ECONOMIC RISK OF GEOTHERMAL PROJECTS

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Management methods for evaluating business opportunities involving uncertainties have included the concept of risk analysis. Risk analysis can be a powerful tool to compare the economic attractiveness of the various investments available to the business community. Natural resource development groups utilize this technique to select their exploration targets and to appraise the anomalies found. Additional funds can be allocated to those providing the opportunity for greatest return per dollar risked.

What is the risk factor used in economic analysis? When the probability of occurrence of any given event has been established, the risk factor will be known. The mathematical concept of risk factor can be considered as: The probability that an event will occur in one of several ways is the sum of the probabilities of the occurrence of all the possible ways that event can occur.

For example, a review of exploration work on geothermal prospects determines that in basin fill areas containing water saturated rocks four electrical resistivity anomalies are due to low resistivity sediments and one is due to an unusual amount of heated pore water.

The chances for being successful in a temperature confirmation drilling program on these resistivity anomalies will be 1:5. The probability of being successful is not the same as risk. In this example, in five attempts at success in a series when the risk is 1:5, the probability of success is approximately 68 percent.

The summation of risks involved in geothermal development evolves to essentially the question: Can the energy compete with other sources of energy available to the customer and still provide a reasonable rate of return on the necessary investment? The competitive fuel in the area of major geothermal steam occurrences is fuel oil. Coal is a strong competitor for hot water flash systems. Coal prices will probably follow oil prices in the next two decades. At this time hot water systems at temperatures below 400° F. cannot produce the energy for electricity generation inexpensive as coal fueled generating plants.

A look at the oil supply situation will provide a background for assessing the risk of oil prices increasing more rapidly than cost associated with geothermal development.

Saudi Arabia oil production is around 8.7 to 9 million barrels per day. Two years ago that country produced 10.2 million barrels a day. Present capacity is believed to be 11 million barrels per day. ARAMCO has added about three million barrels per day capacity during the past two years. The capability for producing much more exists. The willingness to produce in increased amount is another thing that poses a risk to the assumption they will. The Saudis are determined to maintain OPEC as an effective organization and will continue their production at around 8 to 9 million barrels per day. World oil demand should continue to increase 2 to 3 percent per year until the end of 1980.

OPEC production in 1978 was approximately 29 million barrels per day. This has gradually moved back to the 1977 high of 30 million barrels per day.

All free world net growth in oil demand (now 48 million barrels per day) during the next three years will be satisfied by non-OPEC sources: Mexico, North Slope and the North Sea.

Until 1985 world oil prices will be increasing, about the average rate of inflation. From 1985 on, world oil prices will be increasing at accelerating rates as OPEC countries maximize their return on a diminishing number of barrels.

Natural sources of heat above 450° F. in the western United States can produce electricity at prices competitive with low sulfur coals shipped from the Powder River Basin of Wyoming to the electricity generating centers supplying western Nevada and California. Water within the low energy 150° F. temperature range can provide processing heat, if the source is in a location where the energy can be used in the United States. It is expected that sulfur limits for fuel oil will be set similar to coal. To meet such standards, additional investment and costs will be required to prepare acceptable fuel. With such increases in cost, additional new uses for geothermal heat (energy) will become practical. As that happens, more people become interested in joining the exploration search to find and develop new deposits of heat for production of energy.

The development of a geothermal reservoir is capital-intensive, requires expert planning, and long times from initial expenditure until positive income is achieved. The utilization of a geothermal reserve requires extensive engineering, approximately two years in negotiation and planning with governmental agencies, and significant capital. (35 to 50 million dollars per 50 mw.)

The costs of maintaining and operating producing fields is about four to five times greater than the capital investment. An important portion of this cost is associated with the injection system that collects the cooled water and returns it to the sub-surface reservoirs after the heat is removed. Reducing these costs is an essential objective if geothermal energy is to remain competitive with other fuels.

Countries with high fuel costs and geothermal sites are now developing a wide variety of geothermal plants. Japan appears to be building the most efficient flash systems for use in hydrothermal areas with reservoir temperatures above 350° F.

Useful geothermal reserve assessment requires professional engineering analysis. The goal is to determine how much heat can be produced at a useful rate and temperature for at least 20 years from one area. This demands a thorough understanding of the manner in which heat is transported to areas of accumulation, how it accumulates, the methods and costs to find, produce and convert to a useable form of energy. With those studies in hand, a person can then determine what part of this resource can be sold in competition with other fuels and thereby establish the size of the reserve.

The supply of geothermal energy has been related to: all the heat present above an arbitrary temperature datum; the amount of heat between certain temperature levels, that heat contained in producing water, and; that heat contained in the rock framework transferred to the moving body of water.

The amount that could be produced in the United States if the government would provide incentives equal to other energy sources is now thought to be between 12,000 and 15,000 megowatts.

These incentives have included tax credits, deductions in tax calculations, investment tax credits, rapid depreciation, and depletion allowances. Other incentives include aid in exploration, aid in developing, engineering of generating plants, financing of generating plants, and reservoir engineering studies. Very little has been prepared showing the increased benefit to governmental programs, including tax revenue by demonstrating the increased flow of dollars from projects that would become profitable with this aid compared to project tax revenues that would be commercial without this aid. Dr. Robert Rex has calculated that for a 48 net mw plant paying 25 mils/KWH for the energy the government income would be more than 213 million dollars during the 30 year productive life. If this were on private land the government income would be 178 million dollars.

The actual potential of geothermal energy is affected by how the resource and reserves are calculated. These calculations must consider availability and application of governmental incentives, the price of other energy sources, versus the market price of geothermal energy, and the reliability of the production forecast. The size of required investment, the expected profit generated by those investments, plus the availability of lands to explore will be the motivating forces in developing the true potential of geothermal energy in the United States.

The most important factor in converting any resource into a reserve is how the individuals that are actively dedicated to discovery and development attack the problem. The key to successful reserve development is the quality of the people assigned to the task.

The critical economic factors affecting the risk of a geothermal project being successful can be considered in two categories. The first is that associated with the production of the geothermal energy. The second is in the conversion of the energy into a useful form for the production of electricity.

The energy producer, after finding the geothermal anomaly, must consider his risk of resource development concentrated into four major items. These are the reservoir life, the sales price for the energy, the plant design, and the pricing structure. Other opportunites for investment will affect the amount of money he may dedicate to the program.

The number of years of reservoir production at useful temperatures and volume of fluid that can be expected is of utmost importance. The reservoir economic life is affected by the rate of decline in temperature and production as this affects the drilling and equipment investment and the operating costs.

The risk the project succeeds depends upon the price of energy produced. The sales price defines the cash flow available for development and operating expense. This price establishes the limits of investment that can be made and the potential rate of return on this investment. The competitive stature of the resource will be prescribed by the price of the delivered energy. The final size of the economic reserve is thus determined by these factors. That size then determines the amount of risk the energy producer can assume at various stages of exploration and development.

The plant design affects the cost of designing the production mode as the delivered product must conform to the requirements of the plant. Single-phase fluid delivery (for other than dry steam) requires greater investment to maintain that phase from the reservoir into the plant than does a two-phase system. Injection disposal facilities are dependent upon the plant requirements. The rate of production from the reservoir is also dependent upon the plant design. The limits of fluid temperature useful in running the plant are established by the plant's design. The life of the producing facility is seriously affected by this factor.

The pricing structure can encourage efficiency in developing new reservoirs or negate the advantage of searching for deeper, though hotter, horizons. Provisions for reservoir failure can allow the taking of a greater risk in developing the reservoir to its maximum size. If the reservoir performance must be guaranteed by the producer, he can then only develop the amount of energy that has very little risk. Thus, the fuel producer and the utility have little chance for maximizing their return on the use of this impressive source of energy unless pricing structures recognize this effect.

Electricity producers are not prepared to undertake projects that have a risk of complete failure in the early stages. They are not oriented to taking risks of the magnitude considered acceptable by natural resource developers. For instance, developers know the risk of finding one million barrels of oil with a wildcat is about one in forty times being successful. So their organization has the ability to provide for the unsuccessful exploration ventures effect on their marketable supply of energy. The ability to evaluate and predict the reservoirs' capability for producing certain quantities of fluid is highly developed in oil companies because the few successful finds must be developed to their full capacity.

Utilities historically expect a certain amount of fuel to be delivered on schedule throughout the plant's lifetime. The utility organization has not developed the capability of being comfortable with reservoir engineering analysis. Geothermal energy does not provide the risk abatement feature of having another source of supply that can be brought in to augment a premature declining geothermal energy supply. This is the major risk the utility management recognizes in the economic viability of building a geothermal plant. The risk of having a favorable cost at the Busbar for the electricity produced can be determined after the design of the generating plant has established the production requirements for delivery of the geothermal energy. These requirements are strong factors in the producer of the energy identifying his costs of production and therefore a likely energy sales price.

The fixed costs affect the final price of produced electricity. Dry steam plants can be constructed for a lower investment than single-flash plants. The single-flash plants require a lower investment than the double-flash design.

The lower efficiency of the single-flash plant requires a much higher volume of fluid to be produced and handled to produce the same number of kilowatt hours. This effect of these design segments on the producer of energy and producer of electricity create the risk that each will have selected the optimum design for their components.

Knowing the size of the available fuel supply lowers the risk of underfinancing a development project. For rocks to be considered a reservoir, there must be sufficient horizontal and vertical permeability to allow the fluid to move easily. A 6,000-foot to 8,000-foot well must sustain flow rates of more than 100,000 pounds of steam per hour, or 500,000 pounds of water (at no less than 325 degrees Fahrenheit) per hour for 20 to 25 years to be considered commercial for electricity generation. Direct use of heat for industrial or space heating and cooling does not require such high heat output. The lower temperatures for such uses can be found in a greater number of anomalies. However, their usefulness is dependent upon low cost being achieved in development and production.

The geologic model that is generally accepted by geothermal explorers and developers has three basic requirements:

1. A heat source (presumed to be an intrusive body) that is about 2000° F. and within 40,000 feet of the surface.
2. Meteoric waters circulating to depths of 10,000 feet where heat is transferred from the conducting impermeable rocks above the heat source.
3. Vertical permeability above the heat source connecting the conducting rocks with a porous permeable reservoir that has a low conductivity impermeable heat retaining member at its top.

Geological investigation is the necessary ingredient that makes all exploration techniques useful. Broad reconnaissance of the surface data integrated into subsurface data is used to find an area of general interest. The ingenuity of the prospect finder in using data available to all workers determines whether an exploration program moves into advanced stages of using the proper combinations of the acceptable methods.

Geologic interpretation of the data acquired may justify the money required for exploratory drilling. The results of the drilling must be integrated into the geologic investigation to determine if a promising prospect is present.

The investigation must establish that:

1. High heat flow or strong temperature gradients are present at depth.
2. The geology provides reasonable expectation that a reservoir sequence of rocks is present at moderate depths from 2000 to 6000 feet.
3. The sequence of rocks offers easy drilling with minimal hole problems.
4. A high base temperature and low salinity waters as indicated by geo-chemistry of water sources should be present. The surface alteration and occurrence of high heat flow should cover an area large enough to offer the chance for a field capacity of more than 200 megawatts.

Table I (adjusted for 1980 costs) from C. Heinzelman's presentation of October 15, 1977 illustrates exploration techniques and associated costs. The overall amount of money (per succesful prospect) required is 3 million to 4.75 million 1977 dollars. This provides for limited failure and followup costs, but does not include the other exploration failures and land costs.

Table I

Exploration Techniques and Approximate Costs

Objective	Technique	Approximate Cost ($)
Heat Source & Plumbing	Geology	$ 20,000
	Microseismicity	15,000
Temperature Regime	Gravity	20,000
	Resistivity	25,000
	Tellurics and magneto-tellurics	50,000
	Magnetics	15,000
	Geochemistry (hydrology)	12,000
	Land analysis and permitting	25,000
	Temperature gradient - 20 holes(500' or less)	100,000
	Stratigraphic holes -4	160,000 - 240,00
Reservoir Characteristics	Exploratory and confirmation tests -3-	1,800,000 - 4,000,00
	Reservoir testing	250,000

To establish a discovery approximately $2,500,000 - $5,000,000 will be required.

This is probably the minimum expenditure needed to change a portion of the resource base into an area of reserve with production potential.

Upon deciding that a significant geothermal anomaly exists, the rate of engineering expenditures must increase rapidly to determine whether the development can proceed into a commercial venture. Essentially, there are no set figures for what it costs to develop a geothermal field. The basic reason for this is that each depends upon engineering the development to be compatible with the geology of the accumulation, and the requirements of the electricity generating system. The electricity generating system must be designed within the constraints of available temperature, rate of production, and ambient conditions of the field site. The key variables affecting risk are:

1. Temperature of the fluids produced.
2. Composition of the reservoir fluids.
3. Composition of surface or near surface fluids.
4. Geology of the reservoir framework.
5. Flow rates that can be sustained by the reservoir.
6. Cost of drilling in the prospect area.
7. Well spacing and geometry of the producing and injection sites.
8. Turbine system to be used.
9. General operating costs in the area.

Test Wells - Thermal evaluation requires the drilling of test holes. Heat flow and temperature gradient evaluation requires drilling to intermediate depths. Confirmation drilling requires holes drilled to the actual reservoir for diagnostic evaluation.

