hazardous pollutants still exist. Fortunately, present technology seems capable of solving this problem (Bowen and Groh, 1971; Fenner and Klarmann, 1971; Laird, 1971; Rex, 1971). Pollution devices, high exploration and drilling costs, and unexpected maintenance costs may increase the costs of geothermal power production. The aspect may be offset by two facts that will become more evident within the next two decades: 1) As fossil fuel supplies decrease, prices for these products will increase, with electric companies passing this increase on to the consumer. The possibility, therefore, exists that even with unexpected increases in cost, geothermally-produced electricity may become less expensive than electricity produced in fossil fuel plants. 2) Science is finding new ways of increasing the versatility of geothermal resources, thereby making it a more attractive source of power.

Today, the world's present facilities to produce power are strained. Each summer many cities have blackouts or brownouts because they are unable to convey to consumers the needed quantities of electricity. Each winter fuel needed for heating becomes scarcer and more expensive. In January 1973, for instance, the

City of Denver, Colorado, had to close schools temporarily and curtail the use of natural gas because of a fuel shortage, only one of many such examples. Development of geothermal resources will not replace fossil fuels but it could certainly lend a helping hand in getting us out of a rapidly developing energy crisis. The recent United Nations seminar on geothermal energy held in New York summed up this point of view (*) when the energy experts present generally agreed that such energy from the natural heat of the Earth's core is one of the most promising sources of relatively non-polluting energy, and should be developed on a world-wide scale.

(*) New York Times News Service, January 14, 1973

BIBLIOGRAPHY

1

ALLEN, D.R.

1972

LEGAL AND POLICY ASPECTS OF GEOTHERMAL RESOURCE DEVELOPMENT.

WATER RESOURCES BULLETIN 8(2):250-256. SWRA W72-08976.

ALTHOUGH ONLY ONE SIGNIFICANT COMMERCIAL GEOTHERMAL ELECTRICAL POWER DEVELOPMENT EXISTS IN THE US, THE PROSPECTS FOR CONSIDERABLE EXPANSION IN THE FUTURE SEEM VERY GOOD. SOME PHYSICAL PROBLEMS MAY ACCOMPANY GEOTHERMAL RESOURCE DEVELOPMENT, INCLUDING POSSIBLE GROUNDWATER CONTAMINATION, SUBSIDENCE OF OVERLYING GROUND AREAS, INCREASED LOCAL SEISMIC ACTIVITY, AND INCREASED NOISE. THESE PROBLEMS MUST BE CONSIDERED WHEN A GUIDING LEGAL STRUCTURE IS DEVELOPED FOR GEOTHERMAL RESOURCES. THE MOST BASIC LEGAL PROBLEM IS THE EXACT DEFINITION OF GEOTHERMAL RESOURCES. IN FAILING TO FACE THIS QUESTION, CONGRESS HAS LEFT TWO MAJOR ISSUES UNRESOLVED. THESE CONCERN OWNERSHIP OF THE RESOURCE, AND THE RULES GOVERNING ITS EXPLOITATION. ANY SOLUTIONS SHOULD BE MADE IN LIGHT OF THE UNITARY NATURE OF A GEOTHERMAL RESERVOIR. WHILE MINERAL LEASING LAWS MAY OFFER THE MOST SATISFACTORY SCHEME FOR RESOURCE OWNERSHIP, THE TRADITIONS OF SURFACE AND GROUNDWATER CONTROL MAY BE MORE APPROPRIATE FOR MANAGING A GEOTHERMAL RESERVOIR THAN THOSE CAPTURE PRINCIPLES TRADITIONALLY ASSOCIATED WITH PETROLEUM EXPLOITATION. NEW INSTITUTIONAL ARRANGEMENTS MUST BE FOUND TO CIRCUMVENT THE USUAL FEDERAL-STATE DISPUTES.

GEOTHERMAL STUDIES/LEGAL ASPECTS/ENVIRONMENTAL EFFECTS /WATER LAW /
THERMAL POWERPLANTS/REGULATION

2

ALONSO ESPINOSA, H./MOOSER, F.

1964

EL POZO M-3 DEL CAMPO GEOTERMICO DEL CERRO PRIETO, B.C., MEXICO.

ASOCIACION MEXICANA GEOLOGOS PETROLEROS, BOLETIN 16(7-8):163-177.
ANAG(1966)0659.

THE PROLIFIC FUMAROLIC AND SOLFATARIC ACTIVITY IN THE LAGUNA VOLCANO, WHICH OCCUPIES AN AREA OF 10 SQUARE KM SOUTH OF CERRO PRIETO, BAJA CALIFORNIA, LED TO DEVELOPMENT OF A GEOTHERMAL FIELD. IN APRIL 1964 THE M-3 WELL WAS DRILLED, WHICH PRODUCES STEAM AND WATER FROM A FIRST ZONE AT DEPTH OF 600-900 M UNDER 18 ATM PRESSURE AND AT A TEMPERATURE OF 210 DEGREES C., REACHING A YIELD OF 200 TONS AN HOUR; A SECOND ZONE IS BETWEEN 2,300 AND 2,632 M, AT WHICH DEPTH QUATERNARY FLUVIAL SANDS AND LACUSTRINE MUDS LIE ON GRANTIC ROCK OF THE CRETACEOUS BASEMENT. THE M-3 WELL IS LOCATED ON A BLOCK(HORST), ADJACENT TO AN EXTRAORDINARY VERTICAL SINKING EAST OF THE SAN JACINTO FAULT. THE THERMAL ACTIVITY SEEMS TO ORIGINATE FROM MAGMA OF INTERMEDIATE COMPOSITION, LYING AT GREAT DEPTH.

GEOTHERMAL STUDIES/MEXICO/STEAM/WELLS/VOLCANOES/MAGMATIC WATER

=IDENTIFIERS:/BAJA CALIFORNIA/CERRO PRIETO FIELD

3

ANONYMOUS

1970

GEOTHERMAL GROWING AS A POWER SOURCE.

ELECTRICAL WORLD 173(25):32-34.

DISCUSSES EXPERIENCES OF JAPAN, US, AND USSR IN GEOTHERMAL ELECTRICAL POWER GENERATION. THE MAGMA MAX POWER CYCLE, RECENTLY DEVELOPED, USES HOT WATER FROM GEOTHERMAL WELLS TO FLASH ISOBUTANE IN A HEAT EXCHANGER FOR PROPULSION OF A TURBINE. KEEPING THE GEOTHERMAL WATER UNDER PRESSURE PREVENTS THE DEPOSITION OF IMPURITIES IN THE EQUIPMENT. THE EXPERIENCE OF PACIFIC GAS AND ELECTRIC INDICATES THAT ELECTRICAL POWER MAY BE ECONOMICALLY PRODUCED FROM GEOTHERMAL ENERGY.

GEOTHERMAL STUDIES/ELECTRIC POWER/THERMAL POWERPLANTS/COSTS/WELLS/
THERMAL WATER/HEAT EXCHANGERS/HYDROSTATIC PRESSURE

=IDENTIFIERS:/ISOBUTANE/IMPURITIES

BAKER, C.H., JR.

1968

THERMAL SPRINGS NEAR MIDWAY, UTAH.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 600-D:63-70.
ANAG(1969)J5178. SWRA W69-03568.

A GROUP OF THERMAL SPRINGS NEAR MIDWAY, UTAH, IS SURROUNDED BY A DEPOSIT OF CALCAREOUS TUSA THAT COVERS AN AREA OF ABOUT 4.5 SQUARE MILES AND LOCALLY IS AT LEAST 70 FEET THICK. THE SPRINGS INCLUDE BOTH FLOWING THERMAL SPRINGS AND HOT POTS, WHICH ARE SMALL POOLS OF WARM WATER OCCUPYING SHALLOW CRATERS IN THE TOPS OF CONICAL OR HEMISPHERICAL MOUNDS OF TUSA. EXTINCT HOT POTS (DRY CRATERS) AND SOLID MOUNDS OF TUSA AS MUCH AS 10 FEET HIGH ARE ALSO COMMON. WATER FROM THE FLOWING SPRINGS AND HOT POTS IS NOT HIGHLY MINERALIZED (THE TOTAL DISSOLVED SOLIDS RARELY EXCEEDS 2,000 MG/L), BUT IT IS SATURATED WITH RESPECT TO CALCIUM CARBONATE. SPRING WATER, OF METEORIC ORIGIN, ENTERS THE CARBONATE BEDROCK IN THE NEARBY WASATCH RANGE AND MOVES RAPIDLY THROUGH FRACTURES AND SOLUTION OPENINGS. THE GEOTHERMAL GRADIENT IN THE VICINITY OF MIDWAY IS ABNORMALLY HIGH, BUT REASONS FOR THE HIGH HEAT FLUX ARE NOT KNOWN. (AUTHOR).

THERMAL SPRINGS/UTAH/CRATERS/METEORIC WATER/THERMAL PROPERTIES

5

BARNEA, J.

1972

GEOTHERMAL POWER.

SCIENTIFIC AMERICAN 226(1):70-77. SWRA W72-04172.

THE PRESSURE ON WORLD ENERGY RESOURCES HAS GENERATED NEW INTEREST IN TAPPING GEOTHERMAL FIELDS, AND THIS HAS BEEN HEIGHTENED BY PROJECTS SHOWING THAT OTHER USEFUL PRODUCTS MAY BE OBTAINED IN ADDITION TO ELECTRIC POWER. DRY STEAM FIELDS PRODUCING ELECTRICAL POWER HAVE A CURRENT UPPER LIMIT OF 55 MEGAWATTS BECAUSE OF LIMITATIONS ON TURBINE SIZE. THEY MAY ALSO PRODUCE FRESH WATER DIRECTLY FROM STEAM CONDENSATION OR AS A CHEAP HEATING MEDIUM IN DISTILLATION PLANTS. WET STEAM FIELDS WILL ALSO HAVE A VARIETY OF USES BESIDES POWER PRODUCTION, THE TREND IN DEVELOPMENT OF SUCH FIELDS BEING TO ENGINEER MULTIPLE-USE INSTALLATIONS. ECONOMIC AND ENVIRONMENTAL IMPACT CONSIDERATIONS CONFIRM THE DESIRABILITY OF GEOTHERMALLY-PRODUCED POWER. IMPROVED EXPLORATION METHODS ARE YIELDING IMPORTANT NEW DISCOVERIES. INCLUDED ARE INFRARED PHOTOGRAPHS AND NON-TECHNICAL DIAGRAMS OF POWERPLANTS, HOUSE-HEATING, AND MULTIPURPOSE INSTALLATIONS.

GEOTHERMAL STUDIES/THERMAL POWERPLANTS/ELECTRIC POWER/STEAM/MULTIPLE-PURPOSE PROJECTS/CONDENSATION/RESOURCES DEVELOPMENT/EXPLORATION

=IDENTIFIERS:/DRY STEAM FIELDS

6

BARTON, D.B.

1970

CURRENT STATUS OF GEOTHERMAL POWER PLANTS AT THE GEYSERS, SONOMA COUNTY, CALIFORNIA, USA.

UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PAPER. 13 P. SWRA W71-11813.

ELECTRIC POWER IN COMMERCIAL QUANTITIES FROM GEOTHERMAL STEAM HAS BEEN PRODUCED AT THE GEYSERS, CALIF., SINCE 1960. FOUR STEAM TURBINE-GENERATORS HAVE BEEN INSTALLED WITH A TOTAL PRODUCTION CAPACITY OF 82,000 KW. TWO MORE UNITS OF 55,000-KW CAPACITY EACH ARE UNDER CONSTRUCTION AND MORE UNITS ARE PLANNED. FIFTY-TWO WELLS HAVE BEEN DRILLED, GREATLY ENLARGING THE KNOWN BOUNDARIES OF THE STEAM FIELD. ACTUALLY, THE BOUNDARIES OF THE FIELD HAVE NOT BEEN CLEARLY DETERMINED. SEVERAL STEP-OUT WELLS SOME DISTANCE FROM THE PRODUCTION AREAS HAVE BEEN SUCCESSFUL. THE EXISTING TURBINE-GENERATORS TAKE STEAM AT 350 DEGREES F. AND 80 OR 65 PSIG PRESSURE. THE NEW UNITS WILL USE STEAM AT 100 PSIG PRESSURE. THE STEAM FLOW IS GREATER THAN THE COOLING TOWER EVAPORATION, AND THE EXCESS WATER CONTAMINATED WITH AMMONIA, SULFIDES, AND BORON PRESENTS A DISPOSAL PROBLEM: INJECTION WELLS ARE BEING USED FOR DISPOSAL. THE STEAM SUPPLY IS SLIGHTLY SUPERHEATED AND CONTAINS AMMONIA, CARBON DIOXIDE, AND HYDROGEN SULFIDE. THESE PRESENT CORROSION PROBLEMS TO PLANT EQUIPMENT, BUT PROPER SELECTION OF MATERIALS HAS REDUCED CORROSION TO ACCEPTABLE LIMITS. THE 4 EXISTING UNITS ARE DESIGNED TO RUN AT CONSTANT LOAD UNATTENDED, OPERATING PERSONNEL ARE NORMALLY PRESENT DURING DAYTIME ONLY. (USBR)

GEOTHERMAL STUDIES/THERMAL POWERPLANTS/PIPELINES/WELLS/STEAM/ELECTRIC POWER/CALIFORNIA /CORROSION/DESIGN DATA/DRILLING/INJECTION WELLS / BRINE DISPOSAL

=IDENTIFIERS:/GEYSERS FIELD, CALIFORNIA/IMPURITIES/TURBOGENERATORS

7

BIROSEYE, H.S.

1969

GEOHERMAL POWER RESOURCES IN THE SOUTHWEST.

NEW MEXICO, BUREAU OF MINES AND MINERAL RESOURCES, CIRCULAR 101,
P.86-96.ANAG(1970)04953.

GEOHERMAL POWER PROSPECTING INCLUDES DETAILED GEOLOGIC MAPPING, GEOCHEMICAL SURVEYING (INASMUCH AS MUCH OF THE WATER IS DETECTABLE CHEMICALLY), AND GEOPHYSICAL SURVEYING (BY DETECTING ANOMALIES WITH VERY SENSITIVE HEAT-SENSITIVE DEVICES). THE GEOHERMAL AREAS OF THE WORLD ARE CONFINED TO VOLCANIC REGIONS WHICH HAVE UNDERGONE FAULTING. IN THE UNITED STATES, SUCH FAULT CONTROLLED AREAS ARE FOUND IN UTAH AND NEW MEXICO. IN UTAH, HYFERTHERMAL OCCURRENCES ARE, FOR THE MOST PART, IN PROXIMITY TO THE STATES NORTH-TRENDING FAULT SYSTEMS AND ARE CLOSELY RELATED TO CENOZOIC IGNEOUS ROCKS. HOT SPRINGS ARE COMMON IN NEVADA ALSO ALONG NORTH-TRENDING FAULT LINES. NUMEROUS THERMAL ANOMALIES OCCUR IN NEW MEXICO IN THE RIO GRANDE STRUCTURAL TROUGH, AND SOME IN SMALLER TROUGHS WEST OF THE RIO GRANDE.

GEOHERMAL STUDIES/SOUTHWEST U.S./EXPLORATION/UTAH/NEVADA/NEW MEXICO/
/FAULTS(GEOLOGIC)/HOT SPRINGS/GEOLOGIC INVESTIGATIONS

=IDENTIFIERS:/RIO GRANDE TROUGH

BIROSEYE, H.S.

1971

GEOTHERMAL POWER IN NEW MEXICO.

NEW MEXICO ACADEMY OF SCIENCE, BULLETIN, SPRING, 1971, P. 1-8.

THE GEOPHYSICAL FACTORS RESPONSIBLE FOR THE FORMATION OF GEOTHERMAL STEAM ARE BRIEFLY DISCUSSED. GEOTHERMAL STEAM MAY BE AN INTEGRAL PART OF THE PROCESS BY WHICH METALLIC DEPOSITS SUCH AS COPPER, LEAD, ZINC, GOLD, AND SILVER ARE FORMED. THE CHARACTERISTICS OF GEOTHERMAL AREAS ARE EXAMINED AND THE DIFFERENCES BETWEEN SATURATED AND DRY GEOTHERMAL SYSTEMS ARE POINTED OUT. THE LATTER IS TO BE PREFERRED BECAUSE OF ITS GREATER ECONOMIC VALUE AND LACK OF ENVIRONMENTALLY-DELETERIOUS BY-PRODUCTS. MAPS OF WORLDWIDE GEOTHERMAL AREAS AND NEW MEXICO HYPER-THERMAL AREAS ARE PRESENTED. OF THE ROUGHLY 60 KNOWN THERMAL AREAS IN NEW MEXICO, THE ONLY SYSTEMATIC DRILLING HAS BEEN IN THE VALLES CALDERA, A DRY STEAM FIELD OF POSSIBLY SEVERAL MILLION KW POTENTIAL. SIX OR SEVEN THERMAL PROSPECTS ALONG THE RIO GRANDE TROUGH ALSO APPEAR TO HAVE ECONOMIC POTENTIAL.

GEOTHERMAL STUDIES/THERMAL POWER/STEAM/NEW MEXICO/EXPLORATION/
DRILLING/MAPS/

=IDENTIFIERS:/DRY STEAM FIELDS/VALLE CALDERA/RIO GRANDE TROUGH

9

BIRMAN, J.H.

1969

GEOTHERMAL EXPLORATION FOR GROUND WATER.

GEOLOGICAL SOCIETY OF AMERICA, BULLETIN 80(4):617-630.
ANAG(1969)00762.

SINCE 1961, PRECISE GROUND-TEMPERATURE MEASUREMENTS HAVE BEEN MADE AT SHALLOW DEPTH IN A NUMBER OF GEOLOGICAL TERRANES AND CLIMATES. THE OBJECTIVE HAS BEEN TO INVESTIGATE THE EFFECTIVENESS OF SHALLOW GEOTHERMAL TECHNIQUES IN GEOLOGICAL EXPLORATION. THE THERMAL SENSORS USED ARE THERMISTORS INDIVIDUALLY CALIBRATED TO WITHIN .02 DEGREES CENTIGRADE. IT WAS FOUND THAT SHALLOW-EARTH TEMPERATURES CAN BE RELATED TO THE OCCURRENCE OF GROUND WATER. SHALLOW, MOVING GROUND WATER PRODUCES LOW TEMPERATURES AND LOW ANNUAL DRIFT RATES, DUE TO DAMPING OF THE ANNUAL TEMPERATURE WAVE. CONVERSELY, DRY SHALLOW BEDROCK, BECAUSE OF HIGHER CONDUCTIVITY AND LOWER SPECIFIC HEAT, PRODUCES RELATIVELY HIGHER TEMPERATURES AND HIGHER DRIFT RATES. OTHER PERMUTATIONS OF OBSERVED TEMPERATURE AND DRIFT RATE REFLECT INTERMEDIATE CONDITIONS OF BEDROCK AND GROUND-WATER DISTRIBUTION. AS A CASE STUDY, THE GEOTHERMAL SURVEY OF JOHNSON VALLEY IS DESCRIBED. THIS IS A CLOSED BASIN SYSTEM IN SOUTHERN CALIFORNIA, WHICH SHOWS A DIRECT RELATIONSHIP BETWEEN GROUND TEMPERATURE AND DEPTH TO WATER AS MEASURED IN WELLS.

GEOTHERMAL STUDIES/EXPLORATION/GROUNDWATER/SOIL TEMPERATURE/
CALIFORNIA/GEOLOGIC INVESTIGATIONS

=IDENTIFIERS:/JOHNSON VALLEY

10

BODVARSSON, G.

1970

EVALUATION OF GEOTHERMAL PROSPECTS AND THE OBJECTIVES OF GEOTHERMAL EXPLORATION.

GEOEXPLORATION 8(1):7-17.

THIS REVIEW LEANS HEAVILY ON THE AUTHOR'S EXPERIENCE IN ICELAND. IT IS FELT THAT THE MAIN FIELD CONDITIONS CHARACTERIZING HIGH-POWER GEOTHERMAL RESERVOIRS ARE: RESERVOIR TEMPERATURE, RESERVOIR VOLUME, RESERVOIR PERMEABILITY, AMOUNT OF RESERVOIR WATER, MAIN GROUNDWATER LEVEL, TYPE AND AMOUNT OF CHEMICAL IMPURITIES, DRILLABILITY, AND THE PRESENCE OF HIDDEN RESERVOIR. BECAUSE OF LOW TEMPERATURE AND PRESSURE, GEOTHERMAL STEAM IS ONLY ABOUT ONE-HALF AS EFFICIENT AS STEAM FROM FUEL IN PERFORMING MECHANICAL WORK. INDIRECT AND DIRECT METHODS OF GEOTHERMAL RESOURCE EXPLORATION ARE OUTLINED.

GEOTHERMAL STUDIES/EXPLORATION/STEAM/THERMAL POWER

=IDENTIFIERS:/ICELAND

11

BOWEN, R.G.

1971

ELECTRICITY FROM GEOTHERMAL, NUCLEAR, COAL SOURCES: AN ENVIRONMENTAL COMPARISON.

ORE BIN 33(11):197-209.

RECOGNIZING THAT WHILE THE PRODUCTION OF ELECTRICAL ENERGY IS GROWING RAPIDLY AND THAT THE GROWTH OF HYDROELECTRIC POWER GENERATION WILL SOON CEASE WHILE OTHER METHODS OF POWER GENERATION ARE UNDESIRABLE OR TOO FAR IN THE FUTURE, IT IS FELT THAT NUCLEAR (FISSION) REACTORS, COAL-FIRED GENERATORS, AND GEOTHERMAL PLANTS ARE THE LIKELY SOURCES OF ELECTRICAL POWER IN THE NEAR FUTURE. THE PROBABLE OR ACTUAL ENVIRONMENTAL IMPACT OF EACH OF THESE THERMAL SOURCES IS EVALUATED AND COMPARED WITH THE OTHERS FOR LAND, AIR, AND WATER. A DRY STEAM GEOTHERMAL PLANT IS THE ONLY TYPE OF THERMAL POWER PLANT THAT DOES NOT COMPETE WITH OTHER USES OF WATER. NOR DOES GEOTHERMAL POWER HAVE THE CYCLE OF MINING, MILLING, REFINING, ENRICHMENT, FABRICATION, REPROCESSING, AND WASTE STORAGE THAT IS INVOLVED IN THE PRODUCTION OF BOTH FOSSIL AND NUCLEAR FUELS. THIS SELF-CONTAINED ASPECT SEEMS TO CONVEY AN ECONOMIC ADVANTAGE TO DRY STEAM GEOTHERMAL POWER PRODUCTION WHICH IS BORNE OUT BY THE EXPERIENCE OF TWO PLANTS IN OPERATION.

ELECTRIC POWER/GEOTHERMAL STUDIES/ENVIRONMENTAL EFFECTS/STEAM/THERMAL POWERPLANTS/NUCLEAR POWERPLANTS/COALS/POWERPLANTS/COMPARATIVE BENEFITS

=IDENTIFIERS:/DRY STEAM FIELDS

12

BOWEN, R.G.

1972 A

GEOTHERMAL GRADIENT STUDIES IN OREGON.

ORE BIN 34(4):68-71

BECAUSE OF A LACK OF ECONOMIC INCENTIVES, AND BECAUSE OF THE COMPLEXITY OF THE CONDUCTIVITY MEASUREMENTS, NO HEAT FLOW MEASUREMENTS HAVE YET BEEN MADE IN OREGON. WHEREVER DRILL HOLES OCCUR, GEOTHERMAL GRADIENT MEASUREMENTS HAVE BEEN MADE OVER THE LAST FEW YEARS. IT IS RECOGNIZED THE GEOTHERMAL GRADIENTS DO NOT PRESENT AS ACCURATE A PICTURE OF GEOTHERMAL RESOURCE POTENTIAL AS DO HEAT-FLOW MEASUREMENTS. GRAPHS ARE PRESENTED OF GEOTHERMAL GRADIENTS MEASURED AT SIX SCATTERED POINTS IN THE EASTERN OREGON DESERT COUNTRY.

GEOTHERMAL STUDIES/OREGON/HEAT FLOW/BOREHOLES/MEASUREMENT/THERMAL PROPERTIES

13

BOWEN, R.G.

1972 B

GEOTHERMAL ACTIVITY IN 1971.

ORE BIN 34(1):12-14.