Heat flow and temperature gradients measured in the upper 100 to 500 feet of depth are useful in describing the area where the heat transfer is most intense. These do give a qualitative analysis as to the location and shape of the hottest near surface heat accumulation. Linear projection of temperatures obtained near the surface cannot be used to predict the temperatures that will be encountered 2000 to 3000 feet below the surface, even if the section below has a uniform lithology and the geothermal gradient is a straight slope. The temperature for a fluid-saturated system cannot be projected to a maximum above that for boiling water at the pressure calculated for the depth of projection. At some point along the boiling point curve, the temperature of the system may become isothermal and the rocks and fluids will have the same temperature for many hundreds of feet deeper. The rock temperature may decrease as a hole is drilled deeper if the hole is on the descending edge of a plume of hot water or merely below the spreading top of a plume. Heat flows from a hot body to a cooler body. This is not a function of being above or below a reference point of depth.

To lower the risk that the performance of the geothermal cell can be predicted, deep tests must be drilled. These holes must be of sufficient size to adequately determine the ability of the reservoir to produce fluids above 365° F. at rates approaching 100,000 pounds of steam per hour, or 500,000 pounds of liquid per hour.

To determine if a commercial development is possible, three or four wells must test the reservoir to obtain the basic reservoir engineering data. Reservoir pressure drawdown and buildup analysis must be conducted to determine reservoir permeability and extent. Fluid characteristics and analysis of non-condensible gas present require extensive flow testing. Injectivity testing is required to develop plans for disposal and pressure maintenance systems. Rocks may produce fluids easily, but may not accept them on return to the reservoir. This must be established in the laboratory and confirmed in the field for a developer to consider risking the investment needed to develop a field. The utility customer needs the same assurance.

A summary of estimated development costs after exploration expenses for the field supply, power plant, and ancillary equipment for a 50-megawatt hot water flash unit is as follows:

Table II

Development wells - 12	$ 14,400,000
Injection wells - 6	6,000,000
Pipelines	2,800,000
Miscellaneous field expense (includes interest and working capital)	9,000,000
Power plant	35,000,000
	$ 67,200,000

Economic Considerations

To obtain an economic comparison of geothermal fuels with the more widely used fuels is quite difficult, because each geothermal area requires a plant design specifically useful for that local area. The California Geyser's steam price of 17.5 mills per kilowatt hour is as inexpensive as geothermal energy can be produced in the United States today. This is a dry steam fuel, and the operators have more than a decade of experience in drilling, completion, and production operations. Optimum techniques have been developed so that maximum steam production per dollar invested can be maintained. The high energy content of this fluid provides a competitive heat rate, easy to construct collection systems, and the most simple of plant and reinjection facilities. The actual cost of the wells is frequently as high as $1,500,000, but the operation and the high utility of the steam allows a minimal price for the energy.

The wide variation of estimates of fuel costs and electricity generating costs derives from treatment of fuel processing and storage expense, income taxes, ad valorem taxes, insurance, interest during construction, return on investment required, and specific requirements for plants in the area of operation for the estimating companies.

The utility usually expects to earn a minimum of 25 percent return on investment on its equity portion of the investment. The exploration and producing investors have learned that a minimum acceptable rate of return on investment for their portion of the projects is 25 percent return on investment. The average conventional energy venture (non-geothermal) usually obtains about twice this rate of return to compensate for the risks involved. The prime rate has risen so high today that low risk venture returns will provide a ROI that is nearly as attractive.

The return on investment for the developer is most sensitive to the price received for the energy. Next to reliability of supply, the utilities' desires to use geothermal energy in electricity generating systems is dependent upon its price being low enough to make its use worthwhile. Much like coal and uranium, geothermal fuel prices will be a negotiated price between the supplier and the user. Each field will have significant differences in design so a uniform price cannot be expected for construction of the production facilities, or construction of the utilities conversion plant.

The nature of the reservoir geometry and the ability of the reservoir to respond to changes in production, rates, and temperatures, will determine the final costs for producing electricity from each geothermal project.

The basic structure of price must provide an attractive rate of return to the prospector. To achieve this, the prospector's risk capital investment and time at risk before income must be minimized. Most important, the revenue should reflect the actual value of the energy sold.

Cost Comparisons

The cost comparisons between the various sources of energy that will be available and useable for electricity generation during the next decade will affect the rate of geothermal energy's growth. The economic desirability of the production or use of a fuel is sensitive to its price. Regulatory requirements have direct effect upon production and construction costs. The tax treatment for each fuel system is a dynamic one. This makes it very difficult to assess the resulting economics.

The amount of money needed to construct and operate plants to use each fuel is a strong component of how much the electricity producing customer will pay per unit of fuel. The average coal and oil burning plant uses 8,500 to 10,500/Btu/kwh. A nuclear plant uses about 14,000 Btu/kwh. Geothermal plants use between 21,000 to 33,000 Btu/kwh.

Oil

Electricity produced from oil fired plants is directly related to the cost of low sulfur fuel oil. An oil fired turbine generator plant costs between $400 - 500 per kilowatt. A combined cycle plant is about $360 per kilowatt. The difference in heat factor, operating cost, and available capital for these plants establish which will be used for meeting the increased demand and plant replacement schedule within a utilities service area. The estimated cost developed by Stanford Research Institute of fuel oil in mills per kilowatt hour is approximately 23 mills per kilowatt hour. Strong competition between suppliers results in a stabilizing effect upon the overall price of oil. Utility planners have estimated the range of price of oil to be 20.5 to 21 mills per kilowatt hour. These cost ranges combined with the new plant costs will produce electricity between 33 and 44 mills per kilowatt hour. This figure must be adjusted for the strong energy price increase during the last twelve months.

Coal

Coal prices are related to specific sources of supply and dedication of specific sources of coal to certain plants. Coal does not presently have the wide range of usefulness that oil enjoys today. This limits the substitution of one coal for another.

The price of steam coal and plant construction costs to meet environmental requirements result in an estimated price of 35 mills for electricity generated in new coal plants. Fuel suppliers currently estimate coal can be delivered within a 1,000-mile radius for 10 to 15 mills per kilowatt hour if surface mining methods are used.

Nuclear

Nuclear fuel plants appear to offer the least expensive electricity for a non-indigenous source of energy.

The utility industry estimates they will be paying 6 to 6.5 mills per kilowatt hour for nuclear fuels and plant costs in 1977 dollars will be $800 to $1,000 per kilowatt. The estimated cost of electricity from such plants will be between 32 to 34 mills per kilowatt hour.

Geothermal

Comparison of conventional electricity prices with geothermal steam prices are a matter of public record. This is the least expensive of all thermal systems employed in the United States. To obtain a comparison of hot water flash steam plants, it is necessary to use developments outside the United States for performance factors. Economics of hot water flash to steam projects continue to be impressive. Cerro Prieto's development is very encouraging as exploratory work confirms this development can exceed 500 mw. The improvement in heat recovery with double flash units would reduce the cost of electricity and increase the size of reserves significantly. Seventy-five megawatts have now been developed and work is underway on the next 75 megawatts. The first unit of 75 megawatts was developed for $264/kw and produced electricity for approximately $.008, tax free. Today, costs would be about twice that amount. The cost includes the well field operation as this is an integrated operation. It is estimated the second 75 megawatt plant will produce electricity for about 16 mills, tax free.

It is possible to use the development work at Momotombo Nicaragua to evaluate the costs of developing a hot water flash field today. DeGolyer McNaughton, the international consulting firm, and Herman Dykstra, a reservoir engineering consultant, have completed examination of all the field test data from Momotombo. Tests using bottom hole pressure devices in selected wells were combined with field flowing tests. The firm concluded that double flash turbines could produce 96 megawatts for more than 30 years using the portion of the reservoir developed. Subsequent completion tests have demonstrated more than 100 megawatt capacity.

Turbine specifications prepared provide for a plant turbine with 80 psig first stage and 20 psig second stage. The power plant for this 225° C. field may have two 35 megawatt units in operation by mid-1980. The estimated cost for the electricity generating plant installed will be $460 per kilowatt. A savings of $26 million in foreign exchange would result from this development.

Steam

Geyser's steam price is about as inexpensive as geothermal energy can be produced today. The 1979 price of 17.5 mills per kilowatt hour is well below the competitive value of this energy. Twenty-five mills per kilowatt hour would be a price more nearly reflecting its actual value in an area using oil or coal for electricity generation.

PG&E's plant #15 is expected to cost $320 per kilowatt with provisions for H_2S treatment. This is an increase of 250 percent over the average of the 1961-1974 period. In the same period, the cost of electricity generated averaged about 5.6 mills per net kilowatt hour. 1979 operating costs will have increased the busbar price to 25 to 30 mills per kilowatt hour.

Summarizing the preceding discussion on comparison of costs and resultant prices of electricity, we can tabulate oil, coal, nuclear versus geothermal as follows:

	Oil	Coal	Nuclear
Fuel mills per kilowatt hour	20-23	9-11	6-7
Plant $/kw	400-500	780-1000	1000-1200
Electricity Busbar mills/kwh	33-34	38-40	38-40

	Geothermal		
	Steam	Flash 450°F.	Binary
Fuel mills per kilowatt hour	17.5	18-22	26-30
Plant $/kw	320	450-475	500-1000
Electricity Busbar mills/kwh	25-30	27-32	40-48

Reserve Esitmates

With these competitive conditions and an idea of the required investments in plant and fields, we can estimate the potential reserves identified in relation to the proven reserve.

The proven reserves of the Geysers is now 1507 megawatts. The potential reserves are another 1200 megawatts. To infer that the hot water area surrounding the dry steam reservoir will produce waters that will be used in flash steam plants is reasonable. Inferred hot water flash reserve should be approximately 1,000 megawatts.

The proven reserves in the Imperial Valley are 400 megawatts. Potential reserves of Brawley, East Mesa, Heber, Niland, and Westmoreland total 1600 megawatts. Reserves have been inferred with anothe 1,000 megawatts in these and similar anamolies within the province. Considerable work must be done on conversion systems, and deep drilling in the California portion of the Imperial Valley if another 5,000 megawatts are to be moved from the resource category into the reserve category in the next 20 years.

In the western Utah area Roosevelt is the only area with proven reserves. It appears that sufficient testing and plant design work has been completed to assign 80 megawatts to that classification. 120 megawatt potential and 300 megawatt inferred reserves can be assigned to Roosevelt on information now available. The remainder of that general area including Cove Fort - Sulfurdale, Thermal-Black Mountain, should have 1,000 megawatts potential reserves and 500 megawatt inferred.

Dixie Valley should have 100 mw potential if continuity of productive zones can be established. Another 400 mw may be inferred on similar anomalies within the Valley. South Nevada from Tonopah to Ely should contain 500 mw of potential and inferred reserves. Testing of potential areas in Nevada has not progressed to the stage where proven reserves can be assigned. The potential reserves of Phillips' three areas, and Chevron's two areas in the norhtern half of the state, indicates 400 megawatt reserve. An additional 600 megawatt can be inferred on the basis of drilling data being extrapolated with geophysical surveys. With continued confirmation success in the Carson sink area, an additional 500 megawatts could be moved from resource to inferred reserves. New Mexico's Valles Caldera is considered as having 100 megawatt potential reserve. From the size of the anomaly and the temperature indicated by surface springs, an inferred reserve of another 300 megawatts should be assigned. This area has a total reserve of 400 megawatts.

Summary

Electricity Generation Reserves

	Proven (Measured) MW	Potential (Indicated) MW	Inferred (Geol-Geoph) MW
Geysers	1520	1240	1000
Imperial Valley	400	1600	1000
Coso-Lassen			700
Long Valley Mammoth			
Randsburg			
Dixie Valley		100	400
Roosevelt	80	120	300
Cove Fort			
Sulfurdale			
Black Mountain-Thermal		300	400

	Proven (Measured)	Potential (Indicated)	Inferred (Geol-Geoph)
N. Nevada - Fallon to Winnemucca		400	600
S.Nevada Tonopah to Ely		200	300
New Mexico		100	300
Alvord Area		100	100
Alvord to Vale			300
Subtotal	2050	4160	5400
Total	11,600 megawatts		

The direct use of geothermal heat in the United States is on a local project basis except in Klamath Falls, Oregon and Boise, Idaho. Local greenhouse operations, individual processing plants in industrial and agricultural projects, are found throughout the western United States, Alaska, Texas and the southeast Appalachians. It is estimated these present direct uses represent proven reserves of 35 megawatts. It is easy to estimate the direct use potential is two to three times the 11,600 mw indicated as electricity generation reserves. The geographic distribution of direct use reserves is the major constraint to such development.

Reserves cannot be assigned to geopressure-geothermal projects. It is hoped the government research work in progress can develop sufficient data to provide inferred reserves in 20 years. The resource is large but definition criteria are not established.

An oil accumulation to provide 164,000,000 barrels per year for 30 years would require 4.9 billion barrels to be available for production. Consider that less than 0.2 of 1 percent of all wildcats drilled in the United States during the last four years discovered producible reserves over the life of the field greater than 1 million barrels of oil.

To assess the impact of the development of this reserve now identified plus the stimulus such development will give to exploration requires an assumption that the governmental agencies believe indigenous sources of energy are necessary to the economy of the U.S.A.

Stanford Research Institute, The University of California, Riverside, and Science Application Ind. have each provided thoughtful studies on the effect of tax incentives for the development of geothermal resources. The effect of such tax treatment has been focused on the resulting price of electricity or upon how much income this would "shelter" for the producer. This focus should be changed. The size of increased resources resulting from incentives should be emphasized.