THE GEYSERS FIELD IN SONOMA COUNTY, CALIFORNIA, CONTINUES TO BE THE ONLY COMMERCIAL ELECTRICITY-PRODUCING AREA FROM GEOTHERMAL STEAM IN THE U.S. DURING THE YEAR, CAPACITY INCREASED FROM 86 TO 192 MEGAWATTS, AND WILL INCREASE ANOTHER 220 MEGAWATTS OVER THE NEXT TWO YEARS WHEN TWO NEW PACIFIC GAS AND ELECTRIC PLANTS ARE COMPLETED. EFFORTS OF THE FEDERAL GOVERNMENT IN CLASSIFYING GEOTHERMAL RESOURCE AREAS (KGRAS) AND IN ISSUING RULES AND REGULATIONS ON GEOTHERMAL RESOURCE EXPLOITATION, ARE DESCRIBED. VARIOUS COOPERATIVE COMMERCIAL VENTURES IN THE IMPERIAL-SALTON SEA AREA ARE LISTED.

GEOTHERMAL STUDIES/CALIFORNIA/GEYSERS/EXPLOITATION/THERMAL POWERPLANTS/STEAM

=IDENTIFIERS:/GEYSERS FIELD, CALIFORNIA/SALTON SEA/IMPERIAL VALLEY

14

BOWEN, R.G./GROH, E.A.

1971

GEOTHERMAL-EARTH S PRIMORDIAL ENERGY.

TECHNOLOGY REVIEW 74(1):42-48.

A GENERAL REVIEW ON GEOTHERMAL POWER WHICH DISTINGUISHES ITSELF FROM OTHER SIMILAR REVIEWS IN ITS CONSIDERATION OF THE ECONOMICS AND ENVIRONMENTAL EFFECTS OF GEOTHERMAL POWER. EXPLORATION COSTS, AMORTIZED AT 14 PERCENT PER YEAR FOR A ONE MILLION KW FIELD, WOULD BE ONLY 0.175 MILLS/KWH. EVERY INDICATION IS THAT GEOTHERMAL POWER COSTS WILL BE LESS THAN THAT PRODUCED BY COAL, NUCLEAR, AND EVEN HYDRO METHODS. GEOTHERMAL PLANTS DO NOT NEED A SUPPLEMENTAL SOURCE OF COOLING WATER, SO, SIGNIFICANTLY, GEOTHERMAL PLANTS, UNLIKE OTHER TYPES OF THERMAL PLANTS, DO NOT COMPETE WITH OTHER USERS OF FRESH WATER. IT IS ALSO FELT THAT THE POTENTIAL QUANTITY OF GEOTHERMAL ENERGY, WORLDWIDE, HAS BEEN UNDERESTIMATED IN THE PAST.

GEOTHERMAL STUDIES/THERMAL POWER /ENVIRONMENTAL EFFECTS/COSTS/
EXPLORATION/ECONOMICS/COMPARATIVE COSTS/COMPARATIVE BENEFITS

15

BRADBURY, J.J.C.

1971

THE ECONOMICS OF GEOTHERMAL POWER.

UNITED NATIONS NATURAL RESOURCES FORUM 1:46-54. SWRA W72-13092.

IN ORDER TO BE A VIABLE ENERGY SOURCE, GEOTHERMAL POWER MUST COMPETE SUCCESSFULLY WITH ALTERNATIVE ENERGY SOURCES SUCH AS NATURAL GAS, SOLID FUELS, HYDROELECTRIC POWER, AND NUCLEAR ENERGY. CONSEQUENTLY, BEFORE UNDERTAKING A GEOTHERMAL POWER PROJECT, IT IS NECESSARY TO HAVE THE BEST POSSIBLE ESTIMATES OF NOT ONLY PROBABLE EXPLORATION EXPENSES, BUT ALSO THE COSTS OF DEVELOPING BOTH WELL FIELDS AND POWER PLANTS. THE COST OF EXPLORATION DEPENDS ON SUCH FACTORS AS GEOLOGICAL STRUCTURE, HYDROLOGY, AND THE DEPTH AND TEMPERATURE OF THE PRODUCTION ZONE. PRODUCTION-DRILLING COSTS ARE A FUNCTION OF SEVERAL FACTORS, INCLUDING REGIONAL GEOLOGICAL CONDITIONS, ROCK PROPERTIES, DRILLING TECHNIQUES, WELL DESIGN, AND WELL DEPTH. THE COST OF A FLUID COLLECTION SYSTEM IN A GEOTHERMAL FIELD DEPENDS UPON SUCH FACTORS AS THE MASS FLOW, THE STEAM-WATER RATIO, AND INTERFERENCE BETWEEN ADJACENT WELLS. THE VARIABLE COSTS ASSOCIATED WITH STEAM SUPPLY ARE VERY SMALL AND CONSIST MAINLY OF WELL AND PIPELINE MAINTENANCE, WHICH TO A CERTAIN EXTENT IS A FUNCTION OF THE CORROSIVE NATURE OF THE GEOTHERMAL FLUID. THUS, THE ECONOMICS OF GEOTHERMAL POWER PLANTS ARE DOMINATED BY COMPARATIVELY HIGH FIXED CHARGES AND LOW VARIABLE COSTS. THE COSTS ASSOCIATED WITH EXPLORATION, DRILLING, AND OPERATING IN MANY PARTS OF THE WORLD ARE QUOTED.

GEOTHERMAL STUDIES/STEAM/VARIABLE COSTS/FIXED COSTS/OPERATING COSTS/
EXPLORATION/DRILLING/ECONOMICS/COSTS/COMPARATIVE COSTS

16

CALIFORNIA, STATE DEPARTMENT OF WATER RESOURCES

1970

GEOTHERMAL WASTES AND THE WATER RESOURCES OF THE SALTON SEA AREA.

SAME AS AUTHOR, BULLETIN 143-7. 123 P.

TO DATE, GEOTHERMAL RESOURCE DEVELOPMENT IN THE SALTON SEA AREA HAS BEEN CENTERED IN THE BUTTES THERMAL AREA WHERE 15 PILOT WELLS HAVE BEEN DRILLED. SUCH DEVELOPMENT HAS BEEN HINDERED BY OPERATIONAL AND DISPOSAL PROBLEMS RELATED TO THE HIGHLY CONCENTRATED BRINES. THIS REPORT EVALUATES THE RESOURCES OF THE AREA IN TERMS OF PRESENT ECONOMIC ASSETS AND FUTURE GEOTHERMAL OPERATIONS. ABOUT 40 MILLION AF UNDERLIE THE BUTTES THERMAL AREA, WHICH IS PART OF 3 BILLION AF UNDERLYING THE IMPERIAL VALLEY. POSTFLASH BRINE FROM A TYPICAL WELL CONTAINS OVER 300,000 TDS, AND THE WELL COULD PRODUCE ABOUT 500,000 TONS ANNUALLY. SINCE THE SALTON SEA IS ALREADY IN ADVERSE SALT BALANCE BECAUSE OF IRRIGATION TAILING INPUTS AND HIGH EVAPORATION RATES, IT IS RECOMMENDED THAT GEOTHERMAL WASTES SHOULD NOT BE DISCHARGED THERE.

GEOTHERMAL STUDIES/CALIFORNIA/BRINES/TEST WELLS/BRINE DISPOSAL/WASTE WATER DISPOSAL/THERMAL WATER

=IDENTIFIERS:/SALTON SEA/IMPERIAL VALLEY/IMPURITIES

CATALDI, R./FERRARA, G.C./STEFANI, G./TONGIORGI, E.

1969

CONTRIBUTION TO THE KNOWLEDGE OF THE GEOTHERMAL FIELD OF LARDERELLO (TUSCANY, ITALY). REMARKS ON THE CARBOLI AREA.

BULLETIN VOLCANOLOGIQUE 33(1):1-27. SWRA W72-05879.

THE DEVELOPMENT AND RESULTS OF GEOTHERMAL RESEARCH IN THE CARBOLI AREA, SOUTHERN LARDERELLO REGION, TUSCANY, ITALY ARE DESCRIBED. INDUSTRIAL EXPLOITATION OF ENDOGENOUS FLUIDS IN THE REGION BEGAN MORE THAN A CENTURY AGO. MANY THERMAL MANIFESTATIONS, SUCH AS HOT SPRINGS, FUMARoles, MUD POOLS, AND GAS EXHALATIONS, WHICH OCCURRED ON OR NEAR THE PERMEABLE MESOZOIC OUTCROPS, HAVE CEASED ACTIVITY. ROCK ALTERATIONS, ENCRUSTATIONS, AND TRAVERTINE DEPOSITS ARE EVIDENCE OF PAST ACTIVITY. SOME GAS(CO₂ AND H₂S) CONTINUES TO ESCAPE IN A FEW PLACES. BORIC ACID WAS PRODUCED FROM THE THERMAL WATERS DURING THE FIRST PERIOD OF INDUSTRIAL EXPLOITATION (1818-1904). SHALLOW HOLES WERE DRILLED TO INCREASE HOT WATER OUTFLOW ALONG FRACTURED CALCAREOUS LAYERS. LARGE AMOUNTS OF BORIC SALTS WERE BROUGHT UP BY THE STEAM. IN THE SECOND PERIOD OF INDUSTRIAL EXPLOITATION (1904-1925) GEOTHERMOELECTRICAL PRODUCTION BECOMES IMPORTANT IN ADDITION TO CONTINUED CHEMICAL PRODUCTS. ADOPTION OF EFFICIENT DRILLING TECHNIQUES RESULTED IN INCREASED USE OF STEAM FOR POWER. DEEPER WELLS WERE DRILLED INTO THE MESOZOIC COMPLEX WHERE OPTIMUM CONDITIONS EXIST FOR THE FORMATION AND USE OF STEAM. CHEMICAL PRODUCTION HAS ALMOST CEASED SINCE 1945 WHILE PRODUCTION OF ELECTRICITY WITH THE NATURAL STEAM HAS STEADILY INCREASED. (USGS)

GEOTHERMAL STUDIES/THERMAL WATER/STEAM/HEAT FLOW/HYDROGEOLOGY /
HYDROELECTRIC PLANTS/GEOLOGIC CONTROL/MESOZOIC ERA/LATENT HEAT/GEYSERS
/MUD/GASES/CARBON DIOXIDE/WELLS/THERMAL POWERPLANTS

=IDENTIFIERS:/ENDOGENOUS FLUIDS/LARDERELLO FIELD, ITALY

18

CATALDI, R./STEFANI, G./TONGIORGI, M.

1963

GEOLOGY OF LARDERELLO REGION (TUSCANY): CONTRIBUTION TO THE STUDY OF THE GEOTHERMAL BASINS. IN NUCLEAR GEOLOGY ON GEOTHERMAL AREAS SYMPOSIUM, SPOLETO, ITALY, SEPTEMBER 9-13, 1963, P. 1-32.

NATIONAL RESEARCH COUNCIL, NUCLEAR GEOLOGY LABORATORY OF PISA. SWRA W72-05881.

DETAILS ARE GIVEN IN GEOLOGICAL SECTIONS, MAPS, AND DESCRIPTIONS OF THE GEOTHERMAL BASINS, WITH PARTICULAR ATTENTION TO THE DRILLED AREAS OF MONTECERBOLI, LARDERELLO, CASTELNUENO, LAGO, LAGONI ROSSI, AND SERRAZZANO. MAJOR TECTONIC COMPLEXES ARE SUMMARIZED AND DESCRIPTIONS ARE GIVEN OF OUTCROPPING ROCKS WITH SPECIAL REGARD TO THEIR GEOHYDROLOGICAL SIGNIFICANCE. THREE OUTCROP STRUCTURES ARE DISTINGUISHED (NORTH TO SOUTH), WHICH FORM THERMALLY ANOMALOUS AREAS WHERE LITHOLOGIC AND TECTONIC CONDITIONS PERMIT METEORIC WATERS TO PERCOLATE THROUGH OUTCROPS OF PERMEABLE TERRAINS AND THEN DIP BENEATH IMPERMEABLE FORMATIONS. ABOUT 26 MILLION CUBIC METERS/YEAR IS THE MAXIMUM STEAM OUTPUT FROM BOREHOLES FOR A 2-YR PERIOD (1962-63). THIS REQUIRES THAT 40 PERCENT OF THE MEAN AVERAGE RAINFALL OF 1,250 MM / YEAR ON THE 34 SQUARE KILOMETER AREA OF ABSORPTION PENETRATE TO THE GROUNDWATER SYSTEM AND CIRCULATE TO DEPTHS NECESSARY TO FORM STEAM. (USGS)

GEOTHERMAL STUDIES/GEOLOGIC CONTROL/STEAM/THERMAL WATER/HEAT FLOW/HYDROGEOLOGY /WELLS/HYDROELECTRIC PLANTS/STRUCTURAL GEOLOGY/NATURAL RECHARGE/RAINFALL DISPOSITION/AQUIFER CHARACTERISTICS

=IDENTIFIERS:/GEOTHERMAL BASINS/LARDERELLO FIELD, ITALY

19

CORTI, R./MARIO, P.D./MONDOLFI, F.

1970

NEW TRENDS IN THE PLANNING AND DESIGN OF GEOTHERMAL POWERPLANTS.

UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF
GEOTHERMAL RESOURCES, PISA, 1970, PAPER. 21 P. SWRA W71-11815.

THE AMOUNT OF ENDOGENIC FLUID THAT CAN BE EXTRACTED FROM A DEVELOPED
GEOTHERMAL AREA IS RESTRICTED AND WILL DIMINISH IN TIME, ALTHOUGH AT A
SLOW RATE. TO COMPENSATE FOR THIS DECREASE AND TO IMPROVE
PRODUCTIVITY, THE AREA MUST BE EXPANDED BY DRILLING AT PROGRESSIVELY
MORE DISTANT SITES. ALMOST INVARIABLY, THE CHARACTERISTICS OF THE
STEAM JETS IN THESE AREAS ARE REMARKABLY DIFFERENT FROM THOSE AT THE
EXISTING SITE, AND SLOWLY EVOLVE BEFORE BECOMING STABILIZED. FOR THIS
REASON, DESIGN OF GEOTHERMAL POWERPLANTS IN ITALY HAS BEEN MODIFIED TO
PROVIDE ADAPTABILITY TO THESE CHANGING CONDITIONS. DECENTRALIZATION
IS PLANNED TO PROVIDE INSTALLATION ALMOST AT THE WELL-HEAD OF SMALL-
CAPACITY PRODUCTIVE JETS CAPABLE OF REMOTE CONTROL FROM A FEW PILOT
POWER STATIONS. THE TURBOGENERATORS USED ARE CAPABLE OF EXHAUSTING TO
THE ATMOSPHERE, HAVE EXTREMELY ELASTIC INTAKE CHARACTERISTICS, AND ARE
SIMPLE AND COMPACT TO FACILITATE TRANSFER AND OPERATIONAL CONTROL.
CONDENSATION TURBOGENERATOR COMPRESSOR UNITS PERMIT RAISING THE
THERMAL LEVEL OF THE HOT SPRING AT INTAKE AND, WHERE APPROPRIATE,
ENSURE ADAPTATION OF THE THERMAL LEVEL OF THE COLD SPRING OF THE CYCLE
TO THE CHARACTERISTICS OF THE ENDOGENIC FLUID TO OBTAIN OPTIMUM USE OF
THE WELLS-POWER STATION COMPLEX. (USBR)

GEOTHERMAL STUDIES/THERMAL POWERPLANTS/DESIGN DATA/DRILLING/PIPELINES
/TEMPERATURE/WELLS/STEAM/STEAM TURBINES/CONDENSERS(LIQUEFIERS) /
COMPRESSORS/POWERPLANTS

=IDENTIFIERS:/ENDOGENOUS FLUIDS/ITALY/TURBOGENERATORS/THERMAL ENERGY

20

CRAIG, H.

1966

ISOTOPIC COMPOSITION AND ORIGIN OF THE RED SEA AND SALTON SEA
GEOTHERMAL BRINES.

SCIENCE 154(3756)1544-1548.

DEUTERIUM AND OXYGEN-18 MEASUREMENTS SHOW THAT THE RED SEA AND SALTON SEA BRINES ARE THE RESULTS OF A SINGLE PROCESS, THE LEACHING OF SEDIMENTS BY SURFACE WATER CIRCULATING DOWNWARD TO A GEOTHERMAL RESERVOIR. THE SALTON SEA BRINE IS DERIVED FROM LOCAL PRECIPITATION BUT THE RED SEA BRINE ORIGINATES 1,000 M SOUTH OF ITS BASIN, ON THE SHALLOW SILL WHICH CONTROLS THE CIRCULATION OF THE RED SEA. ON THIS SILL SEA WATER PENETRATES A THICK EVAPORITE SEQUENCE TO A DEPTH OF 2,000 M, AND, DRIVEN BY ITS INCREASED DENSITY RELATIVE TO SEA WATER, FLOWS NORTHWARD TO EMERGE IN THE BRINEFILLED DEEPS.

BRINES/ISOTOPE STUDIES/DEUTERIUM/LEACHING/SEDIMENT TRANSPORT/
GEOTHERMAL STUDIES/THERMAL WATER/HYDROGEOLOGY

=IDENTIFIERS:/SALTON SEA/RED SEA

21

CRAIG, H.

1969

DISCUSSION [OF PAPER BY H. C. HELGESON, 1968 (Q.V.)]: SOURCE
FLUIDS FOR THE SALTON SEA GEOTHERMAL SYSTEM.

AMERICAN JOURNAL OF SCIENCE 267(2):249-255. ANAG(1969)00594.

THE PROPOSAL BY HELGESON [IBID., V. 266, NO.3, P. 129-166, 1968] THAT
THE SOURCE FLUID FOR THE SALTON SEA GEOTHERMAL BRINE WAS INTERSTITIAL
CONNATE COLORADO RIVER WATER IN THE SEDIMENTS IS EVALUATED
QUANTITATIVELY IN TERMS OF THE DYNAMICS OF THE GEOTHERMAL SYSTEM AND
THE ISOTOPIC COMPOSITION OF THE VARIOUS WATERS INVOLVED. NEITHER BATCH
NOR CONTINUOUS EVAPORATION PROCESSES OPERATING ON ORIGINAL
INTERSTITIAL WATER OF PRESENT DAY COLORADO RIVER COMPOSITION CAN
PRODUCE THE GEOTHERMAL BRINE CHARACTERISTICS PRESENTLY OBSERVED. THE
ISOTOPIC EVIDENCE INDICATES THAT THE SOURCE FLUID WAS METEORIC WATER
DERIVED FROM LOCAL PRECIPITATION AND CIRCULATING DOWNWARD THROUGH THE
SEDIMENTS. (AUTHOR)

GEOTHERMAL STUDIES/BRINES/METEORIC WATER/COLORADO RIVER/ISOTOPE
STUDIES

=IDENTIFIERS:/SALTON SEA

22

CROSBY, J.W.

1971

GEOTHERMAL EXPLORATION.

NORTHWEST CONFERENCE ON GEOTHERMAL POWER, 1ST, OLYMPIA, WASHINGTON, 1971, PAPER. 20 P. SWRA W72-00077.

EXPLORATION TECHNOLOGY FOR GEOTHERMAL SOURCES OF ENERGY IS IN ITS INFANCY. ORIGINAL DISCOVERIES OF GEOTHERMAL ENERGY HAVE BEEN BASED PRIMARILY ON SURFACE MANIFESTATIONS OF A DEEP ENERGY SOURCE. DESIGNATING AREAS FOR DETAILED EXPLORATION OF GEOTHERMAL POTENTIAL WHERE NO SURFACE EVIDENCE IS PRESENT IS A DEMANDING CHALLENGE TO THE EARTH SCIENTIST. DETAILED STUDIES OF REGIONAL GEOLOGY ARE LIKELY TO BE THE MOST PRODUCTIVE. THE BETTER KNOWN AND PARTIALLY PROVEN GEOPHYSICAL METHODS OF GEOTHERMAL INVESTIGATION DISCUSSED ARE: EARTH RESISTIVITY METHOD, SEISMIC METHODS, TEMPERATURE SURVEYS, INFRARED RADIATION, GRAVITY SURVEYS, MAGNETIC SURVEYS, AND CHEMICAL PROSPECTING. EXPLORATION TECHNIQUES MOST LIKELY TO PROVE APPLICABLE IN THE STATE OF WASHINGTON ARE SUGGESTED.

GEOTHERMAL STUDIES/INFRARED RADIATION/GRAVITY STUDIES/SEISMIC STUDIES /MAGNETIC STUDIES/EXPLORATION/HEAT FLOW/RESOURCES DEVELOPMENT/THERMAL POWER/HOT SPRINGS/GEOLOGIC INVESTIGATIONS/RESISTIVITY

DUTCHER, L.C./HARDT, W.F./MCYLE, JR., W.R.

1972

PRELIMINARY APPRAISAL OF GROUND WATER IN STORAGE WITH REFERENCE TO
GEOTHERMAL RESOURCES IN THE IMPERIAL VALLEY AREA, CALIFORNIA.

U.S. GEOLOGICAL SURVEY, CIRCULAR 649. 57 P. SWRA W72-11678.

IMPERIAL VALLEY, CALIFORNIA, OCCUPIES PART OF A DEEP SEDIMENT-FILLED STRUCTURAL BASIN THAT EXTENDS SOUTH FROM THE COACHELLA VALLEY IN CALIFORNIA TO THE GULF OF CALIFORNIA. BECAUSE OF THE EXTREMELY HIGH TEMPERATURES AT DEPTH THROUGHOUT THE BASIN AND AT RELATIVELY SHALLOW DEPTH IN AREAS OF ANOMALOUSLY HIGH HEAT FLOW, THE DEPOSITS ARE UNDERGOING METAMORPHISM. THE ACTIVE METAMORPHISM HAS CAUSED CHANGES IN THE ORIGINAL POROSITY AND PERMEABILITY OF THE ROCKS AND DEPOSITS. THE TOTAL USABLE AND RECOVERABLE WATER IS ESTIMATED TO BE 1.1 BILLION ACRE-FeET, OF WHICH ABOUT 200 MILLION ACRE-FeET IS AT A TEMPERATURE OF 150 C. OR GREATER. THE COMBINATION OF LOW WELL YIELDS, ENERGY COSTS IN EXCESS OF 100 DOLLARS PER ACRE-FOOT FOR LIFTS GREATER THAN 5,000 FEET, AND VERY HIGH COSTS OF WELLS WILL PROBABLY PREVENT PUMPING MOST OF THE ESTIMATED USABLE AND RECOVERABLE WATER. IF AS MUCH AS 1,000 FEET OF PUMPING LIFT WOULD BE ECONOMICALLY JUSTIFIED, ABOUT 100 MILLION ACRE-FeET OF WATER MIGHT BE RECOVERABLE FROM THE SHALLOW AQUIFERS. (USGS)

GROUNDWATER RESOURCES/GEOTHERMAL STUDIES/THERMAL WATER/USABLE STORAGE /CALIFORNIA/WATER COSTS/WATER QUALITY /SALINITY/WATER WELLS/AQUIFER CHARACTERISTICS /WATER YIELD/PUMPING/WATER UTILIZATION/GROUNDWATER RECHARGE/THERMAL POLLUTION

=IDENTIFIERS:/IMPERIAL VALLEY

24

FACCA, G. /TONANI, F.

1964

THEORY AND TECHNOLOGY OF A GEOTHERMAL FIELD.

BULLETIN VOLCANOLOGIQUE 27:143-189.

THIS IMPORTANT PAPER CONSIDERS THE MECHANISMS THAT CONTROL WATER EVAPORATION IN THE FORMATION AS A FUNCTION OF THE DIFFERENCE BETWEEN FORMATION PRESSURE AND WELL PRESSURE. IN AN OVERHEATED STEAM FIELD, THREE ELEMENTS MUST BE DISTINGUISHED: THE HEAT SOURCE, THE PERMEABLE PAYZONE, AND THE IMPERMEABLE CAPROCK. GEOLOGICALLY, THE GEOTHERMAL FIELD IS A TRAP FOR CONVECTION CURRENTS. THE DEPTH HAS GREAT INFLUENCE ON THE BEHAVIOR OF WATER WHICH IS TO PRODUCE OVERHEATED STEAM. THE BEST CONDITIONS ARE IN THE HIGHEST POINT OF THE RESERVOIR BECAUSE THERE THE HYDROSTATIC PRESSURE OF THE WATER IS THE LOWEST AND ITS TEMPERATURE NEAREST TO THE BOILING POINT. DEPTH, EVAPORATION VOLUME, AND PERMEABILITY OF THE FIELD ARE ALSO TREATED.

GEOTHERMAL STUDIES/STEAM/CONVECTION/EVAPORATION/PERMEABILITY/
HYDROSTATIC PRESSURE/TEMPERATURE/GEOLOGIC INVESTIGATIONS

25

FACCA, G. /TONANI, F.

1967

THE SELF-SEALING GEOTHERMAL FIELD.

BULLETIN VOLCANOLOGIQUE 30:271-273.

OPERATIVE FACTORS IN THE SELF-SEALING PROCESS ARE ANALYZED BECAUSE MANY OF THESE FACTORS ARE OF CONSIDERABLE IMPORTANCE IN GEOTHERMAL EXPLORATION. SEALING MAY BE ACCOMPLISHED BY HYDROTHERMAL DEPOSITION OF SILICA AND ARGILLIZATION.

GEOTHERMAL STUDIES/SEALANTS/EXPLORATION/HYDROTHERMAL STUDIES/
DEPOSITION (SEDIMENTS)/SILICA/CLAY MINERALS

26

FENNER, D./ KLARMANN, J.

1971

POWER FROM THE EARTH.

ENVIRONMENT 13(10):19-26,31-34.

THIS PAPER SURVEYS THE PRESENT CAPABILITIES OF GEOTHERMAL POWER AS A TECHNICALLY AND ECONOMICALLY VIABLE MEANS OF PRODUCING ELECTRIC POWER. THE MECHANISMS OF GENERATION AND POWER PRODUCTION ARE DIAGRAMMED AND REVIEWED IN A NON-TECHNICAL MANNER. THE ECONOMICS OF THE PROCESS ARE STILL RATHER UNCERTAIN, PARTLY DUE TO GREAT DIFFERENCES IN THE METHODS OF ESTIMATING COSTS IN EXISTING PLANTS. REVIEWED ARE COST OF EXPLORATION, WELL-DRILLING, POWER PLANTS, ENVIRONMENTAL POLLUTION, LAND, AND PIPELINES TO THE WELLHEAD. VARIOUS ESTIMATES OF WORLD GEOTHERMAL RESOURCES ARE BRIEFLY SURVEYED.

GEOTHERMAL STUDIES/ELECTRIC POWER/EXPLORATION/COSTS/WELLS/THERMAL POWERPLANTS/ENVIRONMENTAL EFFECTS/DRILLING/CONDENSATION

27

FERRARA, G.C./FERRARA, G./GONFIANTINI, R.

1963

CARBON ISOTOPIC COMPOSITION OF CARBON DIOXIDE AND METHANE FROM STEAM JETS OF TUSCANY. IN NUCLEAR GEOLOGY ON GEOTHERMAL AREAS SYMPOSIUM, SPOLETO, ITALY. SEPTEMBER 9-13, 1963, P. 275-282.

NATIONAL RESEARCH COUNCIL, NUCLEAR GEOLOGY LABORATORY OF PISA. SWRA W72-05880

STUDIES INVOLVING MEASUREMENTS OF THE ISOTOPIC COMPOSITION OF CARBON DIOXIDE AND METHANE CONTAINED IN STEAM JETS OF THE GEOTHERMAL FIELDS OF TUSCANY, ITALY ARE DESCRIBED. EXPERIMENTAL TECHNIQUES OF SAMPLING AND ANALYSIS ARE DISCUSSED. ISOTOPIC TEMPERATURE VALUES FOR THIS AREA ARE SIMILAR TO VALUES OBTAINED FOR THE GEOTHERMAL AREAS OF NEW ZEALAND AND FOR THE YELLOWSTONE PARK GEYSERS AND SPRINGS. ISOTOPIC EXCHANGE PROBABLY DOES OCCUR BETWEEN CO₂ AND CH₄ IN GEOTHERMAL AREAS. THE METHODS PRESENTED ARE BELIEVED TO BE USEFUL IN PROSPECTING GEOTHERMAL AREAS. (USGS)

GEOTHERMAL STUDIES/STEAM/CARBON DIOXIDE/METHANE/RADIOACTIVE DATING/
HEAT FLOW/LATENT HEAT/GASES/TEMPERATURE/PRESSURE HEAD/THERMODYNAMIC
BEHAVIOR

=IDENTIFIERS://ISOTOPIC EXCHANGE/STEAM JETS/ITALY

28

FOTIADI, E.E. ET AL

1970

GEOTHERMAL INVESTIGATIONS IN SOME REGIONS OF WESTERN SIBERIA.

TECTONOPHYSICS 10(1-3):95-101.

DATA ON HEAT FLOW AND POSSIBLE LOWER CRUSTAL BOUNDARY TEMPERATURES WERE OBTAINED FOR THE MOHO AREA OF THE WESTERN SIBERIAN LOWLAND. EFFORTS WERE MADE TO CORRELATE HEAT FLOW MEASUREMENTS WITH VARIOUS TOPOGRAPHIC, GEOLOGIC, OR TECTONIC FACTORS. IT WAS CONCLUDED THAT NO IMPORTANT EVIDENCE FOR SUCH CORRELATIONS WAS ESTABLISHED.

GEOTHERMAL STUDIES/HEAT FLOW/TEMPERATURE/GEOMORPHOLOGY/TERRAIN ANALYSIS

=IDENTIFIERS:/SIBERIA

29

FOURNIER, R.O. /MORGANSTERN, J.C.

1971

A DEVICE FOR COLLECTING DOWN-HOLE WATER AND GAS SAMPLES IN GEOTHERMAL WELLS.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 750-C:151-155. SWRA W71-13458.

A SAMPLING DEVICE WITH AN INTERNAL VOLUME OF ABOUT 500 MILLILITERS WAS DESIGNED TO COLLECT LIQUID AND GAS SAMPLES IN WELLS WHERE BOTH STEAM AND WATER ARE PRESENT AT TEMPERATURES UP TO ABOUT 280 DEGREES C. A LONG FLEXIBLE STAINLESS STEEL TUBE SERVES AS THE SUPPORT CABLE. THE SAMPLE DEVICE IS LOWERED IN THE OPEN POSITION AND FLUID FLOWS THROUGH IT DURING ITS DESCENT. CLOSURE IS ACCOMPLISHED BY NITROGEN GAS PRESSURE APPLIED FROM THE SURFACE THROUGH THE FLEXIBLE TUBE TO A PISTON AND PLUNGER WITHIN THE SAMPLE CHAMBER. CONTINUED APPLICATION OF NITROGEN GAS PRESSURE DURING WITHDRAWAL OF THE DEVICE PREVENTS LEAKAGE CAUSED BY CHANGING CONDITIONS OF TEMPERATURE AND PRESSURE. THE SAMPLING DEVICE HAS BEEN USED SUCCESSFULLY TO COLLECT WATER AND GAS SAMPLES FROM RESEARCH HOLES DRILLED IN HOT-SPRINGS AREAS OF YELLOWSTONE NATIONAL PARK, WYOMING. (USGS)

SAMPLING/WELLS/THERMAL WATER/GEOTHERMAL STUDIES/INSTRUMENTATION/STEAM /PRESSURE/WATER TEMPERATURE/DESIGN DATA/HOT SPRINGS

=IDENTIFIERS:/YELLOWSTONE NATIONAL PARK

30

FOURNIER, R.O./TRUESDELL, A.H.

1971

A DEVICE FOR MEASURING DOWN-HOLE PRESSURE AND FOR SAMPLING FLUIDS IN GEOTHERMAL WELLS.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 750-C:146-150. SWRA W71-13457.

A DOWN-HOLE PRESSURE GAGE AND SAMPLER USES LONG FLEXIBLE STAINLESS-STEEL TUBES TO MEASURE PRESSURES IN GEOTHERMAL WELLS BY BALANCING GAS PRESSURE IN THE TUBE AGAINST THE HYDROSTATIC PRESSURE EXTERNAL TO THE TUBE. IN WELLS WITH POSITIVE WELLHEAD PRESSURE, WATER SAMPLES MAY BE COLLECTED FROM ANY DESIRED DEPTH BY ALLOWING WATER TO FLOW UP THROUGH THE STEEL TUBE (PROVIDED BOILING DOES NOT OCCUR DURING ASCENT). (USGS)

PRESSURE MEASURING INSTRUMENTS/SAMPLING/HYDROSTATIC PRESSURE/WELLS/
INSTRUMENTATION/GEOTHERMAL STUDIES/THERMAL WATER/STEAM/PIEZOMETERS/
DESIGN DATA

31

GARRISON, L.E.

1972

GEOTHERMAL STEAM IN THE GEYSERS-CLEAR LAKE REGION, CALIFORNIA.

GEOLOGICAL SOCIETY OF AMERICA, BULLETIN 83(5):1449-1468. SWRA
W72-14351.

DRY, SUPERHEATED NATURAL STEAM FROM WELLS IN THE MAYACMAS MOUNTAINS, NORTH-CENTRAL CALIFORNIA COAST RANGES IS USED TO GENERATE ELECTRICAL POWER. THE SOURCE OF THE HEAT IS A SHALLOW INTRUSIVE MAGMA BODY EMPLACED IN QUATERNARY TO HOLOCENE TIME. MAGMATIC HEAT IS TRANSMITTED THROUGH THE LARGELY IMPERMEABLE COUNTRY ROCK BY CONDUCTION. CONVECTIONAL HEATING TAKES PLACE IN ZONES OF PERMEABILITY AND POROSITY CAUSED BY FAULTING AND SHEARING. MOST OF THE THERMAL FLUID IS DERIVED FROM METEORIC WATER, BUT SOME IS PROBABLY DERIVED FROM THE MAGMA. IN THE EXPLOITED PART OF THE SYSTEM THE FLUID IS IN THE VAPOR STATE. THIS CONTROLS THE TEMPERATURE AND PRESSURE REGIME; RESERVOIR PRESSURES ARE LOWER THAN HYDROSTATIC PRESSURES IN A LIQUID-DOMINATED SYSTEM. GENERATION CAPABILITY WAS 182,000 KWH IN 1971, AND A CAPABILITY OF MORE THAN 600,000 KWH IS PROJECTED FOR 1975. (USGS)

GEOTHERMAL STUDIES/CALIFORNIA/STEAM/THERMAL POWER/HEAT FLOW/GEYSERS/
THERMAL WATER/WATER VAPOR/GEOPHYSICS/AQUIFER CHARACTERISTICS/THERMAL
WATER

=IDENTIFIERS:/GEYSERS FIELD, CALIFORNIA

GEOTHERMICS

1972

A NEW STEAM WELL IN THE TRAVALE GEOTHERMAL AREA (TUSCANY, ITALY).

GEOTHERMICS 1(1):41. 1972. SWRA W72-11467.

ON JANUARY 7, 1972, TRAVALE 22 WELL BLEW OUT WITH AN ENORMOUS OUTPUT OF FLUID (ABOUT 450 TONS/HR). THE WELL WAS DRILLED IN A GEOTHERMAL BASIN LOCATED TO THE EAST OF THE GEOTHERMAL BASIN OF LARDERELLO (ITALY). DRILLING STARTED ON OCTOBER 28, 1971 AND FINISHED ON JANUARY 4, 1972. THE TOTAL DEPTH OF THE WELL IS 688 M; THE WELL REACHED THE MAIN RESERVOIR (TRIASSIC ANHYDRITES AND BRECCIATED MAGNESIAN LIMESTONES) AT A DEPTH OF 642 M. AFTER DRILLING, PRESSURE AND TEMPERATURE MEASUREMENTS WERE CARRIED OUT IN THE WELL WITH AN AMERADO APPARATUS. AT THE WELL BOTTOM THE PRESSURE WAS 64.7 AT A (KG/SQ CM ABSOLUTE) AND THE TEMPERATURE ROSE TO 245 DEGREES C. IN 52 HOURS, WHILE IT WAS 135 DEGREES C. JUST TWO HOURS AFTER THE END OF DRILLING. THE BLOW-OUT OCCURRED 15 HOURS LATER. (USGS)

GEOTHERMAL STUDIES/THERMAL WATER/STEAM/WELLS/DRILLING/THERMAL STRESS/
/TEMPERATURE/PRESSURE/GASES

=IDENTIFIERS://ITALY

GERDES, R.H.

1968

MEETING TOMORROW'S ELECTRIC POWER NEEDS--NEW METHODS, NEW CONCEPTS.

WORLD POWER CONFERENCE, AUGUST 1968, PAPER. 19 F. SWRA W69-03770.

THE UNITED STATES ELECTRIC POWER INDUSTRY MUST INCREASE 6-FOLD BY THE YEAR 2,000 TO MEET THE EXPECTED GROWTH IN ELECTRIC ENERGY USE. TO ASSURE THE SOUNDTEST POSSIBLE BASIS FOR THE CONTINUED GROWTH OF THE INDUSTRY, NEW METHODS AND CONCEPTS FOR POWER GENERATION ARE BEING INVESTIGATED. NUCLEAR POWER IS DOMINATING THE INDUSTRY'S PLANS FOR NEW GENERATION, AND NEW METHODS ARE BEING DEVELOPED. NUCLEAR MAGNETOHYDRODYNAMIC (MHD) GENERATORS MAY REQUIRE EXTENSIVE DEVELOPMENT IN REACTORS. FOSSIL-FUELED MHD GENERATORS MAY BE CLOSE TO REALITY AND APPEAR ECONOMICALLY ATTRACTIVE FOR PEAKING. ELECTROGASDYNAMIC (EGD) GENERATORS WOULD REQUIRE VIRTUALLY NO COOLING WATER AND, THEORETICALLY, SHOULD HAVE HIGH THERMAL EFFICIENCIES, BUT THE APPLICATION OF EGD GENERATORS TO POWER SYSTEMS AWAITS THE DEVELOPMENT OF AN EFFICIENT EGD GENERATOR. GEOTHERMAL GENERATION USING NATURAL STEAM FROM WELLS IS AN EXCELLENT POWER SOURCE IN THOSE LIMITED AREAS WHERE IT IS AVAILABLE. THE UNITED STATES ELECTRIC POWER INDUSTRY IS CONFIDENT THAT IT CAN PROVIDE RELIABLE LOW-COST ELECTRICITY TO MEET THE GROWING NEEDS OF SOCIETY WITH THE METHODS DISCUSSED AND WITH METHODS NOT YET CONCEIVED. (USBR)

ELECTRIC POWER/PEAK POWER/THERMAL POWER/ELECTRIC POWER DEMAND/
GENERATORS/COSTS/FORECASTING/THERMAL POWERPLANTS/COMPARATIVE BENEFITS/
/NUCLEAR ENERGY/MAGNETIC FIELDS/NUCLEAR POWERPLANTS/FOSSIL FUELS

=IDENTIFIERS:/THERMOELECTRIC GENERATORS/MAGNETOHYDRODYNAMIC GENERATORS
/ELECTROGASDYNAMIC GENERATORS

GINSBURG, G.D.

1969

HYDROGEOLOGY OF THE NORTHERN YENISEY REGION (GIDROGEOLOGIYA YENISEYSKOGO SEVERA).

NAUCHNO-ISSLEDOVATEL SKIY INSTITUT GEOLOGII ARKTIKI, LENINGRAD,
SBORNIK STATEY FO GIDROGEOLOGII I GEOTERMII, NO. 1, 136 P. SWRA
W72-03063.

THIS COLLECTION OF 17 PAPERS IS DEVOTED TO A STUDY OF THE HYDROGEOLOGY AND GEOTHERMAL CONDITIONS OF THE LOWER YENISEY REGION, WHICH INCLUDES THE TAIMYR NATIONAL DISTRICT, THE UST -YENISEY ARTESIAN BASIN, THE ANABAR HYDROGEOLOGICAL MASSIF, THE NORTHWEST PART OF THE TUNGUSKA ARTESIAN BASIN, AND THE TURUKHANSK AND KHANTAYKA HYDROGEOLOGICAL REGIONS. A WIDE RANGE OF PROBLEMS IS EXAMINED: (1) GROUNDWATERS OF THE UST -YENISEY BASIN, (2) MINERAL WATERS OF THE NORILSK REGION, (3) BRINES OF THE TURUKHANSK REGION, (4) TEMPERATURE OF THE PERENNIALY FROZEN ROCKS OF NORTHWEST SIBERIA, THE MIDDLE OB REGION, AND THE TAIMYR DEPRESSION, (5) PERMAFROST AND ITS RELATION TO TECTONIC STRUCTURES IN THE UST -YENISEY BASIN, (6) TECTONIC STRUCTURES AND THEIR IMPORTANCE IN THE HEAT DISTRIBUTION OF ROCKS IN THE NORTHWEST REGIONS OF THE SIBERIAN PLATFORM, AND (7) ROLE OF TECTONIC FRACTURING IN THE FORMATION OF TALIKS (THAWED AREAS WITHIN THE PERMAFROST) IN THE TALNAKH AND OKTYABR SKOYE DEPOSITS. A NUMBER OF METHODS ARE GIVEN FOR FINDING THE MINERAL AND ENERGY RESOURCES OF THE AREA: (1) A HYDROGEOCHEMICAL METHOD OF PROSPECTING FOR ORE DEPOSITS IN THE NORILSK REGION, (2) A HYDROCHEMICAL METHOD OF SEARCHING FOR COPPER AND NICKEL SULFIDE DEPOSITS IN THE NORTHWEST PART OF THE SIBERIAN PLATFORM, AND (3) A CAPILLARY-LUMINESCENCE METHOD OF ANALYZING WATER-DISSOLVED ORGANIC MATTER IN ESTIMATING THE OIL AND GAS RESERVES OF LOCAL STRUCTURES. THE CONCLUDING PAPER EXAMINES THE FORMATION OF CRYSTAL HYDRATES OF NATURAL GASES IN THE EARTH'S INTERIOR AND THE POSSIBLE GEOCHEMICAL AND HYDRODYNAMIC CONSEQUENCES OF THIS PROCESS. THE TEXT MATERIAL IS INTENDED FOR USE BY GEOLOGISTS, HYDROGEOLOGISTS, GEOCHEMISTS, AND GLACIOLOGISTS. (USGS)

HYDROGEOLOGY/GEOTHERMAL STUDIES/BOREHOLE GEOPHYSICS/GEOCHEMISTRY /
PERMAFROST /DRILLING/WATER TYPES/WATER ANALYSIS/WATER CHEMISTRY/
GROUNDWATER/MINERAL WATER/SPRINGS/BRINES/SALINITY/ROCKS/METALS/
TEMPERATURE/PRESSURE/HYDRATE PROCESSES /GLACIOLOGY/NICKEL/ZINC

=IDENTIFIERS:/USSR/SIBERIA/MINERALIZATION/TECTONICS/ORE DEPOSITS/
AUREOLES

GODWIN, L.H./HAIGLER, L.B./RIOUX, R.L./WHITE, D.E./MUFFLER, L.J.P.

1971

CLASSIFICATION OF PUBLIC LANDS VALUABLE FOR GEOTHERMAL STEAM AND ASSOCIATED GEOTHERMAL RESOURCES.

U.S. GEOLOGICAL SURVEY, CIRCULAR 647. 18 P. SWRA W72-00096.

THE CLASSIFICATION STANDARDS ARE PRESENTED FOR DETERMINING WHICH FEDERAL LANDS ARE CLASSIFIABLE AS GEOTHERMAL STEAM AND ASSOCIATED GEOTHERMAL RESOURCES LANDS UNDER THE GEOTHERMAL STEAM ACT OF 1970. THE CONCEPT OF A GEOTHERMAL RESOURCES PROVINCE IS ESTABLISHED FOR CLASSIFICATION OF LANDS FOR THE PURPOSE OF RETENTION IN FEDERAL OWNERSHIP OF RIGHTS TO GEOTHERMAL RESOURCES UPON DISPOSAL OF FEDERAL LANDS. A GEOTHERMAL RESOURCES PROVINCE IS DEFINED AS AN AREA IN WHICH HIGHER THAN NORMAL TEMPERATURES ARE LIKELY TO OCCUR WITH DEPTH AND IN WHICH THERE IS A REASONABLE POSSIBILITY OF FINDING RESERVOIR ROCKS THAT WILL YIELD STEAM OR HEATED FLUIDS TO WELLS. THE DETERMINATION OF A KNOWN GEOTHERMAL RESOURCES AREA IS MADE AFTER CAREFUL EVALUATION OF THE AVAILABLE GEOLOGIC, GEOCHEMICAL, AND GEOPHYSICAL DATA AND ANY EVIDENCE DERIVED FROM NEARBY DISCOVERIES, COMPETITIVE INTERESTS, AND OTHER INDICIA. THE INITIAL CLASSIFICATION REQUIRED BY THE GEOTHERMAL STEAM ACT OF 1970 IS PRESENTED. (USGS)

LAND CLASSIFICATION/PUBLIC LANDS/FEDERAL JURISDICTION/GEOTHERMAL STUDIES/STEAM/HOT SPRINGS/THERMAL SPRINGS/LEGAL ASPECTS/WATER LAW/ GROUNDWATER/DOCUMENTATION

=IDENTIFIERS:/GEOTHERMAL STEAM ACT, 1970.

36

GOLDSMITH, M.

1971

GEOTHERMAL RESOURCES IN CALIFORNIA—POTENTIALS AND PROBLEMS.

CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, ENVIRONMENTAL QUALITY LABORATORY, EQL REPORT 5. 45 P. NSF GI-29726. SWRA W72-10550.

THE TECHNOLOGY, COST AND POTENTIAL OF GEOTHERMAL RESOURCES IN CALIFORNIA ARE EXAMINED. THE TWO FORMS IN WHICH THE NATURE OF THE GEOTHERMAL RESOURCE MANIFESTS ITSELF ARE DRY STEAM AND VERY HOT WATER IN THE GROUND. THE PER MEGAWATT INVESTMENT IN A GEYSER'S GEOTHERMAL PLANT IS SUBSTANTIALLY LESS THAN THAT FOR A MODERN FOSSIL PLANT AND FUEL, AND OPERATING COSTS ARE ABOUT 85 PERCENT OF THOSE FOR A MODERN FOSSIL PLANT. ENVIRONMENTAL EFFECTS OF A GEOTHERMAL POWER PLANT INCLUDE INTRUSION OF AN INDUSTRIAL OPERATION INTO NON-INDUSTRIAL AREAS, DISCHARGE OF SURPLUS HOT WATER WHICH MAY BE HIGH IN MINERAL CONTENTS, LAND SUBSIDENCE, SEISMIC ACTIVITY AND WELL BLOWOUT. NOXIOUS GASES ARE OFTEN A BY-PRODUCT OF GEOTHERMAL WELLS. THE NON-CONDENSABLE GASES CONSTITUTE FROM 0.2 TO 1.8 PERCENT OF THE STEAM FLOW AT THE GEYSERS. PRESENT GEOPHYSICAL EVIDENCE INDICATES THAT THE POSSIBILITY FOR SUPPLEMENTING SOUTHERN CALIFORNIA ELECTRIC GROWTH OVER THE NEXT 10 OR 20 YEARS MIGHT BE MET BY THE GEOTHERMAL RESOURCES OF THE IMPERIAL VALLEY.

THERMAL POWERPLANTS/COSTS/ENVIRONMENTAL EFFECTS/CALIFORNIA/
DESALINATION/COOLING TOWERS/HEATED WATER/LAND SUBSIDENCE/SEISMIC WAVES
/AIR POLLUTION/GEOTHERMAL STUDIES/RESOURCES DEVELOPMENT/GEYSERS/STEAM

=IDENTIFIERS://IMPERIAL VALLEY/DRY STEAM FIELDS/IMPURITIES

37

GRISCOM, A./MUFFLER, L.J.P.

1971

AEROMAGNETIC MAP AND INTERPRETATION OF THE SALTON SEA GEOTHERMAL AREA, CALIFORNIA.

U.S. GEOLOGICAL SURVEY, GEOPHYSICAL INVESTIGATIONS MAP GP 754.

SCALE: 1/62,500.

GEOTHERMAL STUDIES/MAAPS/MAGNETIC STUDIES/REMOTE SENSING/AERIAL PHOTOGRAPHY/CALIFORNIA

=IDENTIFIERS:/SALTON SEA

38

HAAS, J.L., JR.

1971

THE EFFECT OF SALINITY ON THE MAXIMUM THERMAL GRADIENT OF A HYDROTHERMAL SYSTEM AT HYDROSTATIC PRESSURE.

ECONOMIC GEOLOGY 66(6):940-946. SMRA W72-07064.