Each study has sidestepped critical questions of: How large a capacity can be economically developed from recognized prospects with the subject incentives? How many would be developed lacking such economic stimuli? What is the flow back to the government agencies in tax revenues if certain incentives are initiated? This demands careful analysis of the possibility of reduced tax flow from projects that are certain to be developed without the incentives versus the increased tax revenue from those projects that would not have been developed without the incentives.

Consideration of the dynamic effect of taxation regulations on an incipient industry will show a tremendous benefit to government agencies in increased tax revenues. Robert Rex prepared the following illustration demonstrates the flow of monies to federal, state and county agencies for a single 48 net megawatt project on federal lands.

ESTIMATED GOVERNMENT REVENUES FROM FIELD DEVELOPMENT PROGRAM

EAST MESA 48 MW PROJECT

10 percent federal royalty payments	$ 70,200,000
federal income taxes	67,110,000
state income taxes	16,590,000
ad valorem taxes	59,700,000
	$213,600,000

ASSUMES 25 MILS/KWH - 30-YEAR PROJECT LIFE - 6 PERCENT ANNUAL INFLATION RATE

If the reserves now known on federal lands are developed, additional ones will be added in the process of development and by the increased exploration attracted to the area of successful development. Five thousand megawatts production on federal lands and two thousand megawatts on non-federal lands should return to the government $903 million in revenues each year over the first 30 years of the projects' lives. $7.02 billion would flow to the federal government as royalty, $9.4 billion as income tax. $2.3 billion would be allocated to the various states' income tax revenues and more than $8.4 billion to local county governments as ad valorem taxes.

Summary

In 1973 the geothermal reserves in the United States were 500 megawatts. reserves identified since 1970 total about 11,100 megawatts. This is enough energy to supply the total electrical needs for 11,000,000 people. To generate the same electricity using fuel oil, 164 million barrels per year would be needed. Five billion barrels of oil would need to be discovered to supply the equivalent energy for 30 years.

Geothermal energy can compete with the other types of energy now being used in the United States. To do so, the energy must be available from its reservoir at a temperature above 400° F. Below this temperature, operating costs rise significantly as the number of wells to produce and reinject the fluid increases.

Tax incentives must be provided to encourage significant investment in the mid-temperature hot water resources if this type energy is to be developed.

The cost of the plants rise rapidly as the temperature of the reservoir decreases. The volume of fluid required to move through the system increases rapidly to supply the required heat. There are economic limits established by temperataure that must be recognized. If the Btu content of a ton of coal drops, there is a point where it is not useable for power production. The same is true for oil and gas fluids as their associated water or inert gas ratio increases. Geothermal fluids quality and usefulness is also dependent upon its Btu content per unit volume produced. The building of power plants for mid-temperature projects is critical to the utilization of this large resource.

For this reason, it is difficult to present a specific cost of electricity produced by broad types of resource. The probable range of prices for electricity generated from steam and hot water reservoirs today is:

Steam 450 degrees F and above	24-30	mills/kwh
Hot water flash - below 400° F	36-50	
above " "	27-32	
Binary	40-48	

Research must continue on how to make fluids with temperatures below 400°F. useful. The technology is now mature. There are vast quantities of heat in this resource awaiting the solution to the economic problems of using this low grade heat.

Risk capital must be readily available in units of 10 to 15 million dollars at the beginning of exploration. Development to 400 megawatts may require up to $100 million investment before payout of the first 50 megawatt unit is obtained. The investors with sufficient money to carry out a successful program will compare the return of invested capital offered by similar projects (utilizing similar technology and business know-how). The projects offering the best rate of return for similar risk and investment will usually be the ones selected for funding.

The biggest problem in obtaining risk capital is the uncertainity of the business. This includes the discrimination in tax treatment of hot water versus steam. This precludes being able to market the energy at competitive prices and obtain as favorable rate of return as other industries offer. Prospective investors should have assurance that government rules and regulations will encourage the discovery and use of this energy.

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ELECTRICAL RESISTIVITY TECHNIQUES

IN GEOTHERMAL EXPLORATION

INTRODUCTION

Analysis of geothermal exploration case histories from about a dozen countries shows that electrical resistivity is a most powerful geophysical exploration technique for geothermal resources (Meidav and Banwell, 1972, in press).

Electrical resistivity techniques measure the specific resistance of rocks of any depth to the flow of electricity. The resistivity of water-saturated rocks depends upon the rock temperature, salinity of the saturating fluid, clay content, formation factor, and steam or gas content.

The resistivity in geothermal areas is usually lower than the resistivity in the surrounding non-thermal areas, because most of the above factors tend to work together to reduce the resistivity of geothermal reservoirs. The resistivity contrast between hot, water-saturated rocks within the geothermal area and the colder surrounding rocks may be as great as 1:100 but is often of the order of 1:5 (Meidav and Banwell, 1972). Because of that great contrast in electrical properties between hot rocks and the colder surrounding area, electrical resistivity techniques have proven invaluable in geothermal exploration (cf. for example Banwell and MacDonald, 1965; Meidav, 1970; Keller, 1970).

The resistivity of vapor-dominated reservoirs can be higher than that of surrounding rocks, thus creating an important exception to the above rule.

In liquid-dominated systems, the relationship between the resistivity of the rock, the salinity of the saturating fluid, the formation factor and the temperature are graphically shown in Figure 1. It is seen that by measuring the resistivity on the earth's surface (labelled "Rock Resistivity"), by estimating the formation factor of the rocks it is possible to either estimate the temperature of the reservoir fluids (if the salinity is known) or to estimate the salinity, if the temperature at depth can be approximated.

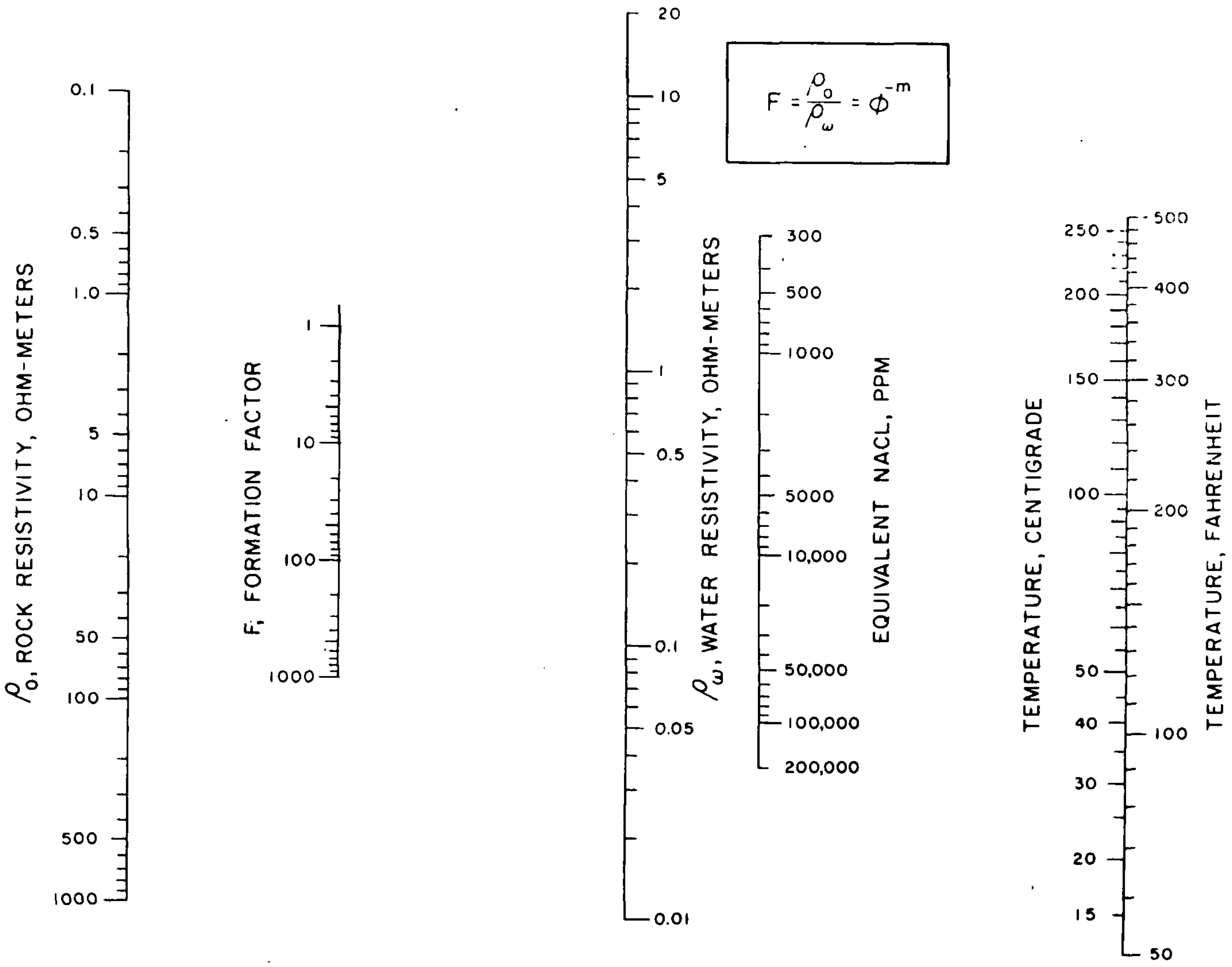

Figure 1. A nomogram for relating resistivity, which is measurable on the earth's surface, to temperature or salinity of the rocks at depth.

1. RECONNAISSANCE RESISTIVITY TECHNIQUES

A. THE ROVING DIPOLE TECHNIQUE

The roving dipole technique is designed to facilitate rapid reconnaissance of large areas, in order to select specific targets for detailed investigation. The advantage of this technique is that it is lower in cost per unit area, is faster than other methods, and does not require straight survey lines, making it especially useful in rugged terrain. The shortcoming of the method is that it only provides a general evaluation of the areas surveyed

Figure 2 is a map showing the resistivity contours derived from illuminating a geothermal area in Indonesia from two different locations. Although in agreement generally, the difference between the two sets of contours reflects the difference in effective probing depth at each receiver station relative to sources A and B.

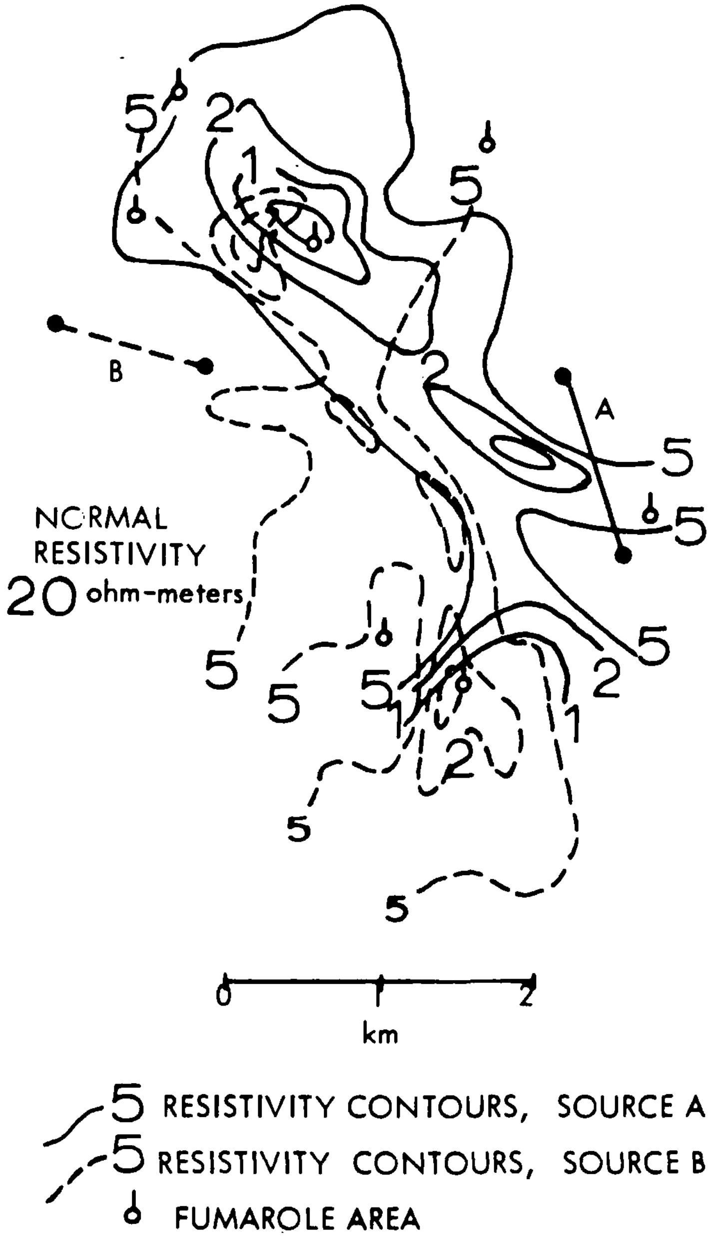

Figure 2. Roving dipole survey, Indonesia, using two different transmitter locations (A and B). The low resistivity areas coincide with the location of surface thermal features (fumaroles).

The interpretation of roving dipole data is facilitated through the preparation of electrical conductance maps. At large transmitter-receiver distances, in areas underlain by a very resistive basement, conductance maps are not affected as much by the distance factor as are the resistivity maps. Figure 3 schematically shows the electrical conductance profiles that would be obatined over two common geological situations. It should be noted that at short distances the apparent conductance C_a is not equal to the true conductance because at short transmitter-receiver distances, the physical condition for establishing conductance (i.e., a large distance from the source compared with depth to the basement) is not fulfilled. However, by multiple-illumination, i.e. by roving across the area in more than one direction, it is possible to establish the correct conductance value of the area. Moreover, multiple coverage permits some preliminary three-dimensional determination of conductivity and thickness components of the area under investigation.

Roving dipole techniques also permit the execution of detailed depth soundings in the vicinity of each of the widely separated current electrodes. Such soundings may be referred to as monopole soundings. They provide very smooth data, when no lateral discontinuities exist.

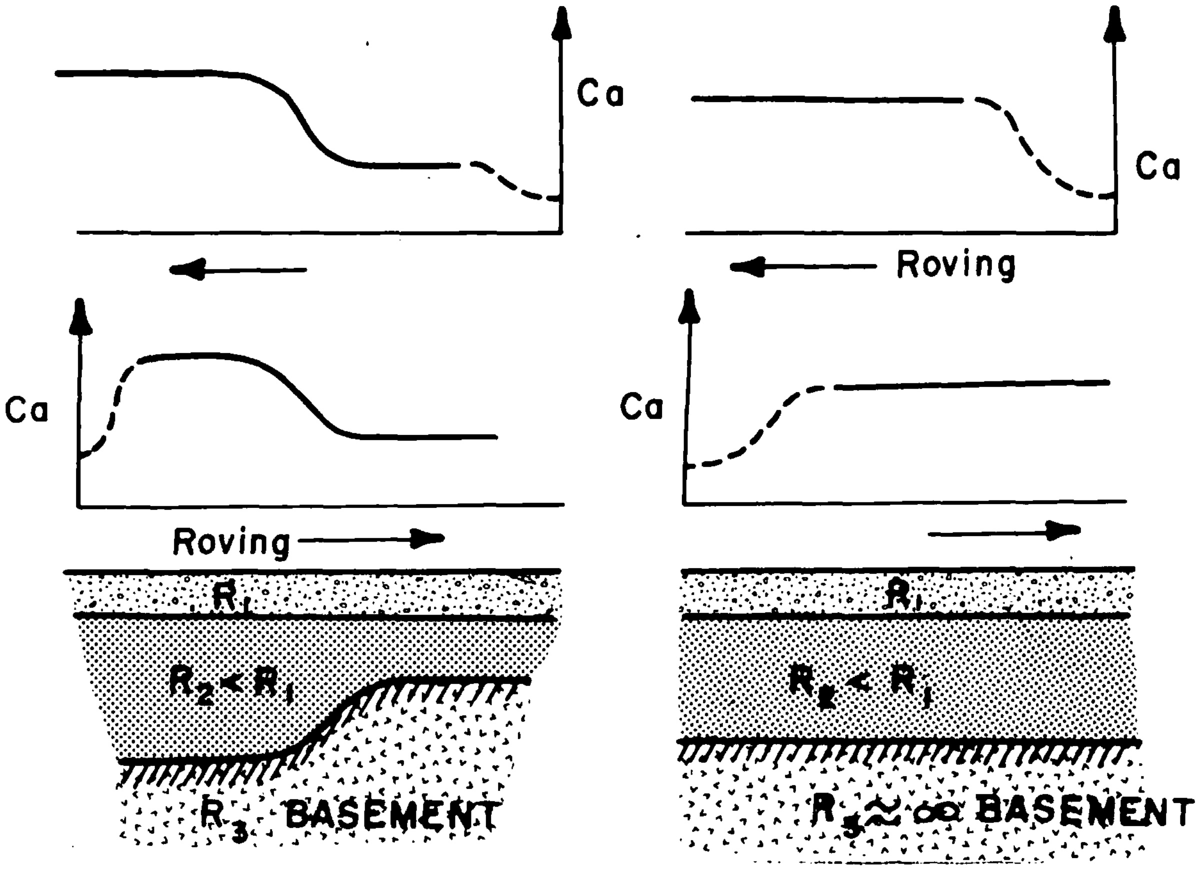

Figure 3. Synthetic apparent electrical conductance (C_a) profiles over a three-layered earth, where the middle layer is the most conductive one. Note that at short distances, the apparent conductance (broken line) is different from the true conductance (solid line)

B. CONSTANT DEPTH PROFILING

This technique also provides a rapid reconnaissance of large areas. Its advantage, as with the roving dipole method, lies in speed. Its major disadvantage lies in the need to carry the transmitter to the center of the station to be explored, which might be logistically difficult in some cases.

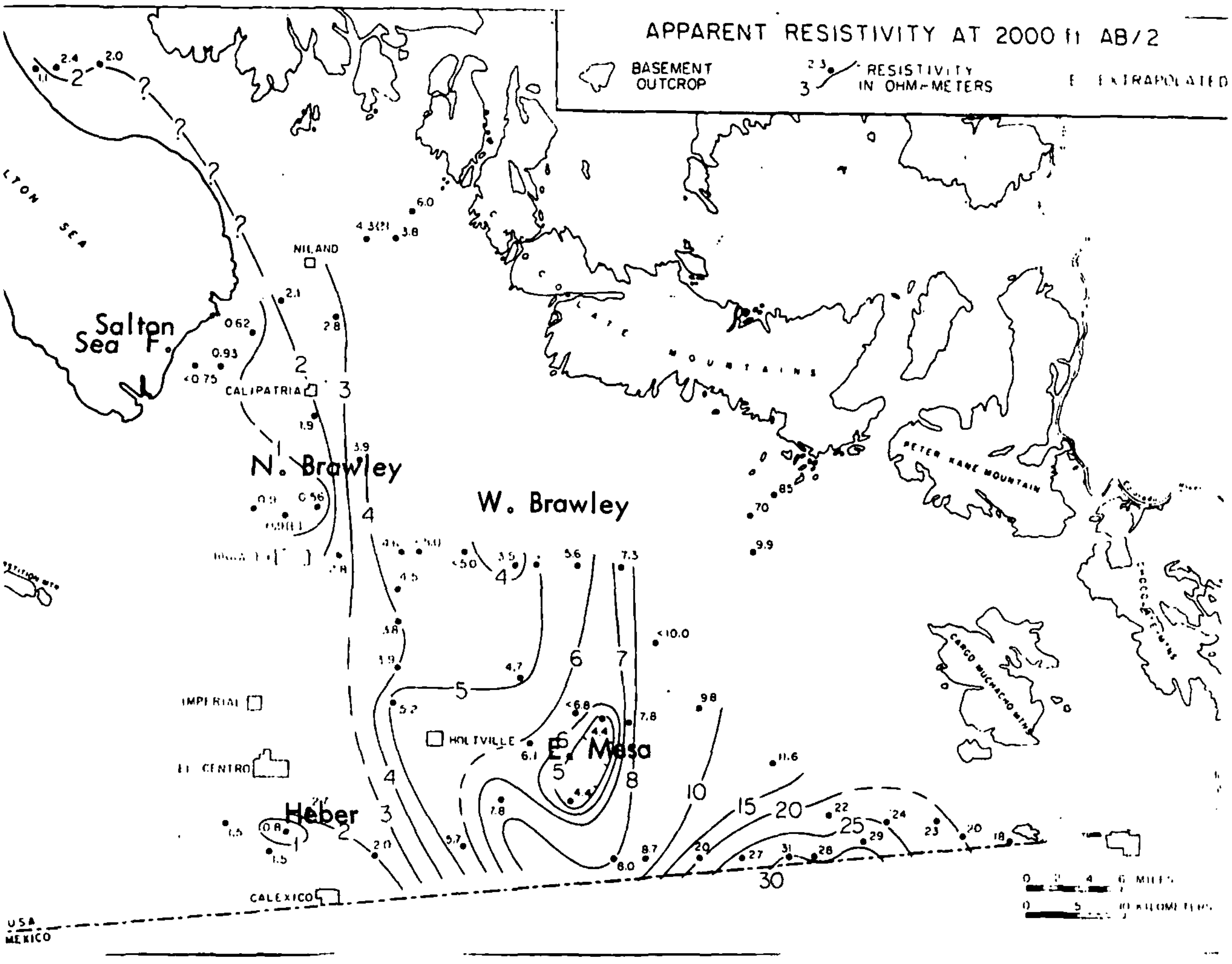

Figure 4. Apparent resistivity map for a 2,000' constant depth profiling of the Imperial Valley, California. Note the regional resistivity gradient upon which the various geothermal fields, partly discovered through this resistivity survey, are superimposed.

2. SEMI-DETAILING TECHNIQUES

DIPOLE-DIPOLE PROFILING

The dipole-dipole technique has been extensively utilized in mineral exploration, and recently in geothermal exploration. The advantage of the dipole-dipole technique is that it provides a resistivity cross-section in line of the dipole-dipole profile. It has been successfully employed by the U. N. in Kenya in delimiting the boundaries of a geothermal field, as well as the location of a major fault running through that field.

The dipole-dipole technique may be regarded as a semi-detailing technique. It is slower than the roving dipole technique, but provides greater detail along the profile. This technique requires reasonably straight lines to be run. It may be used to advantage to obtain finer details of anomalies detected by any of the reconnaissance techniques, or, if funds permit, as both the reconnaissance as well as detailing technique. However, depth computations from dipole-dipole data must be evaluated with some caution, because the very shallow resistivity distributions (at depths less than 1.4n), which greatly affect the rest of the deeper data are not normally available.

3. DETAILING TECHNIQUES

SCHLUMBERGER DEPTH SOUNDINGS

The Schlumberger depth sounding technique has been employed successfully for detailed determination of layering in terms of electrical resistivity of earth strata to a great depth (cf. for example, Meidav and Furgerson, 1972). This technique is the most proven of the various depth sounding techniques, with a very large repertoire of experience for interpretation of the data. The technique is used to resolve some of the finer details of the geologic structure of the area. A survey utilizing the Schlumberger depth soundings exclusively has been conducted across the Imperial Valley of California (Meidav, 1970). Three of the residual resistivity lows have been drilled after the conclusion of that survey, confirming the relationship between resistivity lows and temperature highs. Figure 5 shows the resistivity cross-section which was derived from the Schlumberger depth soundings. We predict that the Brawley resistivity low will prove the existence of a significant geothermal reservoir when drilled eventually.

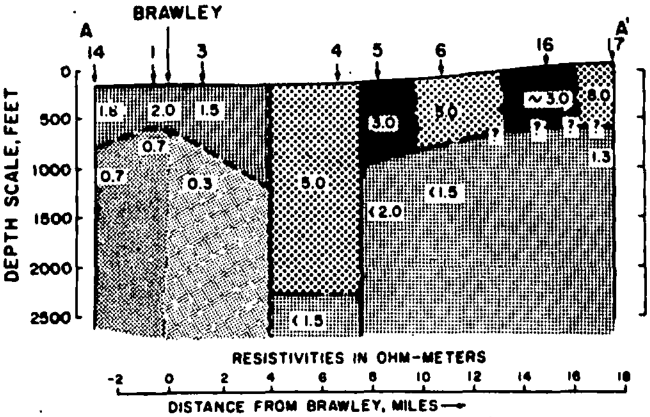

Figure 5. A resistivity cross-section across the North Brawley anomaly in the Imperial Valley, showing the location of suspected faults, and the very low resistivity associated with the Brawley geothermal field. The cross-sections were constructed from resistivity depth sounding data.

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GEONOMICS, INC.
Exploration, Evaluation, and Development of Natural Resources

Newsletter No. 6

Tellurics and Magneto-tellurics in Geothermal Exploration

Electrical resistivity has been commonly utilized for geothermal exploration. Practically all of the known liquid-dominated geothermal reservoirs around the world are characterized by a low resistivity anomaly. The classical approach to the determination of resistivity has been through the use of impressed electrical currents. For geothermal exploration, where incressingly greater depths are being investigated, large electrical power generators are required.

An alternative approach to investigation of the resistivity of the earth is through the use of telluric currents. These natural alternating currents constantly flow in the earth. It is possible to determine the relative conductance of the earth (which is a product of electrical conductivity times thickness) by measuring the relative amplitude of these natural currents at a number of sites simultaneously. The advantage of telluric current exploration is that it is considerably less expensive than any of the induced-current techniques per unit area covered. Basically, it may be considered as a conductance anomaly detection technique. Any anomaly detected would then have to be further analyzed in order to determine the specific conductivity-thickness layer distribution.

It is possible to determine a complete apparent conductivity-versus-depth distribution by recourse to magneto-tellurics (MT). In the MT approach, both the electrical current fluctuations in the earth and the feeble magnetic field fluctuations above are simultaneously recorded. The ratio of the electrical field amplitude to the magnetic field at any given frequency yields the apparent resistivity of the rocks to a depth which depends on the specific frequency. By carrying out an analysis of the ratio of electrical/magnetic amplitudes at different frequencies, it is possible to construct a resistivity-depth graph.

The advantage of MT lies in the absence of need for generators or long wire layout in the field. Hence, MT is particularly useful in rugged terrain operations. Depending upon the depth of exploration desired, one to three stations per day may be occupied. MT cannot be employed easily near cultural noise such as high-power transmission lines.

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In an area such as the Imperial Valley of California, where exceedingly low resistivities have been encountered (less than 0.2 ohm-meters), Geonomics' experience indicates that MT could supplement conventional resistivity in extending the resistivity cross-section to a greater depth.

The unique approach which Geonomics offers to telluric and magneto-telluric exploration is based upon an optimum blend of the two techniques, resulting in a low cost exploration program per unit area covered.

Dr. Ward

from World Oil, vol. 177, #7

Energy shortage stimulates geothermal exploration

Robert L. Fuchs, President, Geosystems Corp., New York, and **Warren H. Westphal,** Vice President, Intercontinental Energy Corp., Denver, Col.