THE TEMPERATURE-DEPTH RELATIONS WERE CALCULATED FOR AN OPEN VEIN SYSTEM WHERE THE LIQUID IS EVERYWHERE VIRTUALLY AT THE BOILING POINT FOR THE CONFINING HYDROSTATIC PRESSURE. THE PRESSURE AT THE TOP OF THE OPEN SYSTEM WAS TAKEN AS 1 ATM. THE EFFECT OF SALINITY ON THE TEMPERATURE-DEPTH RELATION WAS CALCULATED BY A MATHEMATICAL MODEL. SUCH DATA MIGHT BE USEFUL IN MANY APPLICATIONS INCLUDING THE STUDY OF BRINE BEHAVIOR IN GEOTHERMAL AREAS WHICH MAY CONTAIN COMPOSITIONAL STRATIFICATION. THE AVAILABLE DATA FOR NA-CA-K-CL BRINE WHICH IS FOUND NATURALLY IN THERMAL SPRINGS AND IN FLUID INCLUSIONS IN ORE MINERALS. FROM THE DATA PRESENTED, IT IS POSSIBLE TO ESTIMATE THE MAXIMUM DEPTH BELOW THE WATER AT WHICH A CRYSTAL GREW IF THE INCLUSIONS IN THE CRYSTAL INDICATED THERE WAS BOILING AT THE TIME OF GROWTH.

TEMPERATURE/SALINITY/HYDROSTATIC PRESSURE/BRINES/PHYSICO-CHEMICAL PROPERTIES/GEOTHERMAL STUDIES/SODIUM/CALCIUM/CHLORIDES/POTASSIUM/BOILING/CRYSTAL GROWTH/MATHEMATICAL MODELS/THERMAL PROPERTIES

39

HAIGLER, L.B.

1969

GEOTHERMAL RESOURCES. IN MINERAL AND WATER RESOURCES OF ARIZONA.

ARIZONA BUREAU OF MINES, BULLETIN 180:575-580.

DISCUSSES VERY BRIEFLY LOCATION OF KNOWN THERMAL SPRINGS AND WELLS,
WITH SPECIAL ATTENTION TO THE CERRO PRIETO FIELD IN BAJA CALIFORNIA.
THERE IS A PARAGRAPH ON WASTE DISPOSAL. MAPS, BIBLIOGRAPHY.

WASTE WATER DISPOSAL/THERMAL SPRINGS/WELLS/ARIZONA/GEOTHERMAL
STUDIES

=IDENTIFIERS:/BAJA CALIFORNIA/CERRO PRIETO FIELD

40

HAMMOND, A.L.

1972

GEOTHERMAL ENERGY: AN EMERGING MAJOR RESOURCE.

SCIENCE 177(4053):978-980.

THE EARTH'S HEAT IS A POTENTIALLY VALUABLE IF UNCONVENTIONAL SOURCE OF ENERGY THAT COULD BE USED TO GENERATE ELECTRICITY. GEOTHERMAL RESOURCES ARE LARGE AND CAN BE READILY EXPLOITED. THREE TYPES ARE UNDER EXAMINATION: STEAM, HOT WATER, AND HOT ROCK. TECHNICAL PROBLEMS REMAIN TO BE SOLVED, HOWEVER, AS WELL AS CONSIDERATION FOR ENVIRONMENTAL EFFECTS. THIS ARTICLE GIVES A BRIEF DESCRIPTION OF EXISTING LOCATIONS AND DEVELOPMENTS, AS WELL AS SOME ATTENTION TO NEW TECHNIQUES STILL IN THE EXPLORATORY STAGE, SUCH AS AT VALLE CALDERA IN NEW MEXICO. THE MOST LIKELY COURSE OF DEVELOPMENT APPEARS TO BE IN THE DIRECTION OF RAPID DEPLOYMENT OF POWER PLANTS DESIGNED TO USE STEAM SEPARATED FROM HIGH-TEMPERATURE WATER DEPOSITS. USE OF SECONDARY FLUIDS LIKE ISOBUTANE RATHER THAN STEAM TO DRIVE POWER TURBINES IS EXPECTED TO BE NECESSARY FOR LOW-TEMPERATURE WATER AND HOT ROCK SYSTEMS.

GEOTHERMAL STUDIES/ENERGY/INJECTION WELLS/STEAM/SUBSIDENCE/
EXPLORATION/ENVIRONMENTAL EFFECTS/BRINE DISPOSAL/HEATED WATER/
POWERPLANTS/THERMAL POWERPLANTS

=IDENTIFIERS:/GEYSERS FIELD CALIFORNIA/CERRO PRIETO FIELD/ISOBUTANE/
VALLE CALDERA/SALTON SEA

41

HARSHBARGER, J.W.

1972

OVERVIEW OF GEOTHERMAL RESOURCES POTENTIAL IN ARIZONA.

FIELD NOTES FROM THE ARIZONA BUREAU OF MINES 2(2):9-12.

INTENSIVE GEOLOGICAL, GEOPHYSICAL, EXPLORATION SURVEYS AND STUDIES OF THE POTENTIAL GEOTHERMAL RESOURCES IN ARIZONA ARE ACTIVELY UNDERWAY. DATA ON 25 WELLS AND SPRINGS IN LOCALITIES WHERE THERMAL WATERS OF 100 DEGREES F. OR GREATER ARE KNOWN, ARE PRESENTED. THERE ARE NO KNOWN GEOTHERMAL RESOURCES AREAS WHICH PRODUCE GEOTHERMAL STEAM IN ARIZONA, AND NO KNOWN BOREHOLES HAVE BEEN DRILLED TO EXPLORE THE POTENTIAL OF GEOTHERMAL ENERGY. A RESUME OF CONDITIONS RELATED TO POTENTIAL GEOTHERMAL RESOURCES IS GIVEN, WITH THE CONCLUSIONS: 1) THAT THERE ARE NO KNOWN SUCH AREAS IN ARIZONA, ALTHOUGH IN SOUTHERN ARIZONA THERE ARE MANY GEOLOGIC STRUCTURAL AND ROCK CHARACTERISTICS SIMILAR TO KNOWN GEOTHERMAL RESERVOIRS, 2) THAT THERE ARE NO SURFACE INDICATIONS OF STEAM LEAKAGE, BUT THAT THE OCCURRENCE OF THERMAL WATER NEAR FAVORABLE GEOLOGIC FEATURES SUGGESTS THE POTENTIAL OCCURRENCE OF GEOTHERMAL ENERGY, 3) THAT THE APPLICATION OF STUDY, IMAGINATION, AND DATA FROM BOREHOLE DRILLING PROGRAMS COULD LEAD TO SUCCESSFUL GEOTHERMAL DEVELOPMENT.

GEOTHERMAL STUDIES/EXPLORATION/ARIZONA/THERMAL SPRINGS/WELLS/STEAM/
BOREHOLE GEOPHYSICS/WELL DATA/THERMAL WATER/GEOLOGIC INVESTIGATIONS

42

HASE, H.

1971

SURFACE HEAT-FLOW STUDIES FOR REMOTE SENSING OF GEOTHERMAL RESOURCES.

JAPANESE SOCIETY OF PHOTOGRAMMETRY, JOURNAL 10(3):9-17.

NO ABSTRACT

GEOTHERMAL STUDIES/REMOTE SENSING/HEAT FLOW

=IDENTIFIERS:/JAPAN

43

HAYELAND, J.A.

1972

HELLPOWER.

ECOLOGY TODAY 2(1):37-39.

A POPULAR ACCOUNT OF GEOTHERMAL POWER, WITH AN OVERVIEW OF ITS USES AND POTENTIAL. THE AUTHOR EXPLAINS THE DIFFERENCE BETWEEN DRY AND WET STEAM, THE GEOLOGICAL PROCESSES THAT PRODUCE THERMAL WATER, AND INCLUDES BRIEF ACCOUNT OF ACTIVE FIELDS NOW IN PRODUCTION.

GEOTHERMAL STUDIES/STEAM/THERMAL WATER/LEGAL ASPECTS/RESOURCES DEVELOPMENT

44

HEAD, J.

1970

GEOTHERMAL ENERGY FOR GREENHOUSE HEATING.

ORE BIN 32(9):182-183.

ONE POSSIBLE USE OF GEOTHERMAL ENERGY IS IN GREENHOUSE AND SOIL HEATING, NOW BEING DONE IN SEVERAL NATIONS AROUND THE WORLD. THIS ARTICLE DESCRIBES THE COMMERCIAL GREENHOUSE TOMATO-GROWING OPERATION OF OREGON DESERT FARMS, INC., IN THE HIGH DESERT COUNTRY OF OREGON WHERE SUMMERS ARE HOT AND WINTERS COLD. TOMATOES ARE GROWN YEAR-ROUND BY TAPPING GEOTHERMAL HEAT AT 440 FEET BELOW THE SURFACE BY PUMPING COLD WATER INTO HEAT EXCHANGERS. THIS PROVIDES A CONSTANT 70 DEGREE TEMPERATURE WITHIN THE GREENHOUSE UNDER OUTSIDE CONDITIONS OF ZERO DEGREES WITH A 10-MILE PER HOUR WIND. THE GREENHOUSES ARE COOLED IN THE SUMMERTIME BY A SYSTEM OF EVAPORATIVE COOLING AND FANS.

GEOTHERMAL STUDIES/GREENHOUSES/OREGON/TOMATOES/HEAT EXCHANGERS

HELGESSON, H.C.

1968

GEOLOGIC AND THERMODYNAMIC CHARACTERISTICS OF THE SALTON SEA
GEOHERMAL SYSTEM.

AMERICAN JOURNAL OF SCIENCE 266(3):129-166.

THE SALTON SEA GEOHERMAL AREA OCCUPIES A RIFT VALLEY OF THE SAN ANDREAS FAULT SYSTEM IN SOUTHERN CALIFORNIA. THE GEOHERMAL RESERVOIR CONSISTS OF OVER 2000 FEET OF ARKOSIC SAND CONTAINING INTERSTITIAL CONCENTRATED SODIUM-CALCIUM-POTASSIUM CHLORIDE BRINES. NO STEAM IS PRESENT UNDERGROUND. THE SUBSURFACE TEMPERATURE EXCEEDS 300 DEGREES CENTIGRADE AT 3000 FEET. REACTION OF THE GEOHERMAL BRINES WITH THE ENCLOSING SEDIMENTS HAS PRODUCED EPIDOTE-AMPHIBOLITE METAMORPHIC FACIES AT DEPTHS AS SHALLOW AS 4000 FEET. SHALE OVERLIES THE SAND FROM THE SURFACE TO A DEPTH OF 2000 TO 3000 FEET AND INSULATES THE RESERVOIR. AS A RESULT, THE TEMPERATURE-DEPTH PROFILES BELOW ABOUT 3000 FEET APPROACH ADIABATIC GRADIENTS. THE CONDUCTIVE HEAT FLOW IN THE SHALE IS ABOUT 17×10^{-6} CALORIES PER CENTIMETER SQUARED PER SECOND. THERMAL CONVECTION OF PORE FLUIDS APPEARS TO BE THE PRIMARY MECHANISM OF HEAT TRANSFER IN THE RESERVOIR. THE HYDROSTATIC PRESSURE-DEPTH PROFILE IN THE GEOHERMAL AREA INDICATES A FLUID DENSITY OF ONE GRAM PER CUBIC CENTIMETER. THIS OBSERVATION REQUIRES THE TOTAL DISSOLVED SOLIDS CONCENTRATION IN THE PORE FLUIDS TO INCREASE WITH DEPTH PROPORTIONAL TO THE TEMPERATURE INCREASE TO ABOUT 3000 FEET. THE SALINITY AND TEMPERATURE OF THE PORE FLUIDS DECREASE OUTWARD FROM THE CENTER OF THE GEOHERMAL RESERVOIR. THE ENTHALPY OF THE BRINES IN THE RESERVOIR RANGES FROM 220 TO 275 CALORIES PER GRAM, WHICH IS 45 TO 90 CALORIES PER GRAM LESS THAN THE ENTHALPY OF PURE WATER AT EQUIVALENT TEMPERATURES AND PRESSURES. THE BRINES APPARENTLY FORMED BY EVAPORATION OF COLORADO RIVER WATER ORIGINALLY TRAPPED IN THE PORES OF THE RESERVOIR SANDS. (SEE ALSO CRAIG, 1969.)

GEOHERMAL STUDIES/CALIFORNIA/BRINES/COLORADO RIVER/THERMODYNAMIC
BEHAVIOR/HYDROSTATIC PRESSURE/ENTHALPY/THERMAL PROPERTIES/GEOLOGIC
INVESTIGATIONS

=IDENTIFIERS:/SALTON SEA

46

HENY, T.L. / WASSERBURG, G.C.

1971

HEAT FLOW NEAR MAJOR STRIKE-SLIP FAULTS IN CALIFORNIA.

JOURNAL OF GEOPHYSICAL RESEARCH 76(32):7924-7946.

SEVENTEEN HEAT-FLOW MEASUREMENTS WERE MADE IN CRYSTALLINE ROCK NEAR THE SAN ANDREAS, SAN JACINTO, AND GARLOCK FAULTS, CALIFORNIA, IN REGIONS REPRESENTATIVE OF SEVERAL LEVELS OF SEISMIC ACTIVITY. DATA FROM THESE MEASUREMENTS, TOGETHER WITH OTHER HEAT-FLOW DETERMINATIONS IN CALIFORNIA AND OFFSHORE ALONG THE CONTINENTAL BORDERLAND, DO NOT CLEARLY DEMONSTRATE THE EXISTENCE OF A HEAT-FLOW ANOMALY IN THE VICINITY OF THESE MAJOR FAULTS.

HEAT FLOW/CALIFORNIA/FAULTS(GEOLOGIC) /STRUCTURAL GEOLOGY/GEOLOGIC INVESTIGATIONS

47

HEYLUM, E.B.

1966

GEOTHERMAL POWER POTENTIAL IN UTAH.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY, SPECIAL STUDIES 14. 28 P. ANAG(1966)5298.

A BRIEF SUMMARY OF THE POTENTIAL FOR DEVELOPMENT OF GEOTHERMAL ENERGY. PREVIOUS WORK IN UTAH IS LISTED AND MENTION IS MADE OF EXPLORATION METHODS USED THROUGHOUT THE WORLD. THERMAL SPRING AREAS ARE GROUPED INTO THE WASATCH, WESTERN DESERT, SEVIER-SANPETE, PANGUITCH, HURRICANE, AND SNAKE VALLEY AREAS, ALL THWEST DIRECTIONS; SHORT DESCRIPTIONS ARE GIVEN OF EACH AREA INCLUDING PRINROUGHLY PARALLEL OR EN ECHELON AND TRENCING IN NORTH-SOUTH OR NORTHEAST/ SOUCIPAL WARM AND HOT SPRINGS. OIL, GAS, AND WATER WELLS WHICH HAVE PENETRATED WARM OR HOT WATER AT DEPTH ARE LISTED WITH DEPTH AND TEMPERATURES RECORDED; TEMPERATURES ARE GIVEN ALSO FOR A FEW MINES. AVAILABLE CHEMICAL ANALYSES OF HOT SPRING WATERS ARE INCLUDED. THE WASATCH AND WESTERN DESERT AREAS ARE THE MOST EXTENSIVE BUT THE LATTER OFFERS THE GREATER POSSIBLITY FOR DEVELOPMENT OF STEAM WELLS.

GEOTHERMAL STUDIES/UTAH/THERMAL POWER/STEAM/WELLS/EXPLORATION/THERMAL SPRINGS/TEMPERATURE/HOT SPRINGS/CHEMICAL ANALYSIS

48

HOLDREN, J./ HERRERA, P.

1971

ENERGY, A CRISIS IN POWER.

SIERRA CLUB, SAN FRANCISCO. 252 P.

A THOROUGH REVIEW OF THE PROBLEMS OF ENERGY, PARTICULARLY ELECTRICAL POWER, FROM THE POINT OF VIEW OF THE ENVIRONMENTALISTS. GEOTHERMAL POWER IS DISCUSSED IN A CHAPTER ON POSSIBLE IMPORTANT, NON-POLLUTING ENERGY SOURCES. SOME DOUBT IS CAST ON THE POTENTIAL IMPORTANCE OF THIS RESOURCE, BUT FUTURE RESEARCH IS URGED.

ENERGY/ELECTRIC POWER/ENVIRONMENTAL ENGINEERING/THERMAL POWER/
GEOTHERMAL STUDIES

49

HUBBERT, M.K.

1971

THE ENERGY RESOURCES OF THE EARTH.

SCIENTIFIC AMERICAN 224(3):60-70.

FROM THIS QUANTITATIVE SURVEY AND EVALUATION OF WORLD ENERGY RESOURCES, THE AUTHOR COMES TO THE CONCLUSION THAT WHILE THE FUTURE FOR FOSSIL FUELS IS NOT BRIGHT, THE POTENTIAL OF GEOTHERMAL POWER, WHICH HE ESTIMATES AT NO MORE THAN 60,000 MW/YEAR OVER THE NEXT FIFTY YEARS, IS HARDLY MORE SO.

ENERGY/THERMAL POWER/RESOURCES DEVELOPMENT/FOSSIL FUELS/FORECASTING

50

KIERSCH, G.A./CHATURVEDI, L.N.

1968

GEOLOGICAL STRUCTURE AND ITS EFFECT ON THE GEOTHERMAL HYDROLOGY OF
SOUTHWESTERN HREPPAR, ICELAND.

CORNELL WATER RESOURCES AND MARINE SCIENCES CENTER, OWRR PROJECT NO.
A-020-NY, 6 P. SWRA W69-J0309.

INVESTIGATIONS TO DATE INDICATE THE FOLLOWING RESULTS: (1) MOST OF
THE WATER AT BOILING TEMPERATURES OCCURRING AS HOT SPRINGS IN
SOUTHWESTERN HREPPAR IS METEORIC IN ORIGIN, (2) THE WATER CIRCULATES
THROUGH A SYSTEM OF FAULTS AND THROUGH PERMEABLE ZONES BETWEEN BASALT
FLOWS, THE WATER MOVES TO SEVERAL THOUSAND FEET BELOW THE SURFACE AND
IS HEATED BY ABNORMALLY HIGH GEOTHERMAL GRADIENT, (3) RISE OF THIS
HEATED WATER BACK TO SURFACE IS CARRIED OUT AGAIN THROUGH A SYSTEM OF
FAULTS WHICH SLOWLY ENLARGE INTO CONVECTION CONDUITS, AND (4) THE
LOCALIZATION OF HOT WATER IN THE FORM OF HOT SPRINGS IS CONTROLLED BY
A SYSTEM OF FAULTS WHICH ARE ALIGNED IN THREE MAJOR DIRECTIONS.

GEOLOGIC FORMATIONS/HOT SPRINGS/METEORIC WATER/GEOTHERMAL STUDIES/
THERMAL PROPERTIES/FAULTS(GEOLOGIC)

=IDENTIFIERS:/ICELAND

51

KOENIG, J.B.

1967

THE SALTON-MEXICALI GEOTHERMAL PROVINCE.

CALIFORNIA, DIVISION OF MINES AND GEOLOGY, MINERAL INFORMATION SERVICE 20(7):75-81.

DEVELOPMENT OF TWO REGIONS IN THE SALTON-MEXICALI GEOTHERMAL PROVINCE HAVE BROUGHT RENEWED INTEREST TO THE AREA. AT NILAND, IMPERIAL COUNTY, SODIUM AND CALCIUM CHLORIDES WILL BE PRODUCED BY MORTON, INTERANTIONAL, INC., WHILE THE MEXICAN FEDERAL ELECTRICITY COMMISSISION (CFE) WILL PRODUCE ELECTRICAL POWER. EACH WILL BE A SINGLE-PURPOSE OPERATION. MORTON WILL RECOVER THE SALTS BY A SOLAR EVAPORATION PROCESS. STEAM PRODUCED FROM THE WELLS WILL BE USED IN THE FINAL EVAPORATION PROCESS FOR NA₂CO₃. POST-FLASH BRINE RUNS AS HIGH AS 330,000 PPM, SO A REINJECTION WELL HAS BEEN CONSTRUCTED, ALTHOUGH THE POSSIBILITY OF CONTAMINATION OF GROUDWATER SUPPLIES CANNOT BE RULED OUT. RESULTS OF THE PUMPING TESTS IN THE WELLS AT CERRO PRIETO ARE DESCRIBED IN SOME DETAIL. THE RESIDUAL BRINES, SIMILAR IN COMPOSITION TO SEA WATER, WILL BE PIPED TO THE GULF OF CALIFORNIA. A REVIEW OF THE GEOLOGY OF THE REGION INDICATES THAT BOTH FIELDS WERE CREATED BY CRUSTAL THINNING AND ESTABLISHMENT OF CONVECTION CELLS FOR HEAT TRANSFER THROUGH WATER-SATURATED SEDIMENTS. IT IS CONCLUDED THAT FUTURE PROSPECTING FOR HEAT FIELDS IN THE PROVINCE MIGHT CONCENTRATE ON: HIGH GRAVITY ZONES, THICK IMPERMEABLE BEDS IN THE SHALLOW SUBSURFACE, HIGH PRESSURES AND HEAT FLUXES IN SHALLOW WELLS, AND SURFACE HEAT MANIFESTATIONS.

GEOTHERMAL STUDIES/CALIFORNIA/ELECTRIC POWER/BRINES/BRINE DISPOSAL/
INJECTION WELLS/HEAT TRANSFER/HEAT/SOLAR DISTILLATION/EVAPORATION/
EXPLORATION/GEOLOGIC INVESTIGATIONS

=IDENTIFIERS:/SALTON SEA/BAJA CALIFORNIA/CERRO PRIETO FIELD

KOENIG, J.B.

1970

GEOTHERMAL EXPLORATION IN THE WESTERN UNITED STATES. IN UNITED NATIONS SYMPOSIUM ON DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PROCEEDINGS (2)1. 23 P.

GEOTHERMICS, SPECIAL ISSUE, 2. SWRA W71-11612.

OVER 90 PERCENT OF THE GEOTHERMAL PHENOMENA IN THE U.S. ARE IN THE 13 WESTERN STATES, COMPRISING MORE THAN 1,000 WARM AND HOT SPRINGS AND FUMAROLE LOCALITIES. SOME 100 CAN BE CONSIDERED HYPER-THERMAL. AT LEAST 6 PRODUCIBLE FIELDS HAVE BEEN DISCOVERED: THE GEYSERS, CALIF; SALTON SEA, CALIF; CASA DIABLO, CALIF; BECHAME, NEV.; BRADY'S HOT SPRINGS, NEV.; AND YELLOWSTONE NATIONAL PARK, WYO. RESERVOIR BASE TEMPERATURES PROBABLY EXCEED 200 DEGREES C. AT THESE FIELDS. THE GEYSERS PRODUCE DRY STEAM, SALTON SEA PRODUCES BRINE, AND THE OTHERS PRODUCE HOT WATER. ONLY AT THE GEYSERS IS ELECTRIC POWER BEING GENERATED; 83,000 KW OF CAPACITY HAS BEEN INSTALLED AND FACILITIES FOR AN ADDITIONAL 110,000 KW ARE BEING CONSTRUCTED. MANY INSUFFICIENTLY EXPLORED AREAS AND MARGINAL FIELDS WARRANT ADDITIONAL DIRECTED EXPLORATION, INCLUDING: SURPRISE VALLEY, CALIF; THE CARSON SINK, NEV.; THE HIGH CASCADE RANGE IN CALIF, OREG, AND WASH; VALLE CALDERA, NEW MEXICO; PARTS OF THE ALEUTIAN ISLANDS, ALASKA; AND THE ISLAND OF HAWAII. AT LEAST TWO GEOTHERMAL PROSPECTS, CLEAR LAKE, CALIF, AND STEAMBOAT SPRINGS, NEV., HAVE BEEN ABANDONED BECAUSE OF PROBLEMS OF WASTE WATER DISPOSAL AND PLUGGING OF WELLS.(USBR)

GEOTHERMAL STUDIES/GEOLOGIC INVESTIGATIONS/TEMPERATURE/WARM SPRINGS/
THERMAL POWER/WELLS/STEAM/BRINES/DRILLING/HOT SPRINGS/EXPLORATION/
WASTE WATER DISPOSAL/CALIFORNIA

=IDENTIFIERS:/GEYSERS FIELD, CALIFORNIA /YELLOWSTONE NATIONAL PARK/
SALTON SEA/DRY STEAM FIELDS/VALLE CALDERA

53

KOENIG, J.B.

1971

GEOTHERMAL DEVELOPMENT.

GEOTIMES 16(3):10-12.