10-second summary

Geothermal resources are attracting increasing attention as a potentially important contributor to the U.S. energy equation. This article discusses the various types of geothermal deposits, necessary geological conditions, projects now underway, exploration methods used, current activity and the possible impact of this energy source on U.S. requirements.

EXTENSIVE exploration programs now are underway in the western United States to evaluate potential of geothermal energy. A variety of companies are involved in the effort, including many gas and oil producers.

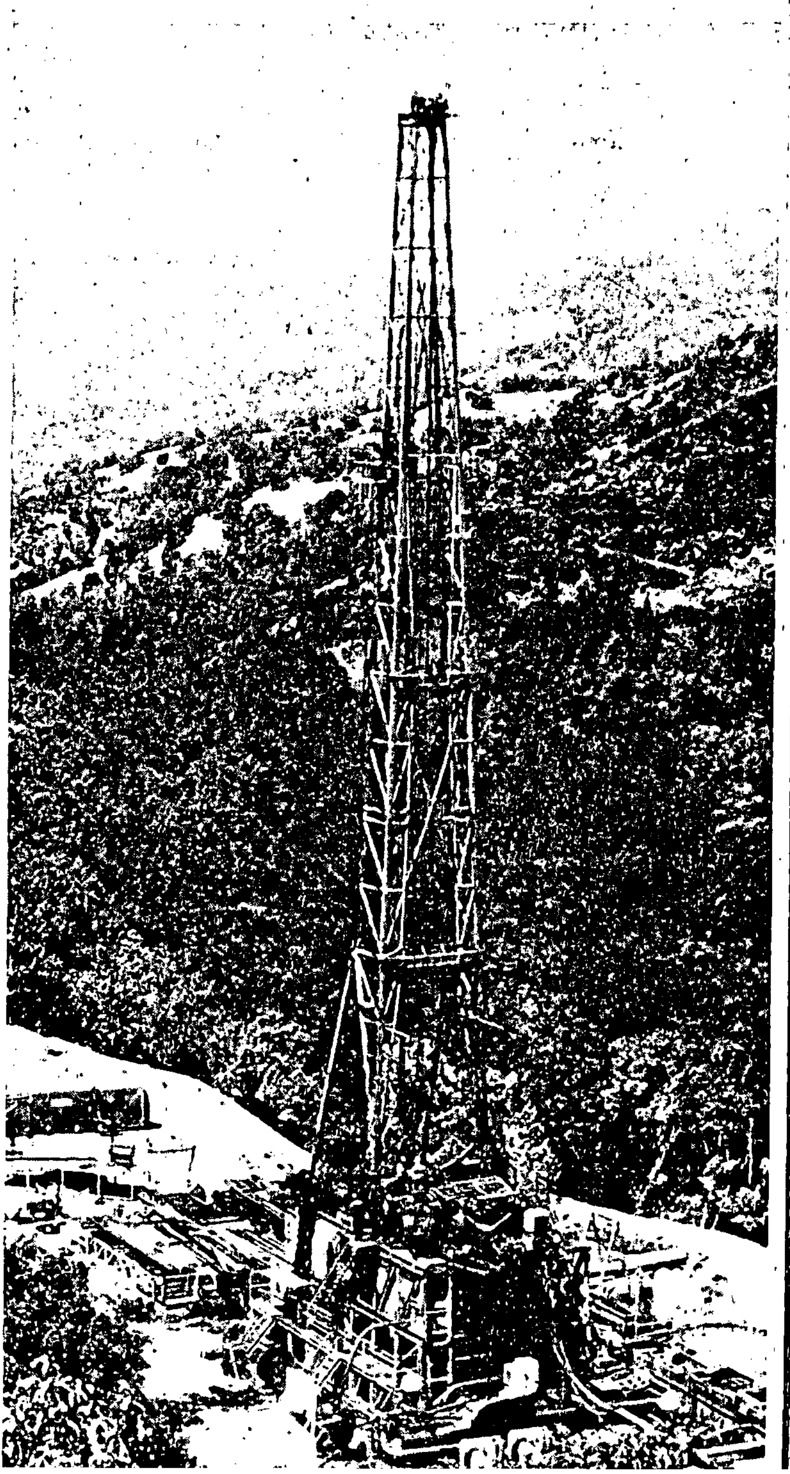
Advantages of geothermal energy as a power source can be demonstrated, and these account for its increasing stature in the energy picture. Environmental impact of electrical power generation using geothermal energy is well below that of other power systems, even though noise, noxious gases and waste water may have to be contended with in the field.

Energy reserves appear to have a long life, although geothermal fields cannot claim to be entirely non-deplet-

EDITOR'S NOTE

Geothermal energy may prove to be an important future U.S. power source. However, extent and potential of geothermal resources in the United States remain virtually unknown, since exploration still is in its infancy and government red tape still precludes investigations in many highly potential areas.

Exploring for and developing geothermal resources involve many of the same techniques and equipment used in finding and exploiting gas and oil reserves. This two-part special report presents latest information on technology used in geothermal operations and points out both advantages and limitations of geothermal energy.



Heavy drilling equipment is required in Geysers field development. This Hoover Drilling Co. rig completing a steam well in the eastern sector of the field is one of three rigs currently active at The Geysers. ➧

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Exploration Strategy for High-Temperature Hydrothermal Systems in Basin and Range Province[1]

S. H. WARD, H. P. ROSS, and D. L. NIELSON[2]

ABSTRACT

A 15-phase strategy of exploration for high-temperature convective hydrothermal resources in the Basin and Range province features a balanced mix of geologic, geochemical, geophysical, hydrologic, and drilling activities. The strategy, based on a study of data submitted under the Department of Energy's Industry Coupled Case Study Program, provides justification for inclusion or exclusion of all pertinent exploration methods. With continuing research on methods of exploration for, and modeling of, convective hydrothermal systems, this strategy is expected to change and become more cost-effective with time. The basic strategy may vary with the geology or hydrology. Personal preferences, budgetary constraints, time and land position constraints, and varied experience may cause industrial geothermal exploration managers to differ with our strategy. For those just entering geothermal exploration, the strategy should be particularly useful; many of its elements may apply in other geologic settings.

INTRODUCTION

Geothermal energy is derived from the heat of the earth. The average heat flowing conductively to the earth's surface is 0.08 W/sq m. If we multiply this value by the total surface area of the earth (5.1×10^{14} sq m), we obtain the total heat flowing from the earth as 4.1×10^{13} W or 41,000,000 MW. Only a fraction of this energy can be extracted economically under current market conditions. However, the crust of the earth contains local hot spots from which extraction of energy, either for direct heat applications or for conversion to electricity, is economical at present.

Geothermal hot spots are manifested as a continuum of seven accepted resource types: magma, hot dry rock, convective hydrothermal, geothermal gradient, deep sedimentary basin, geopressured, and radiogenic. Within the Basin and Range province the most important high-temperature resource type, and the one with which this paper will be specifically concerned, is the convective hydrothermal system.

A generalized model of a convective hydrothermal system is shown in Figure 1. By way of fractures and faults, cold meteoric water descends to the vicinity of a heat source where it heats and convects upward through other structures to the upper parts of the system. Here it is discharged as hot springs, flows laterally along permeable horizons, or is prevented from escaping by a cap rock of low permeability. Many systems may reach temperatures of over 350°C, although temperatures of 275°C and less are more common. In relatively rare instances, boiling at the upper surface of a water table may produce a vapor-dominated hydrothermal system (White et al, 1971).

Hot-water-dominated convective hydrothermal systems are generally classified as high temperature ($>$150°C), intermediate temperature (90 to 150°C), and low temperature ($<$90°C; White and Williams, 1975; Muffler, 1979). Although some of these systems may derive their heat from still molten or hot, crystallized plutonic masses (Smith and Shaw, 1975), others show no association with recent plutonic activity but derive their heat from deep circulation along fault zones in areas of high thermal gradients.

CHARACTERISTICS OF CONVECTIVE HYDROTHERMAL SYSTEMS

Although generalized cross sections of convective hydrothermal systems (Fig. 1) are instructive for showing basic characteristics, these systems are much more complex than the figure indicates. Indeed, the lower parts of the systems, and in particular the heat sources, are speculative. In this paper we shall refer to specific hydrothermal systems in Nevada and Utah (Fig. 2). Figures 3, 4, and 5, as examples, show interpreted cross sections through the upper parts of geothermal systems at Roosevelt Hot Springs, Utah, Cove Fort-Sulphurdale, Utah, and Leach Hot Springs, Nevada. These figures emphasize the structural geology of these areas; unfortunately insufficient work has been done to document the fluid-flow paths within them. Roosevelt Hot

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Doris Cullen, Connie Pixton, and Jeff Hulen prepared the illustrations, Sue Moore and Lucy Stout prepared the manuscript, and D. S. Chapman, G. Crosby, W. E. Glenn, J. N. Moore, R. L. Tabbert, P. M. Wright, and W. Youngquist provided critical reviews of the manuscript. We thank all of them. We are especially grateful to Bob Greider for urging us to write the paper.

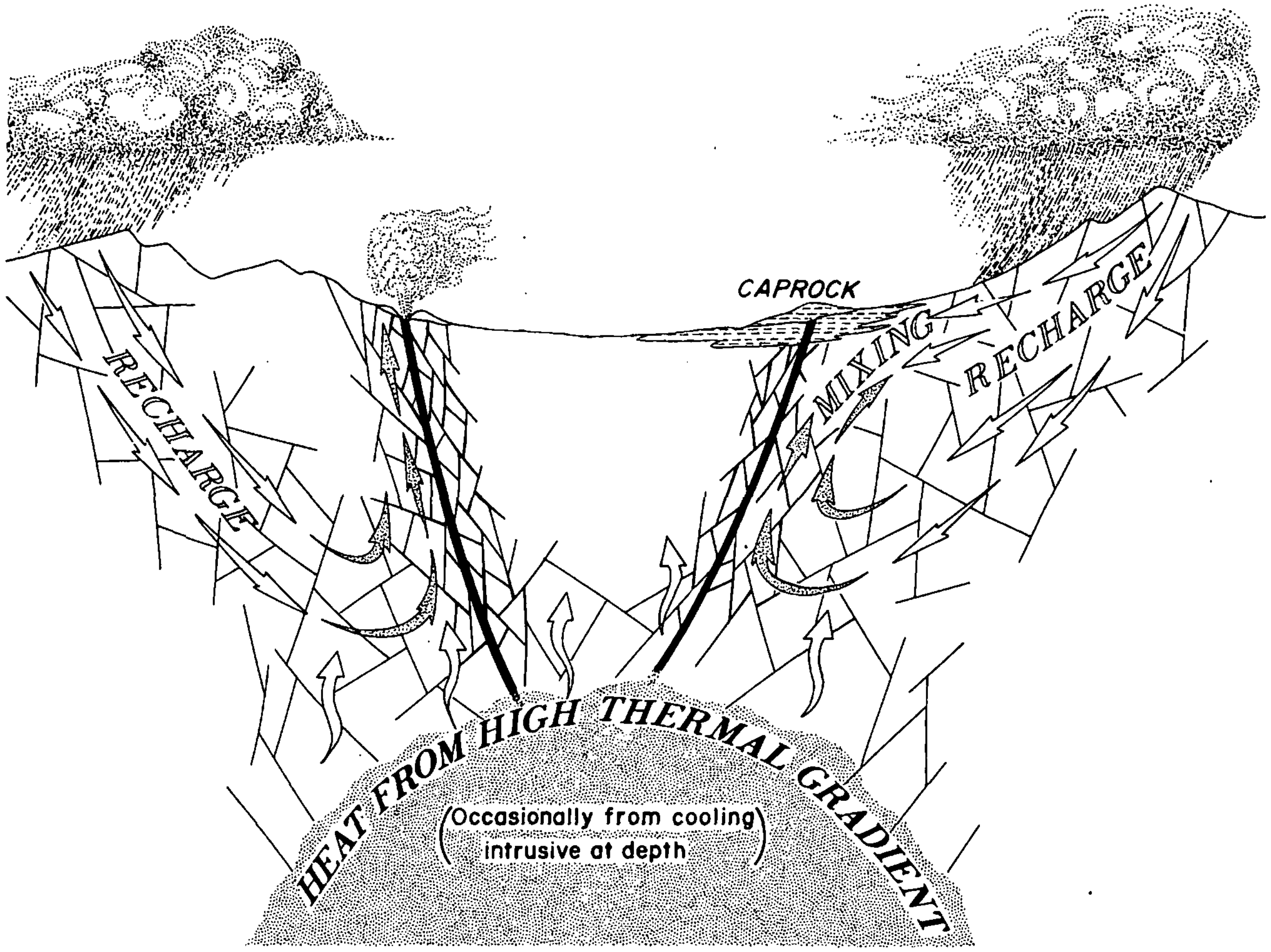


FIG. 1—Generalized model of convective hydrothermal system.

Springs is thought to derive its heat from a cooling magma body at depth; sources of heat for the other systems are unknown, but it is speculated that these systems derive their heat from deep circulation along faults in zones of high thermal gradients.

Figures 3 through 5 show that hydrothermal systems within the Basin and Range province are structurally complex and require two- and three-dimensional modeling. All have undergone several periods of faulting and some have undergone repetitive igneous intrusion. Therefore, it is crucial for the explorationist to understand which of the structures in such areas controls the hydrothermal system and to separate the latter from structures which do not channel fluids but only complicate the geology. Clearly the structure must be understood early in the exploration process for an exploration program to be conducted efficiently (Nielson and Moore, 1979).

In addition to the geologic complexity of the Basin and Range province, practical considerations must be taken into account in defining individual exploration strategies. Extreme topography in some areas complicates not only the performance of geophysical surveys but also the modeling of the results of those surveys (Fox et al, 1978). The presence of playas may negate the usefulness of some of the electrical surveys commonly used in the exploration process. In addition, saline ground waters common in this environment can produce misleading interpretations if the common chemical geothermometers are not correctly applied. The complexity of the basin fill in this province can result in stacked aquifers separated by impermeable horizons. This clearly presents problems for the interpretation of thermal measurements. The basin-fill alluvium and volcanic rocks often negate the usefulness of the seismic techniques. Our experience with the limitations of individual methods is discussed in a subsequent section.

NORTHERN NEVADA PROGRAM

In an attempt to accelerate the development of high-temperature geothermal resources by private industry, the Department of Energy, Division of Geothermal Energy, initiated the Industry Coupled Case Study Program in 1977. The program is designed to offset high initial costs and reduce exploration risk through cost-sharing with industrial partners. In exchange for the government funding, all technical data obtained as part of the agreed-upon exploration program are released to the Department of Energy and made public. In addition, a substantial amount and a variety of existing data generally emphasizing early stage exploration are acquired as part of the DOE/Company contract.

Phase I of the Industry Coupled Case Study Program resulted in contracts for work at two major geothermal systems in southern Utah. Phase II includes work at 12 high-temperature systems in northern Nevada. A summary of the data packages already submitted or forthcoming under Phase II, supplemented by a coherent program from one Phase I area, is presented in Table 1.

Although one or more companies have not submitted all of the geoscience exploration data they obtained for a given area, and hence the data reported may not be a complete list of exploration techniques used, we believe this summary reflects a representative sample of the methods used by the various companies. One is immediately impressed by the diversity of exploration strategies, although certain common denominators are evident as shown in Table 2.

PREVIOUS STUDIES

Ward (1977) summarized the exploration strategies from the literature up to the time of his writing. He referenced articles by Banwell (1970, 1974), Combs and Muffler (1973), Dolan (1975), Furumoto (1976), B. Greider (1975, unpub. ms.), McNitt (1976), and Meidav and Tonani (1976), and showed a strategy containing elements common to his own analysis for the eastern Basin and Range province and to those of the other referenced authors for the areas with which they were then familiar.

McEuen et al (1979) provided analyses of exploration architectures required for each of 12 different physiographic provinces. Their report used tables from an earlier report by Dhillon et al (1978). Table 3 (after Dhillon et al, 1978) lists the applicability of various methods obtained from sampling 35 opinions from individuals and companies. The differences between Tables 2 and 3 are numerous. The common conclusions

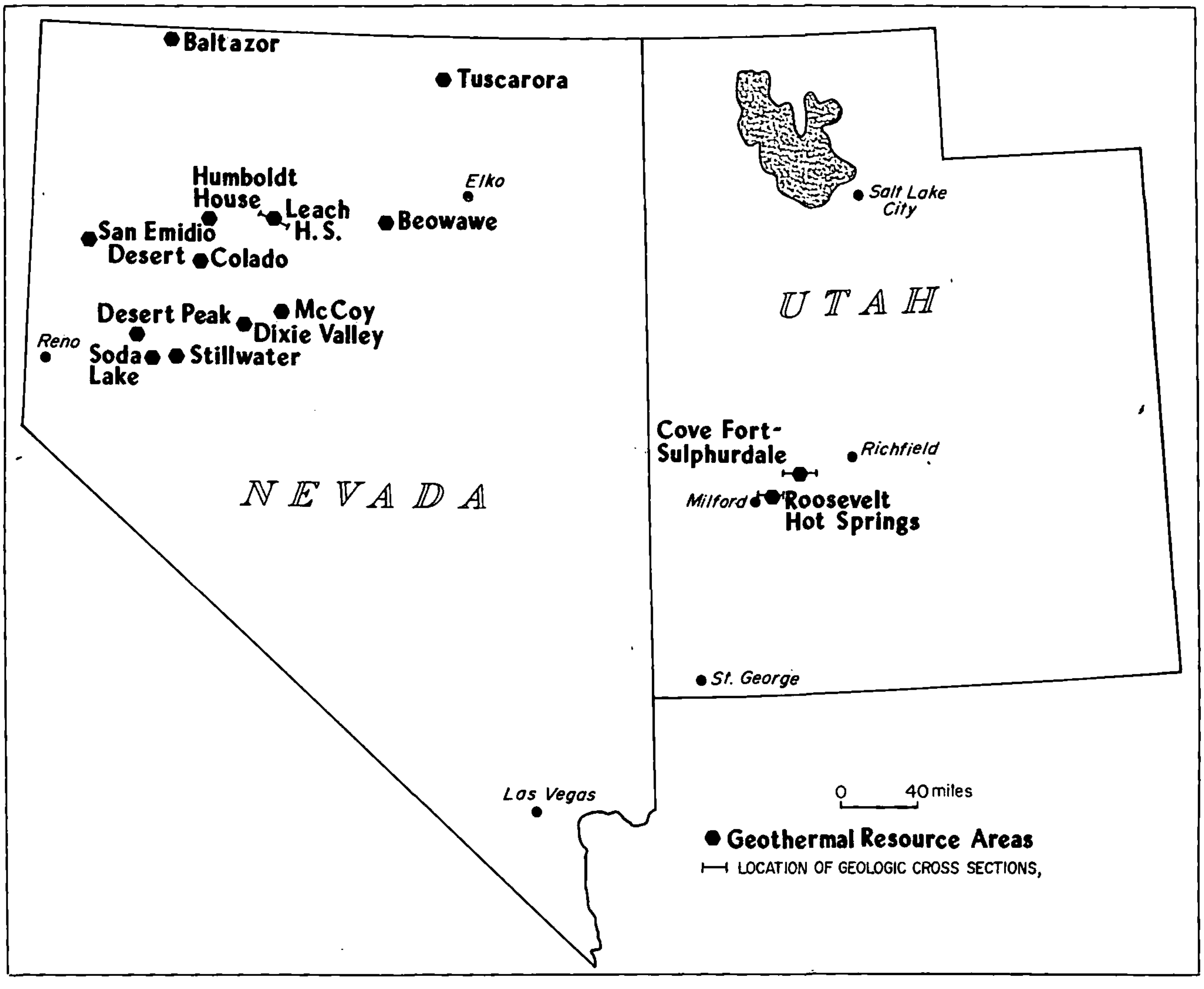


FIG. 2—Index map of Industry Coupled Program hydrothermal systems. Indicated cross sections shown on Figures 3, 4, and 5.

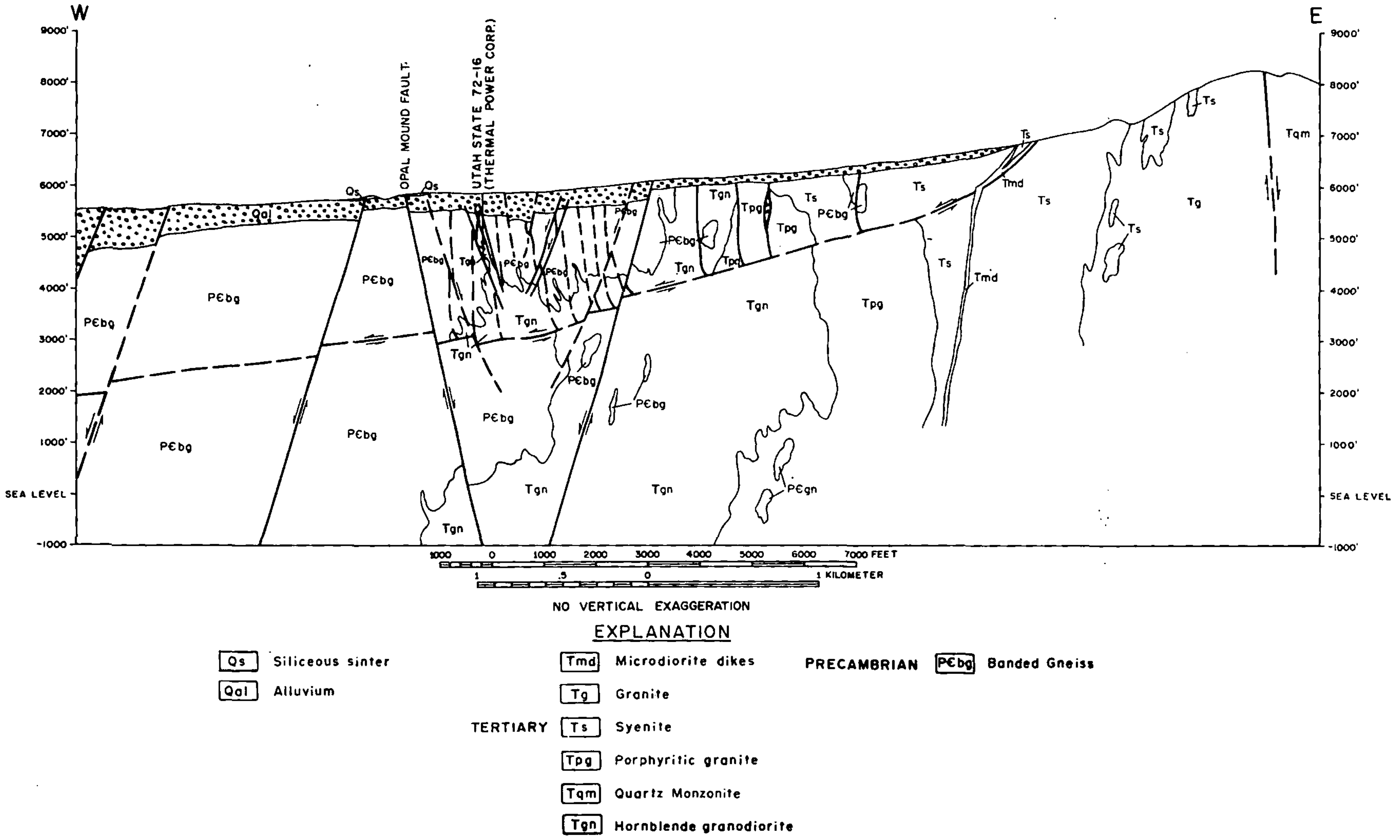


FIG. 3—Geologic cross section of Roosevelt Hot Springs KGRA, Utah (Nielson et al, 1978). Depths are in feet. For location, see Figure 2.

from comparison of the two tables are: (1) thermal methods rank universally highest; (2) surface geology mapping is usually but not always employed; (3) gravimetry is usually employed; (4) some form of electrical method is usually employed; (5) seismic, magnetic, and geochemical methods fall somewhat lower on the priority list; (6) geology and fluid geochemistry, ranked 2 and 3 by Dhillon et al (1978) are poorly represented in the deliverables from the Industry Coupled Case Study Program.

Goldstein (1977) earlier had made an analysis similar to that of the MITRE Corp., but he restricted his attention to northern Nevada. Ball et al (1979) presented an exploration, assessment, and confirmation strategy for the high-temperature resources in the eastern part of the Basin and Range province. Their conclusions are similar to the preceding six conclusions with the exception that photographic imagery and geochemical methods are of high priority in the reconnaissance phase of exploration whereas active seismic methods are of high priority in the detailed phase.

CURRENT ASSESSMENT OF METHODS

We will now consider the methods individually as listed in Table 1 and evaluate their applicability in the