AN ACCOUNT OF THE 1970 UN SYMPOSIUM ON DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, HELD IN PISA, ITALY. DISCUSSIONS AROUND THE THEME OF THE SYMPOSIUM, STATED AS HOW CAN THE SPECIALIZED TECHNICAL KNOWLEDGE OF THE SYMPOSIUM PARTICIPANTS BE TRANSLATED INTO THE DEVELOPMENT OF GEOTHERMAL RESOURCES, ESPECIALLY IN UNDERDEVELOPED COUNTRIES, BROUGHT QUESTIONS OUT CONCERNING THE ECONOMIC FEASIBILITY OF A MULTIPLE-USE GEOTHERMAL PROJECT. IT WAS NOTED THAT TWO UNCERTAIN TECHNOLOGIES, DESALINATION AND GEOTHERMAL POWER GENERATION, WOULD BE COMBINED IN A HIGH-RISK VENTURE THAT WOULD TEND TO DOUBLE THE POSSIBILITY FOR FAILURE AND INCREASE INVESTOR HESITANCY. IT WAS APPARENT THAT GEOTHERMAL POWER GENERATION TO DATE DEPENDS ON THE USE OF STEAM, AND EXPLORATION HAS CENTERED ON DISCOVERY OF DRY-STEAM RESERVOIRS. A NEWLY-DESIGNED SYSTEM, USING ISOBUTANE AS THE HEAT EXCHANGING MEDIUM WAS DESCRIBED WHICH, IF SUCCESSFUL, COULD CHANGE RADICALLY THE COURSE OF GEOTHERMAL EXPLORATION AND SPUR DEVELOPMENT OF LOWER-ENTHALPY HOT-WATER SYSTEMS FOR POWER GENERATION. THE PAPER CONCLUDES WITH A TABLE OF EXISTING AND PROPOSED GEOTHERMAL POWER STATIONS, SHOWING 23 OPERATING, PLANNED, OR UNDER CONSTRUCTION IN 13 COUNTRIES, AND THEIR PROJECTED KW CAPACITY.

GEOTHERMAL STUDIES/RESOURCES DEVELOPMENT/THERMAL POWER /STEAM /
EXPLORATION /HEAT EXCHANGERS /COSTS /ENTHALPY /MULTIPLE-PURPOSE
PROJECTS

=IDENTIFIERS:/DRY STEAM FIELDS/ISOBUTANE

54

LAIRD, A.D.K.

1971

RANKING RESEARCH PROBLEMS IN GEOTHERMAL DEVELOPMENT.

U.S. OFFICE OF SALINE WATER RESEARCH AND DEVELOPMENT, PROGRESS REPORT
711. 33 P. OSW GRANT NO. 14-30-2635. SWRA W72-03777.

DISCUSSES RESEARCH PRIORITIES FOR ESTABLISHING FEASIBILITY OF DEVELOPING GEOTHERMAL RESOURCES IN THE IMPERIAL VALLEY. PRIORITIES IN ORDER OF DECREASING IMPORTANCE ARE RANKED: (1) BRINE CHEMISTRY--FIRST BECAUSE, IF SOME PECULIARITY OF BRINES REQUIRES COSTLY PROCESSING, THE DEVELOPMENT MAY BE PRECLUDED, (2) OVERALL BENEFITS--MUST BE ASSURED BEFORE DEVELOPMENT IS UNDERTAKEN, (3) CHOICE OF SYSTEM, (4) MARKETS, (5) RESERVOIR MANAGEMENT--NEEDED FOR PILOT PLANT PLANNING, (6) DEMONSTRATION-PLANT DESIGN, (7) TECHNOLOGICAL IMPROVEMENTS. EACH OF THE ABOVE TOPICS IS DISCUSSED IN DETAIL TOGETHER WITH THE PREDICTED INTERACTION OF THE VARIOUS PARAMETERS. THE IMPACT UPON AGRICULTURAL, INDUSTRIAL AND SOCIAL DEVELOPMENTS IS DISCUSSED ALONG WITH BENEFITS TO MUNICIPALITIES. THE ENVIRONMENTAL ASPECT IN TERMS OF POSSIBLE POLLUTION, LAND MISUSE, GEOLOGICAL DAMAGE, AND THE RESEARCH NECESSARY FOR THEIR CONTROL IS BRIEFLY EVALUATED. TWO POWER-WATER SCHEMES USING FLASHED GEOTHERMAL STEAM, AND ONE IN WHICH BOILING IS SUPPRESSED ARE DESCRIBED AND BRIEFLY ILLUSTRATED.

DESALINATION/DISTILLATION/GEOTHERMAL STUDIES/BRINE DISPOSAL/
CALIFORNIA/WATER POLLUTION SOURCE/BENEFITS/WATER SUPPLY/ENVIRONMENTAL
EFFECTS/PLANNING/STEAM/RESOURCES DEVELOPMENT

=IDENTIFIERS:/IMPERIAL VALLEY

55

LEAR, J.

1970

CLEAN POWER FROM INSIDE THE EARTH.

SATURDAY REVIEW 53(49):53-61. SWRA W71-08643.

A NON-TECHNICAL DISCUSSION OF GEOTHERMAL RESOURCES AND DEVELOPMENT. CLEARLY EMERGING FACTS OF INTEREST ARE THE VASTNESS OF GEOTHERMAL RESOURCE POTENTIALS IN BOTH THE U.S. AND THE ENTIRE WORLD, AND THE STATUS OF THE U.S. AS A LESS-DEVELOPED NATION IN RESEARCH AND DEVELOPMENT OF GEOTHERMAL RESOURCES, EVEN WITH RESPECT TO ITS NEIGHBOR MEXICO. POSSIBILITIES OF USING THE HEAT OF GEOTHERMAL WATERS FOR DESALINATION AND SUBSEQUENT DILUTION OF COLORADO RIVER WATERS ARE DISCUSSED. THE PAPER CONCLUDES WITH AN EXAMINATION OF THE DESIRABILITY OF CONTINUING ANNUAL INCREASES IN ENERGY CONSUMPTION IN THE U.S.

GEOTHERMAL STUDIES/RESOURCES DEVELOPMENT/DESALINATION/COLORADO RIVER/
ENERGY

56

MAHON, W.A.J./FINLAYSON, J.E.

1972

THE CHEMISTRY OF THE BROADLANDS GEOTHERMAL AREA NEW ZEALAND.

AMERICAN JOURNAL OF SCIENCE 272(1):48-68. SWRA W72-03842.

BROADLANDS IS A HYDROTHERMAL AREA IN THE TAUPO VOLCANIC ZONE OF THE NORTH ISLAND OF NEW ZEALAND. THE NATURAL HEAT FLOW FROM THE AREA IS 17,500 KCALS/SEC. THE AREA OF THE DEEP HOT WATER SYSTEM (9 SQ. KM) IS COMPARABLE TO THAT AT WAIRAKEI. HOT WATER AT TEMPERATURES UP TO ABOUT 300 DEGREES C. CONTAINS NA₂CO₃ (1625 PPM), K₂CO₃ (265 PPM), BORON (32 PPM), AND SILICA AS MAJOR CONSTITUENTS AND OCCURS AT DEPTHS DOWN TO APPROXIMATELY 2,420 METERS. DISSOLVED GAS IN THE WATER IS MAINLY CARBON DIOXIDE, AT A CONCENTRATION LEVEL NEAR 0.14 MOLAL. CONCENTRATIONS OF HEAVY METALS IN THE WATER ARE LOW, BUT PRECIPITATES AND SINTERS DERIVED FROM THE WATER CONTAIN HIGH CONCENTRATIONS OF ARSENIC, ANTIMONY, AND HEAVY METALS. D/H VALUES IN THE WATER ARE SIMILAR TO THOSE PRESENT IN LOCAL STREAMS TO THE EAST, INDICATING THAT A HIGH PROPORTION OF THE HOT WATER IS DERIVED FROM A METEORIC SOURCE. (USGS)

GEOTHERMAL STUDIES/HEAT FLOW/WATER CHEMISTRY/WATER TEMPERATURE/STEAM/
/VOLCANOES/HOT SPRINGS/THERMAL SPRINGS/METEORIC WATER

=IDENTIFIERS:/NEW ZEALAND

MCMILLAN, JR., D.A.

1970

ECONOMICS OF THE GEYSERS GEOTHERMAL FIELD, CALIFORNIA.

UNITED NATIONS SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES, PISA, 1970, PAPER. 17 P. SWRA W71-11650.

THE GEYSERS FIELD IN CALIFORNIA, THE GREATEST KNOWN GEOTHERMAL FIELD IN THE WORLD, IS PROOF THAT GEOTHERMAL ENERGY IS A CONSIDERABLE NATURAL RESOURCE AND AN ECONOMIC, DEPENDABLE SOURCE OF ELECTRIC ENERGY. THE COST OF ELECTRIC ENERGY PRODUCED AT THE GEYSERS IS LOWER THAN 0.005 DOLLARS/KWH, INCLUDING THE ACTUAL PRICE OF THE STEAM AT 0.0026 DOLLARS/KWH. THE AVERAGE COST OF CONVENTIONAL THERMAL AND ATOMIC ELECTRICAL POWER IN CALIFORNIA IS 0.007 DOLLARS/KWH. RECENTLY, WELLS IN THE GEYSERS FIELD HAVE BEEN DRILLED TO AN AVERAGE DEPTH OF 5,000-8,000 FT. AT AN AVERAGE COST OF 150,000 DOLLARS/WELL. STATIC PRESSURE OF THE WELLS IS 500 PSIG WITH BOTTOM HOLE TEMPERATURES OF 500 DEGREES F. THE STEAM TRANSMISSION SYSTEM IS DESIGNED FOR A PRESSURE OF 180 PSIG. THE LONGEST PIPELINE LENGTH TO THE PLANT IS 2,000 FT. PIPELINES ARE DESIGNED FOR AN AVERAGE PRESSURE DROP OF 6 PSI AND TEMPERATURE LOSSES OF ONLY 1 TO 2 DEGREES F. BETWEEN WELL HEADS AND PLANTS. PLANT DESIGN IS BASED ON THE USE OF 20 LB. OF STEAM/KWH. THE CAPACITY OF THE PROVEN GEOTHERMAL FIELD IS PRESENTLY EVALUATED AT 2,500 MW. CORROSION, INCRUSTATION, AND WASTE WATER DISPOSAL PROBLEMS ARE UNDER CONTROL AT THE GEYSERS FIELD. THE PLANT IS DESIGNED FOR UNATTENDED OPERATION. TWO MEN ARE ON DUTY FOR 8 HR./DAY. (USBR)

GEOTHERMAL STUDIES/THERMAL POWERPLANTS /COMPARATIVE COSTS /PIPELINES /WELLS/STEAM/COSTS/WASTE WATER DISPOSAL/ECONOMICS/CALIFORNIA/ CORROSION

=IDENTIFIERS:/TURBOGENERATORS/GEYSERS FIELD, CALIFORNIA

58

MCNITT, J.R.

1965

EXPLORATION AND DEVELOPMENT OF GEOTHERMAL POWER IN CALIFORNIA.

CALIFORNIA, DIVISION OF MINES AND GEOLOGY, SPECIAL REPORT 75. 45P.

A REVISION OF THE 1963 PAPER. FROM 1955 TO 1962, ABOUT 40 EXPLORATORY WELLS WERE DRILLED IN 15 CALIFORNIA GEOTHERMAL AREAS. A MAP OF THE SITES AND A TABULATION OF THE RESULTS ARE INCLUDED. THE GEYSERS THERMAL AREA HAS BEEN THE ONLY COMMERCIALY PRODUCTIVE GEOTHERMAL AREA IN THE US SINCE JUNE 1960. THE GEOLOGY, THERMAL ACTIVITY, HISTORY OF DEVELOPMENT, AND PRODUCTIVITY ARE DESCRIBED. THE RESERVOIR CHARACTERISTICS ARE DETAILED, GRAPHED, AND ILLUSTRATED. SIMILAR TREATMENTS ARE GIVEN THE CASA DIABLO AND SALTON SEA THERMAL AREAS. IN LIGHT OF THE RESULTING DATA AND THE DATA NOW AVAILABLE FROM FOREIGN PROJECTS, IT IS CONCLUDED THAT THERE ARE 3 FUNDAMENTAL PROBLEMS OF GEOTHERMAL DEVELOPMENT: PRELIMINARY EVALUATION, EXPLORATORY WELL LOCATION, AND ESTIMATION OF STEAM RESERVES. EXPERIENCE HAS SHOWN THAT HEAT FLOW INCREASES FROM 3 TO 170 TIMES IN A GEOTHERMAL AREA AS A RESULT OF WELL-DRILLING. GEOLOGIC MAPPING AND GEOPHYSICAL METHODS TO INCREASE WELL LOCATION EFFICIENCY ARE DISCUSSED. FIELD LIFE EXPECTANCY ESTIMATIONS MUST BE BASED ON RATES OF HEAT AND FLUID FLOW IN AN OPEN SYSTEM.

GEOTHERMAL STUDIES/CALIFORNIA/EXPLORATION/RESOURCES DEVELOPMENT/
GEOLOGIC INVESTIGATIONS/STEAM/WELLS/DRILLING/THERMAL POWER/TEST WELLS/
/HEAT FLOW/BOREHOLE GEOPHYSICS

=IDENTIFIERS:/GEYSERS FIELD, CALIFORNIA/SALTON SEA

59

MERCADO, G.S.

1969

CERRO PRIETO GEOTHERMAL FIELD, BAJA CALIFORNIA, MEXICO.

AMERICAN GEOPHYSICAL UNION, EOS 50(2):59.

SITUATED 20 MILES FROM THE U.S. BORDER, THIS FIELD COVERS AN AREA OF APPROXIMATELY 12 SQUARE MILES WHICH HAS BEEN DISTURBED BY FAULTING, SOME EXPRESSIONS OF WHICH CAN BE NOTED ON THE SURFACE. THESE FAULTS BELONG TO THE SAN ANDREAS SYSTEM. MAGMATIC FLUIDS (STEAM AND GAS) RISE ALONG THESE FAULTS FROM DEEP SOURCES, HEATING WATER INTENSIVELY IN PERMEABLE SANDSTONES. SOME 20 DEEP WELLS HAVE BEEN DRILLED IN THE GEOTHERMAL ZONE, AVERAGING BETWEEN 3 AND 5 THOUSAND FEET IN DEPTH. THE 75 MEGAWATT PLANT [COMPLETED IN 1970] IS EXPECTED TO SUPPLY ELECTRICAL ENERGY TO MEET MUCH OF THE POWER REQUIREMENTS OF THE CITY AND VALLEY OF MEXICALI. THE LARGE QUANTITIES OF WASTE WATER, HIGH IN SALTS, MAY BE TREATED FOR RECOVERY OF THE SALTS, INCLUDING BY SOLAR EVAPORATION, SINCE THE ANNUAL EVAPORATION POTENTIAL IN THAT AREA IS ABOUT 150 INCHES AND RAINFALL IS NEGLIGIBLE.

GEOTHERMAL STUDIES/FAULTS(GEOLOGIC) /MAGMATIC WATER/THERMAL
PROPERTIES/THERMAL POWER /DEEP WELLS/BRINE DISPOSAL/WELLS/SOLAR
DISTILLATION/EVAPORATION/WASTE WATER DISPOSAL/SALTS

=IDENTIFIERS:/BAJA CALIFORNIA/CERRO PRIETO FIELD

60

MILLER, L.D.

1968

STEAMING AND WARM GROUND IN YELLOWSTONE NATIONAL PARK: THEIR LOCATION, GEOPHYSICS, VEGETATION AND MAPPING WITH AERIAL MULTISPECTRAL IMAGERY.

UNIVERSITY OF MICHIGAN (PH.D. DISSERTATION). 198 P. DISSERTATION ABSTRACTS 30(2):456B-457B.

THE STUDY WAS DESIGNED AS A FIELD PROGRAM TO DETERMINE THE APPLICATION OF REMOTE MULTISPECTRAL SENSING TECHNIQUES TO COLLECT SYNOPTIC INFORMATION OF ECOLOGICAL SIGNIFICANCE. SITES OF STEAMING AND WARM GROUND IN YELLOWSTONE NATIONAL PARK WERE SELECTED AS THE TEST ENVIRONMENTS. THE STUDY SITES WERE LOCATED USING REMOTE SENSING TECHNIQUES, MORE SPECIFICALLY, AN INTERCOMPARISON OF AERIAL IMAGERY IN THE THERMAL AND VISIBLE SPECTRAL BANDS. THE CONVENTIONAL INTERPRETATION OF FOUR DIFFERENT BLOCKS OF THERMAL AND PHOTOGRAPHIC IMAGERY OF THE STUDY SITES SPANNING 7 YEARS WAS UNDERTAKEN. THE CONTROL SITES STUDIED ON THE GROUND IN DETAIL ALLOWED MEANINGFUL INTERPRETATION TO BE EXTENDED TO THESE THERMAL IMAGES OF THE GENERAL AREA. ADDITIONAL SITES OF STEAMING AND WARM GROUND WERE LOCATED AND RELATIONSHIP BETWEEN THE DISTRIBUTION OF THESE SITES AND THE TOPOGRAPHY WAS INDICATED. CHANGES IN SEVERAL SITES OF STEAMING GROUND WERE INTERPRETED FROM THE 7 YEAR TIME SEQUENCE OF THERMAL AND PHOTOGRAPHIC IMAGERY. FINALLY, IT HAS BEEN POSSIBLE TO PROCESS THE NEW THERMAL IMAGERY TO AUTOMATICALLY PRODUCE ISOTHERMAL MAPS WHICH CORRELATE CLOSELY WITH GROUND RADIATION MEASUREMENTS MADE ON THE TEST SITES DURING THE FLIGHTS. (AUTHOR)

GEOTHERMAL STUDIES/ISOTHERMS/REMOTE SENSING/STEAM/AERIAL PHOTOGRAPHY /MAPPING/THERMAL RADIATION

=IDENTIFIERS://YELLOWSTONE NATIONAL PARK/MULTISPECTRAL IMAGERY

61

MOOSER, F.

1965

PROGRESS REPORT ON RECENT DEVELOPMENTS OF GEOTHERMAL ENERGY AND
VOLCANOLOGY IN MEXICO.

BULLETIN VOLCANOLOGIQUE 28(1):69-73.

PROGRESS IN DRILLING AND ASSOCIATED HEAT FLOW AND GEOLOGICAL
INFORMATION IS REPORTED FOR THE GEOTHERMAL FIELDS AT PATHE HIDALGO,
MEXICO, AND AT CERRO PRIETO IN THE NORTHERN END OF BAJA CALIFORNIA.
NUCLEAR POWER PROPOSALS FOR EXPLOITING GEOTHERMAL FIELDS ARE
DISCUSSED. USING INDIRECT MEASUREMENTS, AN ATTEMPT WAS MADE TO DEFINE
7 GEOTHERMAL PROVINCES IN MEXICO THOUGHT TO REPRESENT ZONES OF HIGH
HEAT FLOW.

GEOTHERMAL STUDIES/HEAT FLOW/MEXICO/VOLCANOES/NUCLEAR POWERPLANTS/
TEST WELLS/EXPLORATION

=IDENTIFIERS:/BAJA CALIFORNIA/CERRO PRIETO FIELD/PATHE HIDALGO FIELD,
MEXICO

62

MOUNT, R.L.

1969

HARNESSING THE HEAT FROM INSIDE THE EARTH TO PRODUCE ELECTRICITY.

SCIENCE FORUM 2(2):20-22.

BECAUSE OF ITS LOCATION ON THE EAST PACIFIC RISE, WESTERN CANADA MAY POSSESS A MODEST QUANTITY OF GEOTHERMAL ENERGY. PRESENT TECHNOLOGY LIMITS POWER GENERATION TO DRY STEAM SITES, AND THE BASIC GEOLOGIC CRITERIA FOR SUCH SITES INCLUDE A LARGE MAGMATIC HEAT SOURCE RELATIVELY CLOSE TO THE EARTH'S SURFACE, A POROUS ROCK FORMATION SATURATED WITH GROUNDWATER ABOVE THE HEAT SOURCE, AND AN OVERLYING IMPERMEABLE CAPROCK. EXPLORATION HAS BEEN FACILITATED BY ADVANCES IN INFRARED AERIAL RECONNAISSANCE TECHNIQUES. THERE IS A GENERAL DISCUSSION OF GEOTHERMAL FIELDS EITHER IN POWER PRODUCTION OR POTENTIALLY PRODUCTIVE. MINERAL RECOVERY MAY ALSO BE ECONOMICALLY IMPORTANT.

GEOTHERMAL STUDIES/EXPLORATION/THERMAL POWER /REMOTE SENSING/
STEAM/INFRARED RADIATION/CANADA/GEOLOGIC INVESTIGATIONS

=IDENTIFIERS:/DRY STEAM FIELDS

63

MOXHAM, R.M.

1969

AERIAL INFRARED SURVEYS AT THE GEYSERS GEOTHERMAL STEAM FIELD.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 650-C:106-122. SWRA
W70-01894.

BOUNDS OF THE RADIANCE ZONE AND THE PRINCIPAL HIGH-TEMPERATURE ZONES
ON AERIAL INFRARED IMAGES ARE PRESENTED AND CORRELATED WITH STRUCTURAL
FEATURES. NO EVIDENCE WAS FOUND OF A REGIONAL GEOTHERMAL ANOMALY.

GEOTHERMAL STUDIES/STEAM/REMOTE SENSING/INFRARED RADIATION/SURVEYS

=IDENTIFIERS:/GEYSERS FIELD, CALIFORNIA

64

MOXHAM, R.M.

1970

THERMAL FEATURES AT VOLCANOES IN THE CASCADE RANGE, AS OBSERVED BY
AERIAL INFRARED SURVEYS.

BULLETIN VOLCANOLOGIQUE 34:77-106.

THERE HAVE BEEN NO SUBSTANTIAL CHANGES IN THE THERMAL PATTERNS AT THE
SUMMIT OF MOUNT RAINIER IN THE PERIOD SEPTEMBER 1964-SEPTEMBER 1966,
WITHIN THE DETECTION LIMITS OF THE INFRARED INSTRUMENTATION. SOME
DIFFERENCES IN RADIANCE ARE ATTRIBUTED TO DIFFERENCES IN SNOW COVER.
THE HIGHEST APPARENT TEMPERATURE IS AT A SNOW-FREE AREA ON THE WEST
FLANK OF THE SUMMIT CONE, SEVERAL HUNDRED FEET BELOW THE WEST CRATER
RIM. AN ANOMALY AT THIS SITE WAS RECORDED ON BOTH INFRARED SURVEYS,
BUT NO PRIOR REPORTS OF THERMAL ACTIVITY HERE HAVE BEEN MADE BY GROUND
PARTIES. OTHER ANOMALOUS THERMAL ZONES AT THE SUMMIT ARE ON THE
NORTHERN QUADRANTS OF BOTH CRATER RIMS.

VOLCANOES/REMOTE SENSING/INFRARED RADIATION/THERMAL RADIATION/SURVEYS
/WASHINGTON/PACIFIC NORTHWEST U.S.

=IDENTIFIERS:/CASCADE RANGE

65

MUFFLER, L.J.P./WHITE, D.E.

1969

ORIGIN OF CO2 IN THE SALTON SEA GEOTHERMAL SYSTEM, SOUTHEASTERN CALIFORNIA.

INTERNATIONAL GEOLOGICAL CONGRESS, 23RD, PRAGUE, 1968, REPORT 17:185-194. SWRA W71-13487.

THE IMPERIAL CARBON DIOXIDE GAS FIELD IN CALIFORNIA PRODUCED IN EXCESS OF 18,400,000 CUBIC METERS OF CARBON DIOXIDE GAS BETWEEN 1934 AND 1954. THE CARBON DIOXIDE FIELD IS PART OF THE SALTON SEA GEOTHERMAL SYSTEM, FROM WHICH A CONCENTRATED BRINE RICH IN CL, NA, CA, K, FE AND OTHER ELEMENTS FROM DEPTHS OF 900 TO 1,600 METERS PRODUCED AT TEMPERATURES UP TO 360 DEGREES C. THE GEOTHERMAL SYSTEM IS ENTIRELY WITHIN UPPER CENOZOIC SANDSTONE, SILTSTONE, AND CLAYSTONE OF THE COLORADO RIVER DELTA. THESE SEDIMENTARY ROCKS WERE ORIGINALLY COMPOSED OF QUARTZ, FELDSPARS, CLAYS, AND APPROXIMATELY 8 PERCENT CALCITE AND 4 PERCENT DOLOMITE. FIVE SMALL RHYOLITE DOMES OF LATE PLEISTOCENE OR RECENT AGE ARE PRESENT IN THE AREA OF THE GEOTHERMAL SYSTEM. EXAMINATION OF DRILL-HOLE CUTTINGS INDICATES THAT ORIGINAL CARBONATES ARE DESTROYED AND CARBON DIOXIDE LIBERATED IN TWO HYDROTHERMAL METAMORPHIC REACTIONS THAT AFFECT THE SEDIMENTS AT DEPTH IN THE HIGH TEMPERATURE ENVIRONMENT OF THE GEOTHERMAL SYSTEM. THE CARBON DIOXIDE LIBERATED FROM THE SEDIMENTS MIGRATES UPWARD AND Laterally TO THE SHALLOW CARBON DIOXIDE RESERVOIRS. THE QUANTITY OF CARBON DIOXIDE LIBERATED IN THE METAMORPHISM IS AT LEAST FIVE ORDERS OF MAGNITUDE GREATER THAN THE RECORDED PRODUCTION OF CARBON DIOXIDE FROM THE FIELD. (USGS).

THERMAL SPRINGS/CALIFORNIA/MINERAL WATER/CARBON DIOXIDE/HYDROGEOLOGY/
/GEOLOGY/HOT SPRINGS/WATER TEMPERATURE/WATER CHEMISTRY/CHEMICAL
ANALYSIS/WATER QUALITY/BRINES/SEDIMENTARY ROCKS

=IDENTIFIERS:/SALTON SEA

67

MUNDORFF, J.C.

1970

MAJOR THERMAL SPRINGS OF UTAH.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY WATER RESOURCES, BULLETIN
13. 60 P. SWRA W71-11779.

AS PART OF A STUDY OF THE SPRINGS OF UTAH, RECONNAISSANCE DATA WERE OBTAINED ON THE THERMAL, CHEMICAL, AND GEOLOGIC CHARACTERISTICS OF THE MAJOR THERMAL SPRINGS OF UTAH. TEMPERATURES OF THE THERMAL SPRINGS STUDIED RANGED FROM 68 DEGREES TO 189 DEGREES F. NEARLY ALL THERMAL SPRINGS IN UTAH ARE IN OR NEAR FAULT ZONES. VERY FEW OF THESE SPRINGS ISSUE FROM VOLCANIC ROCKS, BUT SEVERAL SPRINGS ARE CLOSE TO AREAS OF LATE TERTIARY OR QUATERNARY VOLCANIC ROCKS, ONLY TWO SPRINGS IN THE STATE, ROOSEVELT AND ABRAHAM HOT SPRINGS, ARE IN POTENTIALLY VALUABLE GEOTHERMAL AREAS. SOME THERMAL SPRINGS HAVE LARGE DISCHARGES, LOW DISSOLVED-SOLIDS CONTENTS, AND FAIRLY LOW TEMPERATURES; THESE SPRINGS ARE VALUABLE AS WATER SUPPLIES FOR IRRIGATION AND STOCK USE. AN UNDESIRABLE EFFECT OF THE THERMAL SPRINGS IS THAT THEY ADD SIGNIFICANT AMOUNTS OF WATER HAVING HIGH DISSOLVED-SOLIDS CONTENTS TO SOME STREAMS AND LAKES. (USGS)

THERMAL SPRINGS/UTAH/HOT SPRINGS/WATER YIELD/WATER QUALITY/WATER TEMPERATURE/THERMAL WATER/WATER CHEMISTRY/DISCHARGE (WATER)/WATER RESOURCES/GROUNDWATER/WARM SPRINGS/DATA COLLECTIONS/HYDROLOGIC DATA

67

MUNDORFF, J.C.

1970

MAJOR THERMAL SPRINGS OF UTAH.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY WATER RESOURCES, BULLETIN
13. 60 P. SWRA W71-11779.

AS PART OF A STUDY OF THE SPRINGS OF UTAH, RECONNAISSANCE DATA WERE OBTAINED ON THE THERMAL, CHEMICAL, AND GEOLOGIC CHARACTERISTICS OF THE MAJOR THERMAL SPRINGS OF UTAH. TEMPERATURES OF THE THERMAL SPRINGS STUDIED RANGED FROM 68 DEGREES TO 189 DEGREES F. NEARLY ALL THERMAL SPRINGS IN UTAH ARE IN OR NEAR FAULT ZONES. VERY FEW OF THESE SPRINGS ISSUE FROM VOLCANIC ROCKS, BUT SEVERAL SPRINGS ARE CLOSE TO AREAS OF LATE TERTIARY OR QUATERNARY VOLCANIC ROCKS, ONLY TWO SPRINGS IN THE STATE, ROOSEVELT AND ABRAHAM HOT SPRINGS, ARE IN POTENTIALLY VALUABLE GEOTHERMAL AREAS. SOME THERMAL SPRINGS HAVE LARGE DISCHARGES, LOW DISSOLVED-SOLIDS CONTENTS, AND FAIRLY LOW TEMPERATURES; THESE SPRINGS ARE VALUABLE AS WATER SUPPLIES FOR IRRIGATION AND STOCK USE. AN UNDESIRABLE EFFECT OF THE THERMAL SPRINGS IS THAT THEY ADD SIGNIFICANT AMOUNTS OF WATER HAVING HIGH DISSOLVED-SOLIDS CONTENTS TO SOME STREAMS AND LAKES. (USGS)

THERMAL SPRINGS/UTAH/HOT SPRINGS/WATER YIELD/WATER QUALITY/WATER TEMPERATURE/THERMAL WATER/WATER CHEMISTRY/DISCHARGE (WATER)/WATER RESOURCES/GROUNDWATER/WARM SPRINGS/DATA COLLECTIONS/HYDROLOGIC DATA

MURRAY, W.B.

1972

PRODUCING FRESH WATER FROM BRINE.

WATER AND SEWAGE WORKS 119(1-2):40-43, 54-57. SWRA W72-12661.

SEVERAL METHODS OF PRODUCING FRESH WATER FROM BRINE ARE DISCUSSED. FRESH WATER MAY BE EXTRACTED FROM SALT WATER IN THE PROCESS OF NUCLEAR POWER GENERATION, THROUGH USE OF GEOTHERMAL STEAM AND BRINE, AND BY THE PRODUCTION OF COASTAL FOG. ALTHOUGH RECOVERY METHODS DIFFER, IN EACH INSTANCE, THE ENERGY NECESSARY FOR SYSTEM OPERATION IS OBTAINED FROM THE PROCESS ITSELF. A 1,000-MW NUCLEAR POWER STATION EQUIPPED WITH SPECIAL CONDENSING DEVICES COULD PRODUCE FRESH WATER AT THE RATE OF 30 TO 36 MGD. RECOVERY PROCESSES AND COSTS ARE REVIEWED. USE OF GEOTHERMAL STEAM AS A SOURCE OF HEAT AND WATER TO SATURATE DRY DESERT AIR IS DISCUSSED. BY PASSING THE SATURATED AIR THROUGH A LARGE EXISTING FRESH WATER SUPPLY, WATER COULD BE RECOVERED BY NATURAL CONDENSATION. A THIRD METHOD PRODUCES COASTAL FOGS MOVING INLAND AND DEPOSITING WATER BY ATMOSPHERIC PRECIPITATION. THE SEA FOG COULD BE CREATED ARTIFICIALLY BY PUMPING THE COLD SEA WATER FROM BELOW THE THERMOCLINE TO THE SURFACE OF THE OCEAN AT LOCATIONS JUST OFF THE COAST OF SOUTHERN CALIFORNIA AND ALLOWING THE FOG TO BE SWEEPED INLAND BY WIND. THE FOG COOLS THE LAND AREAS, CAUSING RAIN TO FALL. (USBR)

FRESHWATER/BRINES/DEMINEALIZATION/NUCLEAR POWERPLANTS/FOG/
EVAPORATION/GEOTHERMAL STUDIES /WATER SOURCES/WATER RESOURCES
DEVELOPMENT/COSTS/STEAM/PRECIPITATION(ATMOSPHERIC) /CALIFORNIA/
THERMOCLINE/CONDENSATION/COASTAL STRUCTURES

69

NAKAMURA, H.

1969

MINERAL AND THERMAL WATERS OF JAPAN.

INTERNATIONAL GEOLOGICAL CONGRESS, 23RD, PRAGUE, 1968, REPORT
19145-62. SWRA 70-06553.

THERE ARE ABOUT 13,000 HOT SPRINGS IN JAPAN, MOST OF WHICH ARE
DISTRIBUTED ALONG QUATERNARY VOLCANIC ZONES WHOSE BASEMENT ROCKS
MAINLY CONSIST OF GREEN TUFF OF TERTIARY AGE. THESE SPRING WATERS
CONTAIN CONSIDERABLE AMOUNTS OF CL, SULFATES, CARBONATES, NA, K, AL,
FE, AND SILICATES. THE HOT SPRINGS ARE WIDELY USED IN JAPAN FOR
THERAPEUTIC TREATMENT, BATHING, AND GEOTHERMAL POWER GENERATION.
(USGS)

MINERAL WATER /THERMAL WATER/HOT SPRINGS/WATER CHEMISTRY/WATER
TEMPERATURE/THERMAL POWER

=IDENTIFIERS://JAPAN

70

NETSCHERT, B.C.

1971

THE ENERGY COMPANY: A MONOPOLY TREND IN THE ENERGY MARKETS.

BULLETIN OF THE ATOMIC SCIENTISTS. 27(8):13-17.

THIS IS PART OF A STATEMENT BEFORE THE U.S. SENATE SUBCOMMITTEE ON
ANTITRUST AND MONOPOLY OF THE SENATE COMMITTEE ON THE JUDICIARY. IT
ASSERTS THAT HORIZONTAL ACQUISITIONS IN THE POWER INDUSTRY THREATEN
COMPETITION. THERE IS A STRONG UPWARD PRICE PRESSURE IN ALL OF THE
FUELS MARKETS, AND HORIZONTAL EXPANSION ELIMINATES THE COUNTERVAILING
POWER OF INTERFUEL COMPETITION. THIS COULD MEAN THAT THE EMERGENCE OF
NEW INDUSTRIES BASED ON NEW POWER SOURCES COULD BE CONSIDERABLY
DELAYED.

FUELS/ENERGY/INDUSTRIES/ELECTRIC POWER INDUSTRY/UTILITIES/COMPETITION
/PRICES/COMPETITIVE PRICES/OIL INDUSTRY/NUCLEAR ENERGY/POWER MARKETING
/MONOPOLY/REGULATION

NICHOLS, C.R.

1970

THE GEOLOGY AND GEOCHEMISTRY OF THE PATHE GEOTHERMAL ZONE, HIDALGO, MEXICO.

UNIVERSITY OF OKLAHOMA (PH.D. DISSERTATION). 206 P. DISSERTATION ABSTRACTS 31(7):4139-B.

THE MEXICAN GOVERNMENT'S COMISION FEDERAL DE ELECTRICIDAD HAS OPERATED A 3500 KW TURBO GENERATOR PLANT AT THE PATHE GEOTHERMAL FIELD IN NORTHWEST HIDALGO, MEXICO SINCE 1958. THE PRESENT INVESTIGATION EXAMINES THE VARIABLES WHICH CONTROL THE ALTERATION PRODUCT MINERALOGY DEVELOPED IN AN ACTIVE HYDROTHERMAL AREA. EXPLORATORY DRILLING HAS REACHED A DEPTH OF 1286 M WITHOUT DRILLING THROUGH THE TERTIARY VOLCANIC SEQUENCE OF INTERBEDDED RHYOLITE PUMICE TUFFS AND FLOW BRECCIA, ANDESITE AND OLIVINE BASALT. THE VERTICAL CHEMICAL VARIATION AS DETERMINED BY QUANTITATIVE CHEMICAL ANALYSES BY X-RAY FLUORESCENCE DOES NOT INDICATE AN OBVIOUS OVERALL DIFFERENTIATION TREND. LOW PRESSURE STEAM AT TEMPERATURES OF 100 DEGREES TO 150 DEGREES C. IS PRODUCED FROM A 1200 M LONG PORTION OF A NORTH-SOUTH TRENDING HIGH-ANGLE FAULT. A SECOND SET OF EAST-WEST TRENDING NORMAL FAULTS HAS PRODUCED A SERIES OF GRABENS AND HORSTS PARALLEL TO AN AREA OF SUBSIDENCE THROUGH THE PATHE FIELD. STEAM IS PRESENT AT SHALLOW DEPTH AND CONSTITUTES A HAZARD IN THE CLAY MINES WHICH ARE PRESENT ALONG THE THERMALLY ACTIVE PORTION OF THE FISSURE. THE MINES WORK A ONE-METER WIDE VERTICAL SEAM OF HYDROTHERMAL MONTMORILLONITE, ZEOLITE AND QUARTZ, THUS ALLOWING A FIRST-HAND INSPECTION OF THE PLUMBING OF A GEOTHERMAL SYSTEM.

GEOTHERMAL STUDIES/MEXICO/TEST WELLS/DRILLING/GEOLOGIC INVESTIGATIONS /FAULTS(GEOLOGIC) /STEAM/THERMAL PROPERTIES /EXPLORATION /GEOCHEMISTRY

=IDENTIFIERS:/PATHE HIDALGO FIELD, MEXICO

72

NOGUCHI, T.

1970

AN EVALUATION OF GEOTHERMAL ENERGY IN JAPAN.

TECTONOPHYSICS 10(1-3):31-36.

A CALCULATION OF THE TOTAL STEAM ENERGY IN THE MAGMA CHAMBERS UNDERLYING JAPAN WAS MADE WITH THE INTENTION OF USING IT TO ARRIVE AT A ROUGH ESTIMATION OF THE TOTAL GEOTHERMAL ENERGY OF JAPAN. THE VARIOUS ASSUMPTIONS UNDERLYING THE CALCULATION ARE DISCUSSED. TOTAL CALCULATED STORED ENERGY IS 2.367×10^{18} CAL. ASSUMING AN EFFICIENCY OF 12 PERCENT IN CONVERTING STEAM INTO ELECTRIC POWER, ABOUT 12,000 MW CAN BE GENERATED.

GEOTHERMAL STUDIES/THERMAL POWER /FORECASTING /STEAM/ENERGY

=IDENTIFIERS:/JAPAN

73

O ROURKE, J.T.

1972

CLEAN STEAM. LETTER TO THE EDITOR,

ENVIRONMENT 14(2):48.

MANY ESTIMATES OF GEOTHERMAL POWER COSTS FAIL TO INCLUDE TAX BREAKS AND ARE THEREFORE INVALID. GEOTHERMAL DEVELOPMENT REQUIRES AT LEAST 20-40 ACRES OF LAND PER MEGAWATT, EXCLUSIVE OF ROADS, PIPELINES, POWER PLANTS, AND RELATED FACILITIES. THE GEYSERS PLANT IN SONOMA, CALIFORNIA, VENTS 1,000 POUNDS OF HYDROGEN SULFIDE GAS INTO THE AIR EACH DAY, DEMONSTRATING THE AUTHORS FEELING THAT THE CONCEPT OF GEOTHERMAL DEVELOPMENT BEING SYNONYMOUS WITH NONPOLLUTION IS A MISCONCEPTION, THAT IT CAN BE MADE COMPATIBLE WITH THE ENVIRONMENT ONLY WHEN UNIFORM MINIMUM STANDARDS AND CONTROLS ARE ESTABLISHED, LACKING AT THE PRESENT TIME IN THE U.S. HE POINTS OUT THE COST DIFFERENTIAL IN THE U.S. WHERE TAX BREAKS ARE FIGURED INTO THE RELATIVELY LOW COST, WORLDWIDE, OF 55 DOLLARS PER METER, WITH THOSE OF 98 DOLLARS IN JAPAN, AND OF 172 DOLLARS REPORTED DURING THE FIRST PHASES OF DRILLING IN A NEW GEOTHERMAL FIELD.

GEOTHERMAL STUDIES/AIR POLLUTION/THERMAL POWERPLANTS/STEAM/RESOURCES
DEVELOPMENT/ENVIRONMENTAL EFFECTS/THERMAL POLLUTION/COSTS/TAX RATES

=IDENTIFIERS:/GEYSERS FIELD, CALIFORNIA

74

PAPIN, W.J.

1971 -1972

STEAM CLEANED WATER.

WATER SPECTRUM 3(4):37-39. SWRA W72-05576.

IN ICELAND WATER RESOURCE MANAGEMENT IS UNENCUMBERED BY WATER QUANTITY AND QUALITY ISSUES. TODAY, THREE-FOURTHS OF THE HOMES AND BUSINESSES OF REYKJAVIK, ICELAND ARE HEATED BY NATURAL HOT WATER. THE MAIN GEOTHERMAL RESOURCE IS LOCATED AT REYKIR, EIGHTEEN KILOMETERS FROM REYKJAVIK. A PUMPING STATION AND A MAIN SUPPLY LINE AT REYKIR BRING THE WATER, AT 1540 F., TO REYKJAVIK, WHERE THE WATER IS STORED IN EIGHT TANKS HOLDING OVER TWO MILLION GALLONS AND FUNCTIONING AS FLOW EQUALIZERS. THE WATER IS COMPLETELY POTABLE WITHOUT ANY TREATMENT. SINCE THE SYSTEM IS ONE PROVIDED BY NATURE THE AIR IN REYKJAVIK REMAINS UNPOLLUTED. EXOTIC TROPICAL FRUITS AND PLANTS ARE GROWN AS PART OF THE ICELANDIC GOVERNMENTS EXPERIMENTAL PROGRAM. EXPERIMENTS ARE BEING CONDUCTED TO DETERMINE THE FEASIBILITY OF HARNESSING THE NATURAL STEAM JETS FOR THE PRODUCTION OF ELECTRIC POWER. STUDIES ARE ALSO BEING MADE TO SEE IF NATURAL STEAM POWER CAN BE USED TO EXTRACT SALT FROM SEA WATER OR POSSIBLY OTHER MINERALS AS WELL.

THERMAL WATER/THERMAL POWER/STEAM/WATER POLLUTION/WATER QUALITY/WATER SUPPLY/MANAGEMENT/WATER TREATMENT/AIR POLLUTION/ELECTRIC POWER/SALTS/ ENVIRONMENTAL EFFECTS

=IDENTIFIERS:/ICELAND

75

REX, R.W.

1971

GEOTHERMAL ENERGY, THE NEGLECTED ENERGY OPTION.

BULLETIN OF THE ATOMIC SCIENTISTS 37(8):52-56.

DRY STEAM FROM GEOTHERMAL FIELDS IS A SOURCE OF LOW-COST, NON-POLLUTING POWER. THIS IS BORNE OUT BY EXPERIENCE IN DEVELOPED FIELDS IN ITALY AND NORTHERN CALIFORNIA. TEN THOUSAND MEGAWATTS SUSTAINED PRODUCTION MAY BE POSSIBLE AT THE GEYSERS FIELD IN CALIFORNIA. ALTHOUGH ANOTHER POTENTIALLY IMPORTANT DRY STEAM FIELD HAS BEEN DISCOVERED RECENTLY AT VALLE CALDERA IN NEW MEXICO, IN GENERAL DRY STEAM FIELDS ARE RELATIVELY RARE COMPARED TO HOT WATER GEOTHERMAL AREAS. THE BASIC RESEARCH AND TECHNOLOGY OF HOT WATER FIELDS IS IN AN EARLY STATE OF DEVELOPMENT. SUCH FIELDS OCCUR IN THE IMPERIAL VALLEY OF CALIFORNIA AND NORTHWESTERN BAJA CALIFORNIA. SUCH FIELDS CONTAIN THE PROMISE OF NOT ONLY CHEAP POWER BUT ALSO GEOTHERMAL WATER DESALINATION. FULL DEVELOPMENT OF THE GEOTHERMAL WATER RESOURCES OF THE U.S. IN THE IMPERIAL VALLEY WOULD COST OVER FIVE BILLION DOLLARS, BUT NATIONAL EFFORTS IN THE DEVELOPMENT OF THIS RESOURCE HAVE BEEN LARGELY LACKING.

GEOTHERMAL STUDIES/THERMAL POWER/ENERGY/RESOURCES DEVELOPMENT/
CALIFORNIA/NEW MEXICO/STEAM/DESALINATION/EXPLORATION/THERMAL WATER/
COSTS/HOT SPRINGS/FORECASTING

=IDENTIFIERS:/VALLE CALDERA/BAJA CALIFORNIA/IMPERIAL VALLEY/DRY STEAM
FIELDS/GEYSERS FIELD, CALIFORNIA

76

RINEHART, J.

1970

HEAT FLOW FROM NATURAL GEYSERS.

TECTONOPHYSICS 10(1-3):11-17. SWRA W71-09118.

A NATURAL GEYSER IS A MECHANISM THAT EXTRACTS HEAT FROM THE EARTH. TRAPPED METEORIC WATER IS HEATED AND THEN THROWN CLEAR OF ITS RESERVOIR AS HOT WATER OR STEAM, CARRYING HEAT WITH IT. THERE ARE TWO BASIC TYPES OF GEYSERS: COLUMNAR, DISCHARGING QUANTITIES OF HOT WATER; AND POOL, IN WHICH THE ERUPTION CONSISTS OF A SERIES OF DETONATING STEAM EXPLOSIONS. RESULTS OF TEMPERATURE MEASUREMENTS MADE DEEP WITHIN SEVERAL GEYSERS PERMIT CALCULATION OF THEIR RESPECTIVE APPROXIMATE RATES OF HEAT EXTRACTION. OLD FAITHFUL, WHICH DISCHARGES LARGE QUANTITIES OF WATER, EXTRACTS HEAT AT THE APPROXIMATE RATE OF 1.34 MILLION CAL./SEC. NARCISSUS, AN EXPLOSIVE TYPE GEYSER, DEVELOPS POWER AT THE APPROXIMATE RATE OF 3.3 THOUSAND CAL./SEC, AND SOLITARY, ANOTHER EXPLOSIVE GEYSER, AT THE RATE OF 6.4 THOUSAND CAL./SEC. (USGS)

GEYSERS/HEAT FLOW/HEAT TRANSFER/MASS TRANSFER/HOT SPRINGS/GEOTHERMAL STUDIES/BOILING/CONVECTION/HEAT BALANCE/HEAT BUDGET/STEAM/METEORIC WATER

77

SCHUSTER, R.

1972

TURNING TURBINES WITH GEOTHERMAL STEAM.

POWER ENGINEERING 76(3):36-41.

THE AUTHOR BELIEVES THAT THE MOST REALISTIC ASSESSMENT OF THE MAXIMUM GEOTHERMAL ENERGY POTENTIAL, NATIONAL AND WORLDWIDE, IF FULLY DEVELOPED, WOULD PROVIDE ONLY A FRACTION OF OUR TOTAL FUTURE ENERGY REQUIREMENTS. TECHNICAL FOCUS OF THE ARTICLE IS ON THE GEYSERS FIELD, CALIFORNIA, AND DEVELOPMENTS IN ICELAND. HE CALLS ATTENTION TO CORROSION PROBLEMS AT THE GEYSERS PLANT, AND POINTS UP THE STEAM-GATHERING PIPING THAT DOMINATES ITS LANDSCAPE.

GEOTHERMAL STUDIES/STEAM/EXPLORATION/TURBINES/ENTHALPY/PIPELINES/
CORROSION/ENVIRONMENTAL EFFECTS

=IDENTIFIERS:/GEYSERS FIELD, CALIFORNIA/ICELAND

78

SOKOLOVSKIY, L.G./SHABERDYEV, S.

1967

TERMAL NYYE VODY TURKMENSKOY SSR (THERMAL WATERS OF TURKMENIA).

AKADEMIIA NAUK TURKMENSKOI SSR, IZVESTIYA, SERIYA FIZIKO-
TECHNICHESKIKH, KHIMICHESKIKH I GEOLOGICHESKIKH NAUK 1:110-115. MAPS.
BIGENA 32(8)E68-09378.

THE THERMAL WATERS OF TURKMENIA CAN BE SUBDIVIDED INTO 3 REGIONS. THE WEST TURKMENIAN DEPRESSION CONTAINS THE MOST EXTENSIVE RESOURCES, BUT THESE WATERS ARE HIGHLY MINERALIZED AND CONTAIN HARMFUL COMPONENTS. THE HIGH-TEMPERATURE WATERS OF THE KARAKUM AND THE KRASNOVODSK PENINSULA ARE ALSO INTENSIVELY MINERALIZED. IN THE MOUNTAIN BELT OF THE KOPET-DAG AND THE GREATER BALKHAN THE DEGREE OF MINERALIZATION IS RELATIVELY LOW, BUT HYDROGEN SULFIDE CONTENT INHIBITS UTILIZATION.

THERMAL WATER/MINERAL WATER

=IDENTIFIERS:/U.S.S.R./TURKMENIA

79

SUMMERS, W.K.