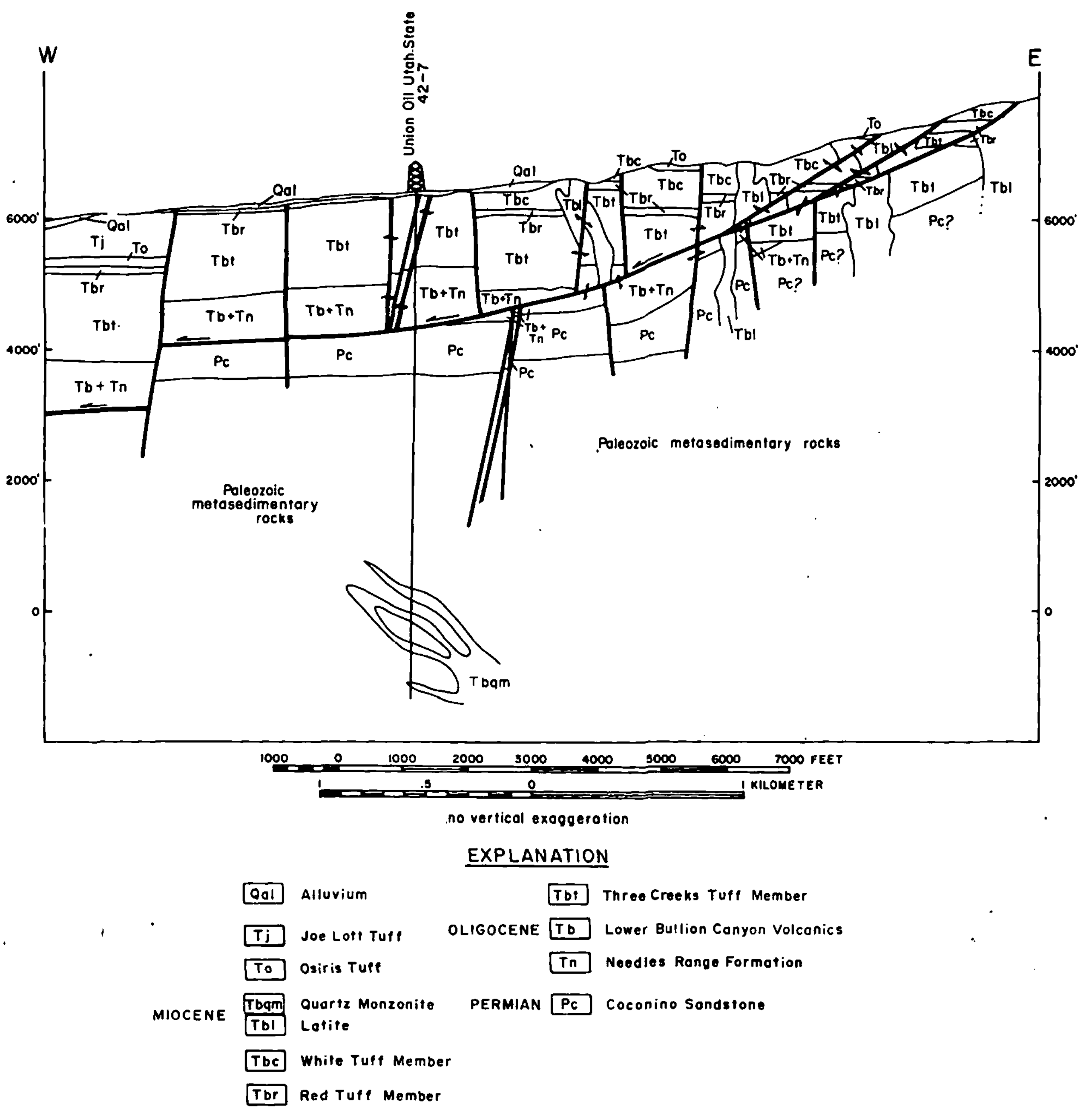
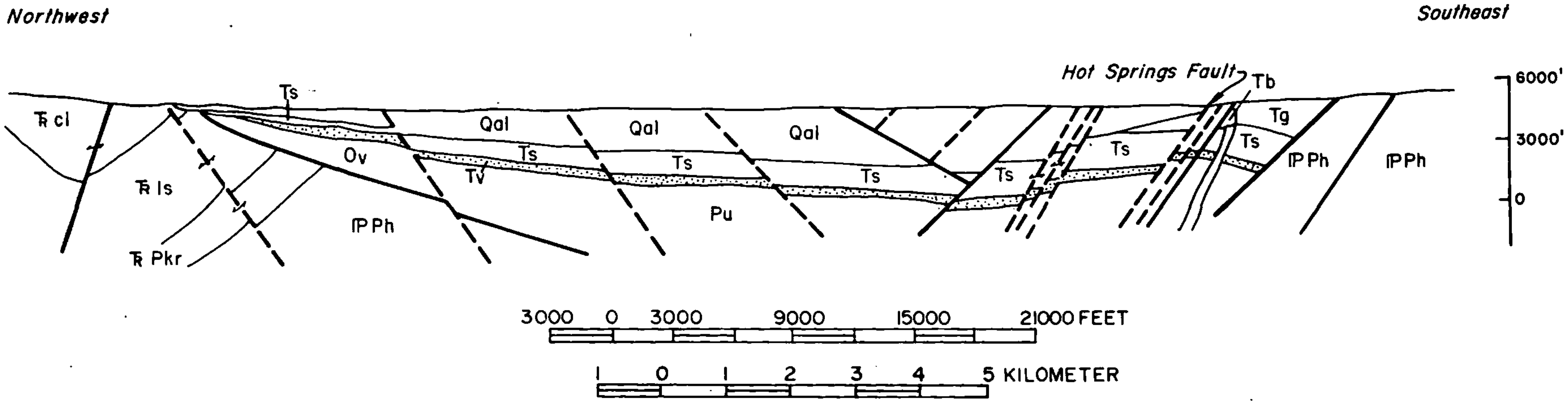


FIG. 4—Geologic cross section of Cove Fort-Sulphurdale KGRA, Utah (Moore and Samberg, 1979). Depths are in feet. For location, see Figure 2.



EXPLANATION

QUATERNARY	Qal	Alluvium
TERTIARY	Tb	Basalt
	Tg	Gravel
	Ts	Sediments and tuffaceous rocks
	Tv	Intermediate to acidic volcanic rocks
MESOZOIC	TR cl	Triassic clastic rocks
	TR ls	Triassic calcareous rocks
	TR Pkr	Koipato formation
PALEOZOIC	IPPh	Havallah sequence
	Ov	Valmy formation
	Pu	Undifferentiated Paleozoic rocks-complexly folded and faulted

FIG. 5—Geologic cross section of Leach Hot Springs KGRA, Nevada (Beyer et al, 1976). Depths are in feet. For location, see Figure 2.

Basin and Range province for areas of some surface expression.

Geologic Mapping

Our evaluation of the exploration efforts included in the Industry Coupled Case Study Program is that geologic mapping is always used in the early program stages, both regional and reconnaissance, but is then largely ignored until drill cuttings return from the first exploration hole. Detailed (1:24,000) geologic mapping of a prospect-size area, 20 to 60 sq km, is not generally done. Instead shortcuts are taken which include compilation of existing maps, photogeology, and perhaps only routine application of several geophysical methods. Complete alteration and structural studies often are omitted or are underfunded.

Our observations reveal that inadequate geologic

Table 1. Geothermal Exploration Strategy Indicated by Industry Coupled Program Data Packages

Data	Baltazor (EPP)	Tuscarora (AM)	McCoy (AM)	Leach H.S. (AO)	Colado (G)	Beowawe (G)	Beowawe (C)	San Emidio (C)	Soda Lake (C)	Stillwater (U)	Dixie Valley (SR)	Desert Peak (P)	Humboldt H. (P)	Cove Fort-Sulphurdale (U)
Gravity	E	X	X	E	E	X		E		E		E	E	E
Ground Mag.					E	X						E		
Aeromag.	E	X'	X				E				E			E
Elec. Res.					E	X	E	E	E	E				E
Magnetotelluric		X	X	X	E		E		E	E	E	E	E	
Audio Magnetotelluric					E									
Self Potential		X	X				E	E						
Seismic Emissions							E	E						E
Microearthquake	E	X	X				E							
Seismic Refl. (weight drop)							E		E					E
Seismic Refl. (CDP12 or 24 fold)			X	X			X	E	E					
Geology	E			E				E			E X	E	E	E
Geochemistry	E			E							E			E
Shallow Temperature											X			
Shallow Thermal Gradient	E	E X	E X	X	E X	X		E	E	E	E			E
Deep Thermal Gradient	X	X	X	X	X	X			E X		E X	E		E
Exploration Well	X	X	X	X	X	X	E	E	E	E	X	X	X	E X
Flow Test (if appropriate	X	X	X	X	X	X	X			X	X	X	X	X

*See Figure 2 for locations.

Company Explanation:

EPP — Earth Power Production
AM — Amax Exploration Inc.
AO — Aminoil USA, Inc.
G — Getty Oil Co.
C — Chevron Resources Co.
U — Union Oil Co. of Ca.
SR — Southland Royalty Co.
P — Phillips Petroleum Co.

E = EXISTING DATA
X = NEW PROGRAM

Table 2. Technique Use by Industry Coupled Case Study Program

Method	Cases (%)	Priority
Shallow Thermal Gradient (~100 m)	71	1
Deep Thermal Gradient (~600 m)	71	1
Magnetotelluric (MT)	71	1
Gravity	71	1
Magnetics	57	2
Geologic Mapping	50	3
Resistivity	50	3
Passive Seismic	43	4
Active Seismic	43	4
Self Potential	29	5
Geochemistry	29	5

mapping by companies may result, for example, in geophysical survey lines along major structures and thermal gradient holes being drilled inadvertently on structural intersections. Without proper recognition of these geologic features, and the bias they interject into the geophysical measurements, the survey or temperature data can be misinterpreted. We believe that detailed geologic mapping would be cost-effective as soon as a commitment is made to acquire land. This commitment would imply intent to carry out a shallow thermal gradient survey and supportive geophysics, as a minimum effort.

We do not naively ignore the possibilities of alluvial or even volcanic cover which may not warrant detailed mapping. This must be assessed as the project proceeds. Neither are we unaware of problems of land acquisition and needs for preliminary encouragement to sell an area to management. We recognize that these considerations may prevent a systematic geologic program.

We presume that detailed mapping is often omitted because it takes longer, requires an experienced and well-trained staff, and is generally still in progress when the geophysical results are obtained. We envision a continuing mapping program, depending on existing maps and outcrop availability, which would allow 1:24,000-scale mapping prior to drilling thermal gradient holes and completing detailed electrical or seismic surveys. Subsequently the base could be refined to include fracture and alteration mapping at 1:12,000 or 1:6,000 for those parts of the area which seem to have most potential. This level of mapping would be completed prior to siting deep thermal-gradient tests or exploration wells.

In conjunction with geologic mapping, it is often desirable to collect suites of samples for petrographic analysis, physical property measurements, geochemical orientation surveys, and potassium-argon and fission-track dating. The locations of these samples should be documented carefully to aid in interpretation of results.

Geochemistry

Aqueous geochemistry ranks third in usage in Table 3, and is probably not correctly represented by the deliverables in Tables 1 and 2. Chemical geothermometry and aqueous geochemistry of available springs and wells is common to most regional and reconnaissance efforts (Truesdall, 1976; Fournier, 1977). It is certainly practiced in the thermal-gradient and exploration-well stage also. The low ranking of geochemistry in Table 2 indicates that geochemical data were not submitted as a deliverable item. The low ranking could also represent the limited interest in soil geochemistry and trace-element surveys. Ewers and Keays (1977) reported well-developed zoning of volatile elements and precious metals in the Broadlands geothermal field, New Zealand. As our case studies and technique development work proceed, we find multielement zoning patterns have developed about high-temperature geothermal systems and about high-temperature fluid entries in geothermal wells (Bamford, 1978). Fluid entries have also been effectively delineated by oxygen isotopes and hydrothermal mineralogy (Browne, 1970; Kendall, 1976; Elders et al, 1978). To a large extent the distribution of radon and mercury can be used to locate zones of past and present permeability and as such can be an aid in mapping and siting of drill holes (Capuano and Bamford, 1978; Nielson, 1978).

Hydrology

No hydrologic data packages were submitted under the Industry Coupled Case Study Program, although we are aware that most companies do not neglect this fundamental data set. Regional hydrologic data are available for many of the basins in the Basin and Range, and this is undoubtedly considered in the initial compilation stages of the project. Such information as number of aquifers, elevation of water table, regional-flow patterns, and water chemistry can be extremely valuable in the initial stages of the exploration program. In addition, hydrologic information is often collected in conjunction with thermal-gradient drilling.

Gravity Method

Gravity methods are often employed. A regional gravity map, with a station density of 1 station per 3 sq km to 1 station per 25 sq km, is generally available as the result of U.S. Geological Survey (USGS) regional studies, of the Department of Defense regional data compilation, or of university-related geophysical studies. Many compilations of these data have been accepted as adequate and several companies supplement this base with detailed profiles. The method offers a relatively low-cost delineation of shallow Basin and Range faults and of alluvial thicknesses. The resolution of these features improves with quantitative numerical modeling but the method is often limited by spatial wavelength aliasing, inadequate density information, relatively small density contrasts, and lack of precise elevation control.

Ground Magnetic Method

Ground magnetic data are sometimes acquired as an addendum to the gravity survey at a modest additional

Table 3. Regional Applicability of Exploration/Assessment Technique*

Technique	Overall	Salton Trough	Basin And Range	Cas-cades	Basaltic Island Region	Snake River Plain	Wasatch Front	Rio Grande Rift	Geysers	Aleutian Arc Island	Appa-lachian	Eastern And SE Plutons	Geo-pressured
Thermal Method	1	1	1	1	2	1	1	1	1	1	1	1	2
Surface Geologic Mapping	2	9	2	2	1	2	2	2	2	2	3	5	9
Gravimetry	3	2	7	5	4	3	7	7	3	4	2	2	5
Electrical Methods	4	3	4	3	3	8	4	3	8	5	8	6	7
Borehole Logging	5	5	8	10	10	4	8	9	7	3	15	4	1
Seismic Methods	6	4	5	8	6	6	5	5	6	6	9	7	3
Liquid Geochemistry	7	6	3	4	5	9	3	4	5	7	6	8	4
Air Photogeology	8	7	6	7	8	5	9	8	4	9	7	9	12
Age Dating	9	10	9	6	7	7	6	6	9	8	10	10	14
Magnetics	10	8	10	9	9	10	10	10	10	11	4	3	6
Gas Geochemistry	11	11	13	13	11	13	13	13	11	12	11	12	8
Remote Sensing	12	12	12	12	13	11	11	11	12	13	12	11	10
Thermal Infrared	13	13	11	11	12	12	12	12	13	10	13	13	11
Other	14	14	14	14	14	14	14	14	14	14	14	14	13

*After Dhillon et al (1978).
1 = Most Applicable to 14 = Least Applicable

charge. The typical station spacing for a gravity survey may severely limit the spatial frequency content of the magnetic survey and considerably reduce its utility. Near-surface magnetic contrasts, arising mainly from Tertiary volcanic rocks within a mountain range or at shallow depth in the alluvium often dominate the ground magnetic survey and this, coupled with a limited survey area, reduces the interpretative value of the survey data. As expected, and as Table 1 demonstrates, airborne magnetic surveys are favored by most of the geothermal companies.