1966

DISTRIBUTION AND OCCURRENCE OF NEW MEXICO S THERMAL WATERS--A
STATISTICAL SUMMARY.

NEW MEXICO GEOLOGICAL SOCIETY, ANNUAL MEETING, 20TH, ROSWELL, 1966,
TECHNICAL PAPER. 9 P. SWRA W69-01239.

OF 67 AREAS IN NEW MEXICO REPORTED TO DISCHARGE GROUNDWATER AT
TEMPERATURES OF 90 DEGREES OR HIGHER, 46 HAVE BEEN SUBSTANTIATED IN
THE FIELD, 10 DO NOT EXIST AT THE LOCATIONS REPORTED OR HAVE LESSER
TEMPERATURES. DATA FOR 46 AREAS THAT HAVE BEEN FIELD CHECKED SHOW
THAT (1) THERMAL WATERS OCCUR IN THE WESTERN HALF OF THE STATE,
PRIMARILY IN RIO GRANDE AND GILA-SAN FRANCISCO DRAINAGE BASINS, (2)
ONLY 16 AREAS HAVE BEEN DISCOVERED BY WELLS WHEREAS 30 AREAS WERE
MARKED BY SPRINGS, (3) WATER ISSUES FROM ROCKS RANGING FROM
PRECAMBRIAN TO CENOZOIC AGE WITH CENOZOIC ROCKS PREDOMINATING, (4)
WATERS ARE ASSOCIATED WITH IGNEOUS AND SEDIMENTARY ROCKS IN EQUAL
PROPORTIONS, (5) WATER OCCURS PRIMARILY IN AREAS OF EXTENSIVE
VOLCANISM AND SECONDARILY IN FAULT ZONES, (6) WATER DISCHARGES FROM
SPRINGS NEAR STREAMS BUT MOSTLY AT POINTS WELL ABOVE RIVER LEVELS (7)
DISCHARGE MAY BE FROM FRACTURES DIRECTLY FROM BENEATH A TALUS COVER,
OR FROM ALLUVIUM OR SOME COMBINATION (1 SPRING DISCHARGED FROM A TUSA
MOUND) (8) MEDIAN PH IS 7.4, MEDIAN MAXIMUM TEMPERATURE IS ABOUT 105
DEGREES F; MEDIAN DISCHARGE OF SPRINGS IS 30.5 PPM AND MEDIUM
CONCENTRATION FOR SODIUM, 146 PPM; MAGNESIUM, 4.55 PPM, POTASSIUM, 4.6
PPM, AND LITHIUM, 0.28 PPM. MOST THERMAL WATERS HAVE BEEN USED FOR
SOME PURPOSE, BUT ONLY 18 ARE NOW BEING USED.

THERMAL WATER/THERMAL SPRINGS/GROUNDWATER/WARM SPRINGS/CHEMICAL
ANALYSIS/TEMPERATURE/AQUIFERS/PH/IGNEOUS ROCKS/GEOTHERMAL STUDIES/NEW
MEXICO/EXPLORATION/WELLS

=IDENTIFIERS:/RIO GRANDE TROUGH

80

SUMMERS, W.K. COMP.

1971

ANNOTATED AND INDEXED BIBLIOGRAPHY OF GEOTHERMAL PHENOMENA.

NEW MEXICO, STATE BUREAU OF MINES AND MINERAL RESOURCES, SOCORRO.
665 P.

THIS MASSIVE WORK, COMPLETED IN A 3-YEAR PERIOD FROM JULY 1969 TO JULY 1971 ON NSF GRANT NO. GN-764, INCLUDES OVER 14,000 ENTRIES COVERING ALL NATURAL, PHYSICAL, AND CHEMICAL ASPECTS OF THE EARTH'S HEAT. IT PURPORTS TO LIST 95 PERCENT OF REFERENCES ON GEOTHERMAL PHENOMENA APPEARING THROUGH DECEMBER 31, 1969, WITH A FEW KEY REFERENCES FOR 1970. AUTHOR, GEOGRAPHICAL, AND SUBJECT INDEXES ARE INCLUDED. A HIGH PERCENTAGE OF THE ITEMS ARE ANNOTATED.

GEOTHERMAL STUDIES/BIBLIOGRAPHIES/HEAT BUDGET/THERMAL POWER/STEAM/HOT SPRINGS

81

SUMMERS, W.K./ROSS, S.H.

1971

GEOTHERMICS IN NORTH AMERICA: PRESENT AND FUTURE.

EARTH SCIENCE BULLETIN 4(1):7-22. SWRA W72-01756.

TODAY THE PRIMARY INTEREST IN GEOTHERMICS IS FOR THE GENERATION OF ELECTRICAL POWER, ALTHOUGH A NUMBER OF OTHER VERY IMPORTANT USES ARE PROBABLE. GEOTHERMAL POWER DEVELOPMENT IS ATTRACTING INVESTMENT CAPITAL FOR A NUMBER OF IMPORTANT REASONS: ELECTRICITY GENERATED IS COMPETITIVE PRICewise WITH ELECTRICITY FROM MORE CONVENTIONAL SOURCES, CAPITAL EXPENDITURES CAN BE MADE ON AN AS NEEDED BASIS, ENVIRONMENTAL IMPACT IS MINIMAL, OTHER PROFITABLE ECONOMIC ACTIVITIES SUCH AS MINERAL EXTRACTION CAN BE CARRIED ON SIDE BY SIDE WITH ELECTRIC POWER PRODUCTION, AND THE RESOURCE SEEMS TO BE VIRTUALLY INEXHAUSTIBLE. DEVELOPED FIELDS IN NORTH AMERICA ARE DESCRIBED, AS WELL AS REGIONS WITH GREAT EXPLORATION POTENTIAL. MAPS ARE INCLUDED OF THERMALLY IMPORTANT AREAS IN THE SALTON-MEXICALI GEOTHERMAL PROVINCE, THE SALTON SEA GEOTHERMAL AREA, THE MEXICALI THERMAL AREA, CALIFORNIA, NEVADA, IDAHO, OREGON, MEXICO, AND CENTRAL AMERICA.

GEOTHERMAL STUDIES/ELECTRIC POWER/THERMAL POWER /EXPLORATION/
ENVIRONMENTAL EFFECTS/MULTIPLE-PURPOSE PROJECTS/CALIFORNIA/NEVADA/
IDAHO/RESOURCES DEVELOPMENT/COSTS/PRICES/OREGON/MEXICO

=IDENTIFIERS:/SALTON SEA/BAJA CALIFORNIA/GEOTHERMAL STEAM ACT, 1970

82

TALBOT, J.B. COMP.

1971

BIBLIOGRAPHY ON GEOTHERMAL RESEARCH.

U.S. BUREAU OF RECLAMATION, ENGINEERING AND RESEARCH CENTER,
BIBLIOGRAPHY 249. 14 P.

CONTAINED ARE 150 CITATIONS FROM BIBLIOGRAPHIC SOURCES AND TECHNICAL PUBLICATIONS COVERING THE YEARS 1964 THROUGH EARLY 1971. THE REFERENCES ARE LISTED ALPHABETICALLY BY PERSONAL AUTHOR, AND NOTATIONS ARE INCLUDED IF THEY ARE NOT IN THE BUREAU LIBRARY IN DENVER. IT IS NOTED THAT THE COVERAGE IS GENERAL AND DOES NOT INCLUDE ANY ONE SPECIFIC AREA.

BIBLIOGRAPHIES/BRINES /FUELS /GEOCHEMISTRY/GEOTHERMAL STUDIES/HEAT TRANSFER/STEAM/THERMAL POWER/HOT SPRINGS/HEAT FLOW/GEYSERS

=IDENTIFIERS://IMPERIAL VALLEY/NEW ZEALAND

83

UNITED NATIONS

1964

UNITED NATIONS CONFERENCE ON NEW SOURCES OF ENERGY: SOLAR ENERGY, WIND POWER AND GEOTHERMAL ENERGY, ROME, 21-31 AUGUST 1961, VOL. 2-3: GEOTHERMAL ENERGY, VOL. 1-2.

UNITED NATIONS, N.Y.

ALTHOUGH NOW OVER TEN YEARS OLD, THIS COMPREHENSIVE COLLECTION OF PAPERS ON ALL ASPECTS OF GEOTHERMAL ENERGY THEN KNOWN IS STILL USEFUL. DETAILED TABLES OF KNOWN FIELDS IN ITALY, NEW ZEALAND, ICELAND, THE UNITED STATES, MEXICO, EL SALVADOR, JAPAN AND THE SOVIET UNION ARE SHOWN, TOGETHER WITH PAPERS ON EXPLORATION (VOL. 1) AND THE HARNESSING OF GEOTHERMAL ENERGY FOR POWER GENERATION AND FOR HEATING (VOL. 2). THE 1970 U.N. CONFERENCE HELD IN PISA CLOSES THE KNOWLEDGE GAP (Q.V.).

GEOTHERMAL STUDIES/EXPLORATION/SURVEYS/HEAT/ENERGY/STEAM/HEATING/
GREENHOUSES/THERMAL POWER

=IDENTIFIERS://GEYSERS FIELD, CALIFORNIA/BAJA CALIFORNIA/CERRO PRIETO
FIELD/PATHE HIDALGO FIELD/MEXICO

84

UNITED NATIONS

1970

SYMPOSIUM ON THE DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES,
PISA, 1970. PROCEEDINGS 2(1).

GEOTHERMICS, SPECIAL ISSUE 2.

NO ABSTRACT

GEOTHERMAL STUDIES/EXPLORATION/RESOURCES DEVELOPMENT/STEAM/BRINES/
DESALINATION/COSTS/GREENHOUSES/WELLS/REMOTE SENSING/DRILLING/
GEOCHEMISTRY/MODEL STUDIES/THERMAL POWERPLANTS/THERMAL POWER

U.S. BUREAU OF RECLAMATION, BOULDER CITY, NEVADA, REGION 3

1971

GEOTHERMAL RESOURCE INVESTIGATIONS, IMPERIAL VALLEY, CALIFORNIA.
STATUS REPORT.

SAME AS AUTHOR, BOULDER CITY, NEVADA. 47 P.

IN 1968 THE BUREAU OF RECLAMATION BEGAN FINANCING GEOTHERMAL STUDIES OF THE IMPERIAL VALLEY BY THE UNIVERSITY OF CALIFORNIA, RIVERSIDE. THIS REPORT SUMMARIZES THE RESULTS OF THE STUDIES, DEVELOPMENT FEASIBILITIES, AND FUTURE PLANS. AS MUCH AS 5 BILLION AF WATER MAY LIE IN STORAGE, TO DEPTHS OF 20,000 FEET, IN THE SALTON TROUGH. SUBSTANTIAL QUANTITIES OF THIS ARE OF LOW SALINITY WITH HIGH HEAT CONTENT, REPRESENTING AN ENORMOUS RESOURCE POTENTIAL FOR ELECTRIC POWER, MINERALS, FRESH WATER, AND SPACE HEATING. IT IS FELT THAT THIS RESOURCE MAY OFFER A SOLUTION TO THE PROBLEM OF WATER SALINITY IN THE LOWER COLORADO RIVER THROUGH AUGMENTATION AND DILUTION, AND THEREBY HELP THE U.S. IN MEETING ITS MEXICAN TREATY OBLIGATIONS. THIS WIDE-RANGING REPORT COVERS GEOPHYSICAL, GEOLOGICAL, HYDROLOGICAL, AND ENGINEERING ASPECTS OF THE SUBJECT. FUTURE LINES OF RESEARCH AND DEVELOPMENT ARE DISCUSSED, AND A TENTATIVE BUDGET THROUGH 1976 IS PRESENTED. THE PROBABLE ENVIRONMENTAL IMPACTS OF GEOTHERMAL DEVELOPMENT IN THE IMPERIAL VALLEY ARE DESCRIBED. THEY APPEAR TO BE MINIMAL IF PROPER LOW-COST PRECAUTIONS ARE TAKEN. DETAILED COLORED MAPS OF THE REGION ARE INCLUDED.

GEOTHERMAL STUDIES/CALIFORNIA/RESOURCES DEVELOPMENT/EXPLORATION/
COLORADO RIVER/MEXICAN WATER TREATY/WATER STORAGE/WATER QUALITY/
ENVIRONMENTAL EFFECTS/THERMAL POWER /SALINE WATER/MIXING

=IDENTIFIERS:/IMPERIAL VALLEY/SALTON SEA

86

U.S. BUREAU OF RECLAMATION, BOULDER CITY, NEVADA, REGION 3

1972 A

PROPOSED DEEP GEOTHERMAL TEST WELL, GEOTHERMAL RESOURCE INVESTIGATIONS, IMPERIAL VALLEY, CALIFORNIA.

SAME AS AUTHOR. 19 P. AVAILABLE NTIS AS PB-206 161-D.

A DEEP GEOTHERMAL TEST WELL IS PROPOSED TO BE DRILLED TO A DEPTH BETWEEN 4000 AND 8000 FEET AT IMPERIAL VALLEY, CALIFORNIA. IT REPRESENTS A FIRST ATTEMPT TO RECOVER STEAM AND BRINE FOR DEVELOPMENT OF DESALTED WATER AND ELECTRIC POWER. THE WELL WOULD HAVE A SLIGHT IMPACT ON THE UNDERGROUND STRATA DUE TO THE COMPARATIVELY SMALL AMOUNTS OF FLUID WITHDRAWN FOR TESTING. DRILLING WOULD REQUIRE THAT APPROXIMATELY 10 ACRES OF NOW BARREN DESERT BE CLEARED FOR DRILLING OPERATIONS. AN ENVIRONMENTAL IMPACT STATEMENT.

GEOTHERMAL STUDIES/DEEP WELLS/TEST WELLS/CALIFORNIA/STEAM/BRINES/
THERMAL POWER /DRILLING/ENVIRONMENTAL EFFECTS

=IDENTIFIERS://IMPERIAL VALLEY

U.S. BUREAU OF RECLAMATION, BOULDER CITY, NEVADA, REGION 3

1972 B

DEEP GEOTHERMAL TEST WELL, GEOTHERMAL RESOURCE INVESTIGATIONS,
IMPERIAL VALLEY, CALIFORNIA (DRAFT ENVIRONMENTAL IMPACT STATEMENT).

SAME AS AUTHOR. AVAILABLE NTIS AS PB-206 161D. 19 P. SWRA
W72-11559.

A DEEP GEOTHERMAL TEST WELL TO BE DRILLED TO A DEPTH BETWEEN 4,000
AND 8,000 FEET IN THE EAST MESA AREA OF IMPERIAL VALLEY, CALIFORNIA,
WOULD HAVE A SLIGHT IMPACT ON THE UNDERGROUND STRATA DUE TO THE
COMPARATIVELY SMALL AMOUNTS OF FLUID WITHDRAWN FOR TESTING. IT WOULD
PROVIDE INFORMATION OF VALUE TO A DETERMINATION OF THE POTENTIAL FOR
GEOTHERMAL RESOURCES TO PROVIDE LARGE QUANTITIES OF DESALTED WATER IN
CONJUNCTION WITH RELATIVELY POLLUTION-FREE PRODUCTION OF ELECTRIC
ENERGY FOR THE WATER AND POWER-SHORT S.W. DRILLING WOULD REQUIRE
THAT APPROXIMATELY 10 ACRES OF NOW BARREN DESERT BE CLEARED FOR
DRILLING OPERATIONS. IMPACT ON FISH AND WILDLIFE, THE AIR, PLANT LIFE,
AND AREA AESTHETICS WOULD BE MINIMAL. ALTERNATIVES CONSIDERED
INCLUDE OTHER METHODS OF INVESTIGATION AND NO TESTING.

ENVIRONMENTAL EFFECTS/CALIFORNIA/GEOTHERMAL STUDIES/TEST WELLS/
MULTIPLE-PURPOSE PROJECTS/DESALINATION /DEEP WELLS/EXPLORATION/WATER
RESOURCES DEVELOPMENT/THERMAL POWER

=IDENTIFIERS://IMPERIAL VALLEY

U.S. CODE CONGRESSIONAL AND ADMINISTRATIVE NEWS

1970

GEOTHERMAL STEAM ACT OF 1970 (EXPLOITATION AND DEVELOPMENT OF GEOTHERMAL STEAM RESOURCES).

SAME AS AUTHOR, P. 6778-6788. SWRA W71-06650.

AUTHORIZING THE SECRETARY OF THE INTERIOR TO MAKE DISPOSITION OF GEOTHERMAL STEAM AND ASSOCIATED GEOTHERMAL RESOURCES, THE CONGRESS OF THE UNITED STATES ENACTED THE GEOTHERMAL STEAM ACT OF 1970 (P.L. 91-581,84 STAT. 1566,15). THE ACT DEFINES GEOTHERMAL STEAM AND ASSOCIATED RESOURCES, INCLUDING: (1) ALL PRODUCTS OF GEOTHERMAL PROCESSES, ENBRACING INDIGENCUS STEAM, HOT WATER, AND BRINES, (2) SIMILAR PRODUCTS RESULTING FROM WATER, GAS OR OTHER FLUIDS ARTIFICIALLY INTRODUCED INTO GEOTHERMAL FORMATIONS, (3) HEAT OR OTHER ASSOCIATED ENERGY FOUND IN GEOTHERMAL FORMATIONS, AND (4) ANY BYPRODUCT DERIVED THEREFROM. THE TERM BYPRODUCT IS DEFINED AS ANY MINERAL (EXCLUSIVE OF OIL, HYDROCARBON GAS, OR HELIUM) FOUND IN GEOTHERMAL FORMATIONS WHICH HAS INSUFFICIENT VALUE TO WARRANT EXTRACTION BY ITSELF. THE SECRETARY OF THE INTERIOR IS AUTHORIZED TO ISSUE LEASES FOR DEVELOPMENT AND UTILIZATION OF GEOTHERMAL STEAM RESOURCES AND TO FORMULATE REGULATIONS GOVERNING LEASES. LEASES SHALL BE SECURED BY COMPETITIVE BIDDING. THE ACT PROVIDES FOR: (1) MAXIMUM ACREAGE OF LEASES PER PERSON, (2) ROYALTY PAYMENTS TO THE GOVERNMENT, (3) DURATION OF LEASES, (4) TERMINATION AND ADJUSTMENT OF LEASES, (5) DUTIES OF LESSEES IN THE EXPLORATION AND EXPLOITATION OF GEOTHERMAL STEAM RESOURCES, AND (6) COEXISTENCE WITH LEASES UNDER OTHER FEDERAL MINING ACTS. THE SECRETARY OF THE INTERIOR HAS BROAD DISCRETION IN FORMULATING REGULATIONS TO IMPLEMENT THE PROVISIONS OF THE ACT.

THERMAL WATER/STEAM/MINERALOGY/ADMINISTRATIVE AGENCIES/LEGISLATION/
THERMAL PROPERTIES /LEASES/PERMITS/FEDERAL GOVERNMENT/WATER TYPES/
WELLS/DRILLING/EXPLORATION/EXPLOITATION/MINING/CONSERVATION/ENERGY/
HEAT/GASES/OIL/HELIUM/RESOURCES DEVELOPMENT/BRINES/GEOTHERMAL STUDIES

=IDENTIFIERS:/GEOTHERMAL STEAM ACT, 1970

U.S. DEPARTMENT OF THE INTERIOR

1971

GEOTHERMAL LEASING PROGRAM (DRAFT ENVIRONMENTAL IMPACT STATEMENT).

SAME AS AUTHOR, WASHINGTON, D.C. AVAILABLE NTIS AS PB-203 102D. 58 P. SWRA W72-09044.

THE MAJOR FEDERAL ACTION INVOLVED IS THE LEASING FOR DEVELOPMENT OF FEDERALLY OWNED GEOTHERMAL RESOURCES. GEOTHERMAL RESERVOIR SYSTEMS ARE OF TWO MAIN TYPES: VAPOR DOMINATED SYSTEMS AND HOT-WATER SYSTEMS. BECAUSE OF THE WIDE GEOGRAPHICAL DISTRIBUTION OF THE LANDS INVOLVED, THE EXTREME RANGE OF ECOLOGICAL AND GEOLOGICAL FACTORS INVOLVED, AND LIMITED EXPERIENCE IN GEOTHERMAL RESOURCE DEVELOPMENT, ONLY A GENERAL DESCRIPTION OF POTENTIAL ENVIRONMENTAL EFFECTS IS MADE. ENVIRONMENTAL EFFECTS ON THE LAND AND LAND USE, SURFACE WATER, GROUNDWATER AND THE GEOTHERMAL RESERVOIRS ARE INCLUDED. THESE EFFECTS ARE OUTLINED AT SIX STAGES OF DEVELOPMENT: EXPLORATION, TEST DRILLING, PRODUCTION TESTING, FIELD DEVELOPMENT, POWER-PLANT AND POWER-LINE CONSTRUCTION, AND FULL SCALE OPERATIONS. THE ONLY ALTERNATIVES WOULD BE POSTPONEMENT OR REFUSAL TO DEVELOP THE ENERGY RESOURCES; HOWEVER, ENERGY NEEDS WOULD HAVE TO BE MET FROM OTHER SOURCES SUCH AS FOSSIL FUEL PLANTS WHICH COULD HAVE A GREATER IMPACT ON THE ENVIRONMENT. PROPOSED RULES FOR LEASING AND OPERATION OF THE PROJECTS ARE INCLUDED.

ENVIRONMENTAL EFFECTS/GEOTHERMAL STUDIES /WATER RESOURCES DEVELOPMENT /GROUNDWATER RESOURCES/GROUNDWATER MINING/GEOLOGY/ENERGY/REGULATION/ LAND USE/WATER QUALITY/WASTE WATER(POLLUTION)/WATER POLLUTION/WATER POLLUTION CONTROL/WILDLIFE HABITATS/LAND SUBSIDENCE/SALINE WATER/ SILTING/ALTERNATE PLANNING/THERMAL POWERPLANTS/TEST WELLS

=IDENTIFIERS:/GEOTHERMAL STEAM ACT, 1970

90

U.S. CONGRESS, 89TH, 1ST SESSION

1965

GEOTHERMAL STEAM ACT OF 1965 (A BILL TO AUTHORIZE THE SECRETARY OF THE INTERIOR TO MAKE DISPOSITION OF GEOTHERMAL STEAM AND ASSOCIATED GEOTHERMAL RESOURCES).

SAME AS AUTHOR. SENATE BILL 1674. 11 P. SWRA W72-06087.

THE SECRETARY OF THE INTERIOR WOULD BE AUTHORIZED UNDER THIS BILL TO LEASE GEOTHERMAL STEAM IN LANDS ADMINISTERED BY HIM, AND IN ANY NATIONAL FOREST. GEOTHERMAL STEAM INCLUDES ALL FLUID PRODUCTS OF GEOTHERMAL PROCESSES, EXCLUDING PETROLEUM PRODUCTS AND HELIUM. IF THE LANDS WERE ACQUIRED BY ANOTHER AGENCY, LEASES MAY ONLY BE MADE WITH ITS CONSENT. ALL LEASES MUST BE ISSUED TO CITIZENS OR CORPORATIONS OF THE UNITED STATES. THE ACT PERMITS COEXISTENCE WITH OTHER LEASES. WHERE OTHER PRODUCTS OCCUR INCIDENTALLY WITH GEOTHERMAL STEAM, SUBSTANTIAL BENEFICIAL USE IS REQUIRED. LEASES ARE FOR A PRIMARY TERM OF 15 YEARS, SUBJECT TO EXTENSION. GEOTHERMAL LEASES MAY BE CONVERTED TO MINERAL LEASES. LEASE AREAS MAY ENCOMPASS BETWEEN ONE AND FOUR SECTIONS. THE SECRETARY IS AUTHORIZED TO PROMULGATE COMPREHENSIVE REGULATIONS TO EFFECTUATE THE ACT. LEASES WILL BE GRANTED TO THE FIRST QUALIFIED BIDDER; COMPETITIVE BIDDING WILL NOT BE USED. LESSEES MUST PAY ROYALTIES OF 10 PERCENT OF STEAM VALUE AND 5 PERCENT OF MINERAL VALUE, IN ADDITION TO RENT. THE ACT WILL NOT ALTER THE WATER LAWS OF ANY STATE.

STEAM/LEASES/FEDERAL RESERVATIONS /ADMINISTRATIVE AGENCIES /PUBLIC LANDS/STATE JURISDICTION/EXPLOITATION/RENT/ROYALTIES /PAYMENT/ LEGISLATION/LEGAL ASPECTS/FEDERAL GOVERNMENT/THERMAL POWER

=IDENTIFIERS:/GEOTHERMAL STEAM ACT, 1965

91

UYEDA, S./WATANABE, T.

1970

PRELIMINARY REPORT OF TERRESTRIAL HEAT FLOW IN THE SOUTH AMERICAN CONTINENT; DISTRIBUTION OF GEOTHERMAL GRADIENTS.

TECTONOPHYSICS 10(1-3):235-242.

THE CONTINENT OF SOUTH AMERICA HAS BEEN LEFT ALMOST ENTIRELY UNEXPLORED GEOTHERMALLY, EVEN THOUGH THE WESTERN PART DISPLAYS MANY CHARACTERISTIC FEATURES OF ACTIVE HEAT FLOW AREAS. TERRESTRIAL HEAT FLOW MEASUREMENTS WERE MADE IN 20 MINES IN THE WESTERN PART OF THE CONTINENT, AND TEMPERATURE DATA WERE OBTAINED FROM OIL FIELDS ALL OVER THE CONTINENT. THERMAL GRADIENT VALUES WERE NORMAL OR SUBNORMAL OVER MOST OF THE CONTINENT. HIGH VALUES WERE CONCENTRATED IN THE ANDES AREA AND WERE OFTEN ASSOCIATED WITH GEOTHERMAL ACTIVITIES. LOWER VALUES WERE OBSERVED ON THE PACIFIC COAST AND ALONG THE AMAZON RIVER.

GEOTHERMAL STUDIES/SOUTH AMERICA/THERMAL PROPERTIES/EXPLORATION/HEAT FLOW/MEASUREMENT

92

VELASCO HERNANDEZ, J./MARTINEZ BERMUDEZ, J.J.

1970

LEVANTAMIENTO GRAVIMETRICO ZONA GEOTERMICA DE MEXICALI, BAJA CALIFORNIA.

CONSEJO DE RECURSOS NATURALES NO RENOVABLES, MEXICO, BOLETIN 74. 20 P.

NO ABSTRACT

GEOTHERMAL STUDIES/MEXICO/RESOURCES DEVELOPMENT

=IDENTIFIERS:/BAJA CALIFORNIA

WALLACE, R.H., JR.

1970

ABNORMAL PRESSURES AND POTENTIAL GEOTHERMAL RESOURCES IN THE RIO GRANDE EMBAYMENT OF TEXAS. IN SYMPOSIUM ON ABNORMAL SUBSURFACE PRESSURE, 2ND, BATON ROUGE, LOUISIANA, JANUARY 30, 1970, P. 87-116.

LOUISIANA STATE UNIVERSITY, SCHOOL OF GEOSCIENCE AND DEPARTMENT OF PETROLEUM ENGINEERING. SWRA W72-12410.

DELTAIC AND NEAR-SHORE MARINE DEPOSITS OF CENOZOIC AGE IN THE RIO GRANDE EMBAYMENT OF TEXAS CONTAIN LARGE QUANTITIES OF FRESH TO MODERATELY SALINE GROUNDWATER AT ABNORMALLY HIGH FLUID PRESSURES. VERTICAL VARIATIONS IN GEOTHERMAL GRADIENTS IN ZONES OF GEOPRESSURE RANGE UPWARD TO 16 DEGREES F. PER 100 FEET, AND GRADIENTS IN EXCESS OF 2.5 DEGREES F. PER 100 FEET ARE COMMON. ISOGEOHERMAL SURFACES AT RELATIVELY SHALLOW DEPTHS IN THE RIO GRANDE EMBAYMENT PROBABLY REFLECT THE SHIFT OF THE CENTER OF DEPOSITION FROM SOUTH TEXAS TO THE MISSISSIPPI EMBAYMENT DURING NEOGENE TIME. IGNEOUS AND METAMORPHIC ACTIVITY ALONG THE MARGINS AND WITHIN THE RIO GRANDE EMBAYMENT HAVE BEEN FACTORS IN THE UPWARD DISPLACEMENT OF ISOGEOHERMAL SURFACES. IN THE TABASCO-WESLACO AREA, HIDALGO COUNTY, TEXAS, GEOTHERMAL GRADIENTS AND ISOGEOHERMAL SURFACES ARE STRONGLY AFFECTED BY GROWTH FAULTING AND DIAPIRISM; DEEP BASIN HYDRODYNAMIC PROCESSES, INCLUDING THERMAL DIAGENESIS OF CLAY MINERALS, CHEMICAL AND THERMAL OSMOSIS, AND REDISTRIBUTION OF SALINITY, ARE RESPONSIBLE FOR THE HYDROLOGIC CONDITIONS. GEOLOGIC AND HYDROLOGIC CONDITIONS IN THE RIO GRANDE EMBAYMENT APPEAR FAVORABLE FOR DEVELOPMENT OF GEOTHERMAL RESOURCES. (USGS)

HIGH PRESSURE/EARTH PRESSURE/WATER PRESSURE/ARTESIAN AQUIFERS/TEXAS/
GEOTHERMAL STUDIES/DIAGENESIS/FAULTS(GEOLOGIC)/CLAY MINERALS/
AQUICLUDES/AQUIFER CHARACTERISTICS/SEDIMENTATION/THERMAL PROPERTIES

=IDENTIFIERS:/RIO GRANDE EMBAYMENT(TEXAS)

94

WARING, G.A.

1965

THERMAL SPRINGS OF THE UNITED STATES AND OTHER COUNTRIES OF THE WORLD. A SUMMARY.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 492. 383 P.

THERMAL SPRINGS ARE WIDELY DISTRIBUTED THROUGHOUT THE WORLD BUT ARE MOST NUMEROUS IN AREAS IN WHICH THERE HAS BEEN VOLCANIC ACTIVITY IN LATE GEOLOGIC TIME. A REVIEW OF THE AVAILABLE LITERATURE HAS REVEALED MUCH INFORMATION ON THE LOCATION OF THE SPRINGS, THE TEMPERATURE OF THE WATER, THE RATE OF FLOW, THE CHEMICAL CHARACTER OF THE WATER AND EVOLVED GASES, AND THE USES MADE OF THE WATER, TABULATED BY COUNTRIES OR GEOGRAPHIC AREAS AND PRESENTED IN THE FIRST PART OF THIS REPORT. ACCOMPANYING THE TABULATED DATA FOR EACH COUNTRY OR GEOGRAPHIC AREA IS A BRIEF DESCRIPTION OF THE GEOLOGY AND A MAP SHOWING THE LOCATION OF THE SPRINGS. THE SECOND PART OF THE REPORT CONSISTS OF A LIST OF SOME 3700 REFERENCES, SOME ANNOTATED BRIEFLY, TO THE LITERATURE ON THERMAL SPRINGS, GROUPED BY COUNTRIES OR GEOGRAPHIC AREAS AND WITHIN EACH GROUP ARRANGED IN ALPHABETICAL ORDER BY AUTHOR.

GEOTHERMAL STUDIES/THERMAL SPRINGS/REVIEWS/SURVEYS/BIBLIOGRAPHIES

WERNER, S.L./OLSON, L.J.

1970

GEOTHERMAL WASTES AND THE WATER RESOURCES OF THE SALTON SEA AREA.

CALIFORNIA DEPARTMENT OF WATER RESOURCES, BULLETIN 143-147. 123 P.
SWRA W71-00356.

DATA AND INFORMATION DERIVED FROM PREVIOUS STUDIES AND FROM INVESTIGATIONS IN THE FIELD CONCERNING WATER RESOURCES AND GEOTHERMAL WASTES OF THE SALTON SEA AREA IN CALIFORNIA ARE EVALUATED. TO DATE, THE DEVELOPMENT OF THE GEOTHERMAL RESOURCES IN THE SALTON SEA AREA HAS BEEN CENTERED IN THE BUTTES THERMAL AREA, SOUTHEAST OF THE SALTON SEA, INVOLVING THE DRILLING OF 15 GEOTHERMAL WELLS. DEVELOPMENT OF GEOTHERMAL RESOURCES IN THE SALTON SEA AREA HAS BEEN HINDERED CONSIDERABLY BY THE LACK OF AVAILABLE DISPOSAL SITES FOR BRINE, BITTERN WASTES, AND ACCUMULATED SALT DEPOSITS. MOREOVER, THE HIGHLY SALINE BRINE HAS CAUSED OPERATIONAL PROBLEMS. ESTIMATED HEAT CONTENT OF THE SALTON SEA GEOTHERMAL RESERVOIR (BUTTES THERMAL AREA) IS A MINIMUM OF 2×10^{10} TO THE 19TH POWER CALORIES. THAT ESTIMATE WAS BASED ON AN UNDERLYING GEOTHERMAL RESERVOIR WHICH WAS ASSUMED TO BE EQUIVALENT TO A CYLINDER 7 KM IN DIAMETER, 3 KM IN THICKNESS, HAVING AN AVERAGE TEMPERATURE OF 250 DEGREES C., AND AN AVERAGE VOLUMETRIC SPECIFIC HEAT OF 0.7 CAL./CU CM. THE SALTON SEA IS THE LARGEST BODY OF WATER IN CALIFORNIA. THE TOTAL VALUE OF PHYSICAL INVESTMENTS RELATED TO THE SEA IS IN THE ORDER OF 900 MILLION DOLLARS. THE SEA S SALINITY IS ABOUT 36,000 PPM-- SLIGHTLY MORE SALINE THAN THE OCEANS-- AND IT IS INCREASING; AND THIS INCREASE COULD BE ACCELERATED BY THE DISCHARGE OF THE STILL SALTIER GEOTHERMAL WASTES. MAPS, PICTURES, AND TABLES OF DATA ARE INCLUDED. (USGS)

WATER RESOURCES/SURFACE WATERS/GROUNDWATER/GEOTHERMAL STUDIES/WASTE STORAGE/WATER QUALITY/CHEMICAL ANALYSIS/SALINITY/TRACE ELEMENTS/RADIOCHEMICAL ANALYSIS/HYDROLOGY/CLIMATIC DATA/STREAMFLOW/IRRIGATION/ GEOLOGY/RECREATION FACILITIES/BRINE DISPOSAL/WASTE WATER (POLLUTION)/ INFLOW/IMPORTED WATER/MUD/VOLCANOES

=IDENTIFIERS:/SALTON SEA

96

WHITE, D.E.

1965

GEOTHERMAL ENERGY.

U.S. GEOLOGICAL SURVEY, CIRCULAR 519. 17 P.

THERE ARE FOUR TYPES OF GEOTHERMAL SYSTEMS: AREAS OF NORMAL GEOTHERMAL GRADIENT, AREAS OF GREATER-THAN-NORMAL GEOTHERMAL GRADIENTS, HOT SPRINGS AREAS CHARACTERIZED BY CONVECTIVE HEAT MOVEMENT IN CIRCULATING WATER AND STEAM, AND COMPOSITE HYDROTHERMAL SYSTEMS INVOLVING BOTH CONVECTIVE AND CONDUCTIVE HEAT TRANSFER. STARTING WITH FIGURES FOR GLOBAL AVERAGE HEAT FLOW AND HEAT STORED ABOVE SURFACE TEMPERATURES IN THE TOP 100 KM OF THE EARTH'S CRUST, AN EFFORT IS MADE, USING THE SCANTY AVAILABLE DATA, TO ESTIMATE THE TOTAL AMOUNT OF HEAT STORED IN EACH TYPE OF GEOTHERMAL SYSTEM AND TO LEAD FROM THIS TO TOTAL WORLD RESOURCES. VARIOUS DIFFICULTIES LIKELY TO BE ENCOUNTERED IN DEVELOPMENT OF GEOTHERMAL RESOURCES ARE CONSIDERED. THE STORED HEAT ESTIMATES LEAD TO THE CONCLUSION THAT EXISTING WORLDWIDE UTILIZATION EQUIVALENT TO ONE MILLION KW CAN PROBABLY BE INCREASED AT LEAST 10 TIMES AND MAINTAINED UNDER PRESENT ECONOMIC CONDITIONS FOR 50 YEARS.

GEOTHERMAL STUDIES/THERMAL PROPERTIES/HOT SPRINGS/HEAT FLOW/HEAT TRANSFER/STEAM/HYDROTHERMAL STUDIES/ENERGY/CONVECTION/CONDUCTION/THERMAL POWER/FORECASTING

97

WHITE, D.E.

1966

GEOTHERMAL ENERGY.

BULLETIN VOLCANOLOGIQUE 29:481-483.

INADEQUATE FLUID SUPPLIES MAY MORE COMMONLY LIMIT GEOTHERMAL FIELD POTENTIALS THAN INADEQUATE HEAT SUPPLY. GEOTHERMAL FIELD CLASSIFICATIONS ARE BRIEFLY DISCUSSED. PROBLEMS CONFRONTING BROAD UTILIZATION OF GEOTHERMAL ENERGY INCLUDE: DISCOVERY OF RESERVOIRS WITH ADEQUATE FLUID AND ENERGY SUPPLIES, DEPOSITION OF CALCIUM CARBONATE OR SILICON DIOXIDE, CHEMICAL CORROSION, EFFLUENTS, AND INAPPLICABILITY OF PRESENT LAWS. OPTIMAL CONDITIONS INCLUDE A HEAT SOURCE, RESERVOIRS OF ADEQUATE VOLUME, PERMEABILITY, AND POROSITY, A LOW-PERMEABILITY CAPROCK INHIBITING CONVECTIVE LOSS. A DISCUSSION ON HYDROTHERMAL FLUIDS FOLLOWS. THIS PAPER WAS ORIGINALLY PRESENTED IN FULLER FORM AT THE IAV INTERNATIONAL SYMPOSIUM ON VULCANOLOGY (NEW ZEALAND), SCIENTIFIC SESSION, NOVEMBER 29, 1965.

GEOTHERMAL STUDIES/EXPLORATION/ENERGY/THERMAL PROPERTIES/HYDROTHERMAL STUDIES/DEPOSITION (SEDIMENTS)

WHITE, D.E.

1969

RAPID HEAT-FLOW SURVEYING OF GEOTHERMAL AREAS, UTILIZING INDIVIDUAL SNOWFALLS AS CALORIMETERS.

JOURNAL OF GEOPHYSICAL RESEARCH 74(22):5191-5201. SWRA W70-00201.

THE HEAT FLUX OF DISCHARGING HOT SPRINGS IS EASY TO MEASURE, BUT THE MEASUREMENT OF HEAT FLUX IN DISCHARGING VAPOR AND THAT LOST BY CONDUCTION THROUGH HIGH-GRADIENT NEAR-SURFACE GROUND OF THERMAL AREAS IS MUCH MORE DIFFICULT. IT WAS OBSERVED THAT SNOW MELTS MUCH MORE QUICKLY IN THE THERMAL AREAS OF YELLOWSTONE PARK THAN IN ADJOINING REGIONS. A RAPID LOW-COST METHOD OF MAPPING AND CALIBRATING DIFFERENCES IN HEAT FLOW, UTILIZING INDIVIDUAL HEAVY SNOWFALLS, IS DESCRIBED AND APPLIED TO A TEST AREA IN THE PARK. THE RESULTING HEAT-FLOW MAP IS THEN COMPARED WITH INFRARED IMAGERY OF THE SAME AREA. THE RESULTS CONTAINED CERTAIN ERRORS, BUT IT WAS CONCLUDED THAT SNOWFALL CALORIMETERY PROVIDES A RAPID LOW-COST MEANS FOR RECOGNIZING LARGE LOCAL DIFFERENCES IN HEAT FLOWS OF HOT SPRING AREAS, AND IN PROVIDING SEMIQUANTITATIVE COMPARISONS WITH NORMAL AREAS.

GEOTHERMAL STUDIES/HOT SPRINGS/SNOWFALL/HEAT FLOW/INFRARED RADIATION/
/THERMAL PROPERTIES/MAPPING/MEASUREMENT

=IDENTIFIERS:/YELLOWSTONE NATIONAL PARK/CALORIMETERS

WHITE, D.E./MUFFLER, L.J.P./TRUESDELL, A.H.

1971

VAPOR-DOMINATED HYDROTHERMAL SYSTEMS COMPARED WITH HOT-WATER SYSTEMS.

ECONOMIC GEOLOGY 66(1):75-97. SWRA W71-05059.

VAPOR-DOMINATED DRY-STEAM GEOTHERMAL SYSTEMS ARE UNCOMMON AND POORLY UNDERSTOOD COMPARED WITH HOT-WATER SYSTEMS. CRITICAL PHYSICAL DATA ON BOTH TYPES WERE OBTAINED FROM U.S. GEOLOGICAL SURVEY RESEARCH IN YELLOWSTONE PARK. VAPOR-DOMINATED SYSTEMS REQUIRE RELATIVELY POTENT HEAT SUPPLIES AND LOW INITIAL PERMEABILITY. AFTER AN EARLY HOT-WATER STAGE, A SYSTEM BECOMES VAPOR DOMINATED WHEN NET DISCHARGE STARTS TO EXCEED RECHARGE. STEAM THEN BOILS FROM A DECLINING WATER TABLE; MOST CONDENSES BELOW THE SURFACE, WHERE ITS HEAT OF VAPORIZATION CAN BE CONDUCTED UPWARD. LIQUID WATER FAVORS SMALL PORES AND CHANNELS BECAUSE OF ITS HIGH SURFACE TENSION RELATIVE TO THAT OF STEAM. STEAM IS LARGELY EXCLUDED FROM SMALLER SPACES BUT GREATLY DOMINATES THE LARGER CHANNELS AND DISCHARGE FROM WELLS. WITH TIME, PERMEABILITY OF WATER-RECHARGE CHANNELS, INITIALLY LOW, BECOMES STILL LOWER BECAUSE OF DEPOSITION OF CARBONATES AND $CaSO_4$. THE LID ON THE SYSTEM CONSISTS IN PART OF ARGILLIZED ROCKS AND CO_2 SATURATED CONDENSATE. LOCAL SUPPLY OF PORE LIQUID AND A GREAT STORED HEAT OF SOLID PHASES ACCOUNT FOR THE PHYSICAL CHARACTERISTICS AND THE HIGH PRODUCTIVITY OF STEAM WELLS. VAPOR-DOMINATED SYSTEMS PROVIDE A GOOD MECHANISM FOR SEPARATING VOLATILE MERCURY FROM ALL OTHER METALS OF LOWER VOLATILITY. MERCURY IS LIKELY TO BE ENRICHED IN THE VAPOR OF THESE SYSTEMS; THE ZONE OF CONDENSATION THAT SURROUNDS THE UNIFORM RESERVOIR IS ATTRACTIVE FOR PRECIPITATING HGS. (USGS)

GEOTHERMAL STUDIES/THERMAL WATER/STEAM/WATER VAPOR/HYDROGEOLOGY/
GROUNDWATER MOVEMENT/MASS TRANSFER/ION TRANSPORT/HEAT FLOW/WATER
TEMPERATURE/GEYSERS/WATER LEVELS/WATER TABLE/HYDROTHERMAL STUDIES

=IDENTIFIERS:/DRY STEAM FIELDS

100

WHITING, R.L./RAMEY, JR., H.J.

1969

APPLICATION OF MATERIAL AND ENERGY BALANCES TO GEOTHERMAL STEAM PRODUCTION, TEXAS A AND M UNIVERSITY, COLLEGE STATION; AND STANFORD UNIVERSITY, CALIFORNIA.

JOURNAL OF PETROLEUM TECHNOLOGY PP 893-900, JULY 1969. SWRA W69-07990.

SOME BASIN THERMODYNAMIC PRINCIPLES ARE PRESENTED THAT ARE APPLICABLE TO GEOTHERMAL FLUID RESERVOIR ENGINEERING. THE EQUATIONS ARE USEFUL FOR ESTIMATING THE INITIAL RESERVOIR CONDITIONS AND FOR MATCHING THE PAST PERFORMANCE AND PREDICTING THE FUTURE PERFORMANCE OF RESERVOIRS FOR WHICH THE ASSUMPTIONS INVOLVED ARE REALISTIC. FURTHER, IT IS DEMONSTRATED THAT THIS APPROACH CAN BE APPLIED TO A FIELD CASE WITH WHAT APPEARS TO BE EXCELLENT ACCURACY. OTHER COMMON RESERVOIR ENGINEERING TOOLS CAN BE MODIFIED FOR APPLICATION TO GEOTHERMAL FLUID RESERVOIRS. (USGS)

GEOTHERMAL STUDIES/STEAM/HEAT FLOW/THERMODYNAMICS /THERMAL POWER/
THERMAL SPRINGS/GEYSERS/WATER VAPOR/THERMAL POWERPLANTS/WELLS

101

WRIGHT, J.J.

1971

THE OCCURRENCE OF THERMAL GRUNDWATER IN THE BASIN AND RANGE PROVINCE OF ARIZONA. IN HYDROLOGY AND WATER RESOURCES IN ARIZONA AND THE SOUTHWEST, VOL. 1, P. 269-290.

AMERICAN WATER RESOURCES ASSOCIATION, ARIZONA SECTION / ARIZONA ACADEMY OF SCIENCE, HYDROLOGY SECTION, PROCEEDINGS OF THE 1971 MEETINGS, APRIL 22-23, TEMPE, ARIZONA. SWRA W72-02229.

EXAMINES ON A REGIONAL BASIS THE OCCURRENCE OF GROUNDWATER HAVING TEMPERATURE CONSIDERED TO BE HIGHER THAN NORMAL, INCLUDING WATER EMITTED FROM NATURAL SPRINGS AND THAT PUMPED FOR IRRIGATION AND INDUSTRIAL PURPOSES. AFTER A BRIEF DESCRIPTION OF THE GEOLOGY OF THE AREA, THE AUTHOR TAKES UP THE GEOGRAPHIC DISTRIBUTION OF ARIZONA S THERMAL WATER, SOURCES OF HEAT AND THEIR RELATION TO STRUCTURE, GEOTHERMAL GRADIENTS, THE QUALITY OF THERMAL WATER AND ITS UTILIZATION FROM SPRINGS AND WELLS. HE CONCLUDES THAT THE OCCURRENCE OF THERMAL WATER IS CLOSELY ALLIED TO STRUCTURAL ELEMENTS, AND SUGGESTS THAT IT IS DOMINANTLY METEORIC WATER. HE URGES FURTHER STUDIES. IN ADDITION TO A BIBLIOGRAPHY, THERE IS A LIST OF WELLS AND THEIR LOCATION, PLUS MAPS.

GEOTHERMAL STUDIES/THERMAL WATER/ARIZONA/METEORIC WATER/THERMAL PROPERTIES/WELLS/GROUNDWATER/STRUCTURE/GEOLOGIC INVESTIGATIONS/WATER QUALITY

=IDENTIFIERS:/BASIN AND RANGE PROVINCE

102

YUHARA, K.

1970

HEAT TRANSFER MEASUREMENT IN A GEOTHERMAL AREA.

TECTONOPHYSICS 10(1-3):19-30. SWRA W71-09117.

IN JAPAN, THERE ARE ABOUT TWENTY GEOTHERMAL AREAS, WHERE HEAT IS TRANSFERRED BY FUMARoles, STEAM WELLS, HOT SPRINGS, STEAMING GROUNDS, EVAPORATION FROM HOT POOLS AND THERMAL CONDUCTION THROUGH THE EARTH. METHODS OF HEAT TRANSFER MEASUREMENT USED AT OWAKUDANI AND SOUNZAN GEOTHERMAL AREAS OF HAKONE VOLCANO ARE OUTLINED. TOTAL MASS DISCHARGE FROM THESE AREAS AMOUNTS TO 129 KG/SECOND AND TOTAL HEAT TRANSFER AMOUNTS TO 10.64 MILLION CAL./SEC. HEAT TRANSFERRED FROM ALL GEOTHERMAL AREAS OF JAPAN MAY BE ESTIMATED ROUGHLY TO BE 2 TIMES 10 TO THE 23RD POWER ERG./YEAR. ADDING TO THIS THE ENERGY RELEASED BY VOLCANIC ACTIVITY, HOT SPRINGS, AND THE NORMAL HEAT FLOW OF NON-VOLCANIC REGIONS, THE TOTAL ENERGY RELEASED FROM THE WHOLE OF JAPAN, EXCLUSIVE OF THAT BY EARTHQUAKES IS ABOUT 9 TIMES 10 TO THE 24TH POWER ERG./YEAR. (USGS)

GEYSERS/HEAT FLOW/HEAT TRANSFER/MASS TRANSFER/HOT SPRINGS/GEOTHERMAL STUDIES/BOILING/CONVECTION/COOLING/HEAT BALANCE/HEAT BUDGET/STEAM

=IDENTIFIERS:/JAPAN

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