Aeromagnetic Method

Regional aeromagnetic data are generally available for the Basin and Range province as part of the USGS regional mapping programs. These data are normally obtained as high-altitude barometric flights with a 2 to 4-km flight-line separation. These data, as at the Baltazor and Carson Sink areas, often show major structural features and aid in forming a generalized geologic model for the prospect area. The data are not sufficiently detailed to warrant quantitative model interpretations or accurate delineation of structural or intrusive features. Follow-up surveys have often been flown at a 0.5 to 1-km line separation as draped flights 50 to 300 m above the mean topographic surface.

Data packages submitted as part of the Industry Coupled Case Study Program and discussions with companies and contractors indicate some interest in Curie point isotherm interpretation of magnetic data. Selected profiles have been flown at several altitudes in an attempt to refine these interpretations. The Curie point interpretation as applied to most known Basin and Range target areas has several problems: (1) the lateral extent of the Curie isotherm high is several times the size of a typical deep fault circulation system; (2) interference at this scale of reversely polarized volcanic units and widely varying susceptibilities complicates the interpretation; (3) there is uncertainty in determining the depth to the bottom of a prism model. Shuey et al (1977) have discussed these and other problems with Curie depth determinations. Yet another problem is multilevel data interpretations which assume two-dimensional geology in far more complex settings.

Magnetotelluric (MT) Method

If one were to accept Tables 1 and 2 at face value, then the MT method would be recommended for use in hydrothermal system exploration due to its advertised attributes of great depth of exploration and ability to detect the hot rock source of heat at depths of several tens of kilometers. Unfortunately, neither of these attributes is necessarily correct. In a three-dimensionally inhomogeneous earth, one's ability to predict the distribution of resistivities at depth is severely limited by the influence of surficial conductors such as alluvial fill or shallow alteration zones (Wannamaker et al, 1978). That a hot rock, when molten, is necessarily a good conductor of electricity must be conjectural, for conductivity in magma at elevated temperature is dependent upon the partial pressure of water (Duba, 1974). Hot dry rocks are good insulators almost by definition. If one uses only the standard one- or even two-dimensional MT interpretation methods when dealing with a three-dimensional earth, then one has no assurance that the method is capable of detecting a hot rock source by means of its assumed high conductivity. Means for surmounting this latter problem are evident (Wannamaker et al, 1980) but are seldom applied. Accordingly, we do not recommend using the MT method until late in the exploration sequence when one is justified in applying the higher cost techniques. The poor lateral resolution of MT interpretation does not make the method well-suited for siting a drill hole to intersect a given structure in the advanced stage of exploration, but it may be used effectively by a consortium of companies for early reconnaissance evaluation of a region.

Electrical Resistivity Method

Resistivity surveys, particularly with the dipole-dipole array, have been used by many companies. A major limitation is the sensitivity to geologic changes at depth which is no more than twice the electrode separation, that is, generally in the range of 600 m for a 300-m dipole using dipole spacings to n = 6 (Roy and Apparao, 1971; Ward et al, 1978). The survey data are sensitive to lateral variations in resistivity, and hence are generally well suited to delineation of high-angle structures, but are not sensitive to dip. Through detailed numerical modeling (Beyer, 1977), a useful map of intrinsic resistivity distributions to depths of 500 m can be generated. At Roosevelt Hot Springs and Cove Fort–Sulphurdale, Known Geothermal Resource Areas (KGRAs) in Utah, low (5 to 10 ohm-m) resistivity zones have been mapped which are probably related to hot, conductive fluids and large zones of wall-rock alteration. Similar results have been obtained for several prospects in northern Nevada.

Self-Potential (SP) Method

Self-potential surveys are being used by a few of the major firms engaged in geothermal exploration. Recent papers by Corwin and Hoover (1979), Fitterman (1979), and Hulse (1979) present a theoretical basis and observed data showing the utility of the method for geologic mapping and geothermal exploration. Our observations are that either polar or dipolar patterns of self-potential anomalies can occur in the Basin and Range province. Sometimes the two patterns are superimposed. Ambiguity in interpretation must therefore be expected. Anomalous patterns often relate to known geologic structures, suggesting a dominant role for the electrokinetic as opposed to the thermoelectric coupling models. Some geophysicists have stated, off the record, that SP surveys are their most cost-effective exploration method, but this may be in part a commentary on the relatively low cost of field surveys. We would reserve their use for a late stage of exploration when resistivity data are also available and where any clue to fluid flow is helpful and justifiable to offset high drilling costs.

Passive Seismic Methods

Within this category fall all the earthquake, microearthquake, and seismic noise or emissions thought to relate to hot-spring or deep-reservoir activity and to active structural deformation. Areas of thick alluvial cover often manifest high noise levels which may obscure the reservoir signature sought in many seismic-noise surveys, if such signature exists (Katz, 1976). Liaw and McEvilly (1979) discussed these problems as evident in studies at Grass Valley, Nevada, and Douze and Laster (1979) discussed them in relation to studies at Roosevelt Hot Springs. The relative cost-effectiveness of the passive seismic methods in locating hidden reservoirs is still very much in doubt, as indicated by limited acceptance (Tables 1, 3) and the conclusions of a recent workshop devoted to these methods (Ward, 1978).

Reflection Seismic Methods

We have inspected reflection seismic data for several Basin and Range geothermal areas including Roosevelt Hot Springs KGRA, Utah, and San Emidio, Soda Lake, and Beowawe in Nevada. The data are generally of two types: shallow penetration weight-drop-type seismic surveys and conventional 12- or 24-fold CDP surveys with various types of processing. The data from the shallow surveys are ambiguous in interpretation and are best evaluated in terms of outcropping geology and other geophysical data. Although the cost is relatively low, it is not apparent that these latter data are cost-effective in structural and bedding delineation in the typical Basin and Range geothermal areas.

Conventional seismic surveys appear to give good definition of Basin and Range border faulting and depths to the base of alluvial fill at Roosevelt Hot Springs KGRA, Utah, and Soda Lake, San Emidio, and Grass Valley, Nevada. In an area of limited outcrop, such as the Carson Sink region, the reflection seismic method would appear to be cost-effective in the delineation of structures and bedding to depths of about 1,000 m. One seismic line which crosses the Mineral Mountains at Roosevelt Hot Springs KGRA shows little obvious lithologic or structural information within the range itself, or within the reservoir, but substantial structural information along the range front. At Beowawe, extensive and varied digital processing was ineffective in eliminating the ringing due to a complex near-surface volcanic section. Majer (1978) found reflection data extremely useful in delineating structure in Grass Valley, Nevada. The cost of this method and the mixed results observed argue against its routine inclusion in a geothermal exploration program. However, where the geology appears to be permissive for reasonable reflection quality, and where predictable acoustic contrasts exist, this may be the most cost-effective way to site exploration wells.

Thermal Methods

The thermal methods are clearly recognized as the most direct indicator of the geothermal resource as indicated in Tables 1-3. Shallow temperature measurements in holes 1 m deep are seldom used because of unknowns in near-surface hydrology, soil thermal properties, topographic corrections, and short-term variations. At the Long Valley and Coso Hot Spring areas in California, and Soda Lakes, Nevada, however, shallow temperature measurements (Le Shack, 1977; Olmsted, 1977) seem to delineate the area of anomalous heat flow in a low-cost manner. In the absence of substantial surface thermal manifestations or favorable geology and without obvious near-surface cold-water flow, a shallow temperature survey of about 5 to 20 sq km could be the best basis on which to plan a shallow (30 to 200 m) thermal gradient program.

Shallow thermal gradient holes ranging from 30 to 200 m deep are almost always used. The holes are logged for temperature and the chips can be used in stratigraphic, alteration, and geochemical studies. In many places it is advisable to measure thermal conductivities and determine heat-flow values. The thermal gradients and observed temperatures still may be influenced by shallow ground-water flow which may obscure or offset the deep thermal anomaly. The omissions of a shallow thermal gradient program in Table 1 probably reflect in two examples data obtained but not submitted as part of the Industry Coupled Case Study Program. In the third example, an exploration well was drilled directly on surface geothermal features and previous high-temperature drilling results. The need for a more systematic thermal gradient data base has since been recognized and was recently completed as a supplemental part of the DOE/Company program.

Deep thermal gradient holes may range in depth from 300 to more than 1,000 m, but generally are in the 300 to 600-m range. The ratio of shallow to deep thermal gradient holes varies but typically is between 1 to 5 and 1 to 10. Results from these holes will help determine the siting of exploration wells (Benoit, 1978).

STRATEGY

As indicated in the foregoing, hydrothermal convection of fluids through structures is a phenomenon that occurs in high-, moderate-, and low-temperature environments. Although systems are basically similar, each has its own unique characteristics. Thus, although a general exploration strategy for hydrothermal systems can be proposed, the strategy will require some modification to fit the demands of most individual exploration projects.

We propose the formulation of exploration models and the constant updating of these models as exploration proceeds. We feel that the most efficient exploration programs are based on a knowledge of the physical/chemical processes within a convection system and interpretation of the geologic, geochemical, geophysical, and hydrologic manifestations of these processes. For each increment of exploration dollars, these models should be updated and the important controlling parameters of systems should be documented, analyzed, and understood. A genetic model is the end point of the entire process with the exploration model approaching the genetic model with each new increment of data. In short, it is not necessary to understand fully a system to explore it; it is sufficient to understand the fundamental processes of a system and to understand its detection by various exploration tools.

Figure 6 portrays our recommended basic strategy for exploring for high-temperature hydrothermal resources in the Basin and Range province in areas of surface thermal manifestations. As noted earlier, modifications to this strategy may be required for specific prospects. The strategy assumes that one starts with a nominal district of 3,000 sq km and finds one high-priority prospect in this area which eventually demands a production test. If other prospects are found in the district, they are herein considered of lower priority than the one drilled for production. We consider that the strategy recommended is a minimum one, yet its cost through drilling and logging and subsequent reservoir modeling is estimated to be $4.6 million if both seismic reflection and magnetotelluric surveys are included.

Where do these costs arise? Each box in the flow diagram of Figure 6 depicts a function or functions whose cost estimate is shown on the right of the box. The sequence of events in the flow diagram has been carefully considered to provide the most cost-effective data gathering consistent with the risk involved. By design, the risk of failure should become less as one moves downward in the diagram, that is, forward in time, so that higher cost or less demonstrated, yet promising, exploration techniques can be justified late but not early. Let us discuss each box, by number.

Literature and Data Search, Compilation, and Analysis (Fig. 6, Box 1)

Invariably, aerial photography, satellite imagery, regional geologic maps, water chemistry, regional gravity data, regional aeromagnetic data, plus relevant geologic reports are available prior to a company's entry into a district. The functions of box 1 dictate that these data must be located, compiled, analyzed, and integrated as a basis for designing the rest of the exploration strategy.

Subsurface information is often available from water wells and oil tests. This material is of use in defining basin stratigraphy, regional hydrologic patterns, and occasionally subsurface temperatures. Compilation of well locations and depths is important for defining the location of wells to be sampled during the district reconnaissance stage.

Chemical and Isotopic Analyses of Waters (Fig. 6, Box 2)

Where the chemistry and light stable isotope analyses of spring and well waters are available in a district, these data are utilized in empirical geothermometric formulae to predict the temperature of last water-rock equilibration, hoping thereby to predict the temperature of the hydrothermal fluid in the reservoir. If the analyses are not available or are of uncertain reliability, the collection and analyses of spring and well waters are usually made. Although the water-temperature predictions from such analyses have uncertainties due to fluid mixing and to the effects of soluble components in wall rocks unrelated to the thermal event, they are nevertheless extremely useful in locating prospects.

During sampling of available wells, pertinent hydrologic data, such as depth to the water table, should be collected.

Initial Field Mapping (Fig. 6, Box 3)

With air photos, imagery, and geologic maps in hand, initial field mapping can be designed to coincide with the initial geochemical sampling and thermal-gradient measurements. Collection of samples of young volcanic and intrusive rocks should be performed at this time. Geologic maps at a scale of 1:62,500, or even more detailed, are available for parts of the Basin and Range province, but these maps are of variable quality and usefulness for the geothermal explorationist. If the area under consideration contains known geothermal resources, it is often advisable to map it in detail at an early stage to document the structural and lithologic controls. Reconnaissance mapping at this stage will also confirm the quality of existing maps and will be valuable in interpreting features defined by the aerial photography. Analysis of these results and the data collected simultaneously in boxes 2 and 4 provide an excellent data base for the definition of a prospect of greater interest.

Thermal Gradients, Available Holes (Fig. 6, Box 4)

Many companies concerned with exploration for high-temperature hydrothermal resources have vigorous programs of measuring temperatures versus depth in all available water wells, oil and gas wells, and mining drill holes. This reconnaissance data collection can be extremely valuable in pinpointing hot spots, but care must be taken to evaluate such effects as cold-water mixing and overflow.

Prospect Mapping (Fig. 6, Box 5)

The homework and district-reconnaissance studies of boxes 1 through 4 invariably lead to identification of a number of prospects. Although not all hot spots are found in the district reconnaissance studies, those that are found are typically given priority and are mapped. We consider it important that, providing exposures are suitable, geologic mapping at a scale of approximately 1:24,000 be done early in the prospect-evaluation stage. Depending on the complexity of an area, a geologist can generally cover a minimum of 3 sq km per day. Thus several man-weeks of effort can generate a detailed geologic map which will be invaluable in planning and

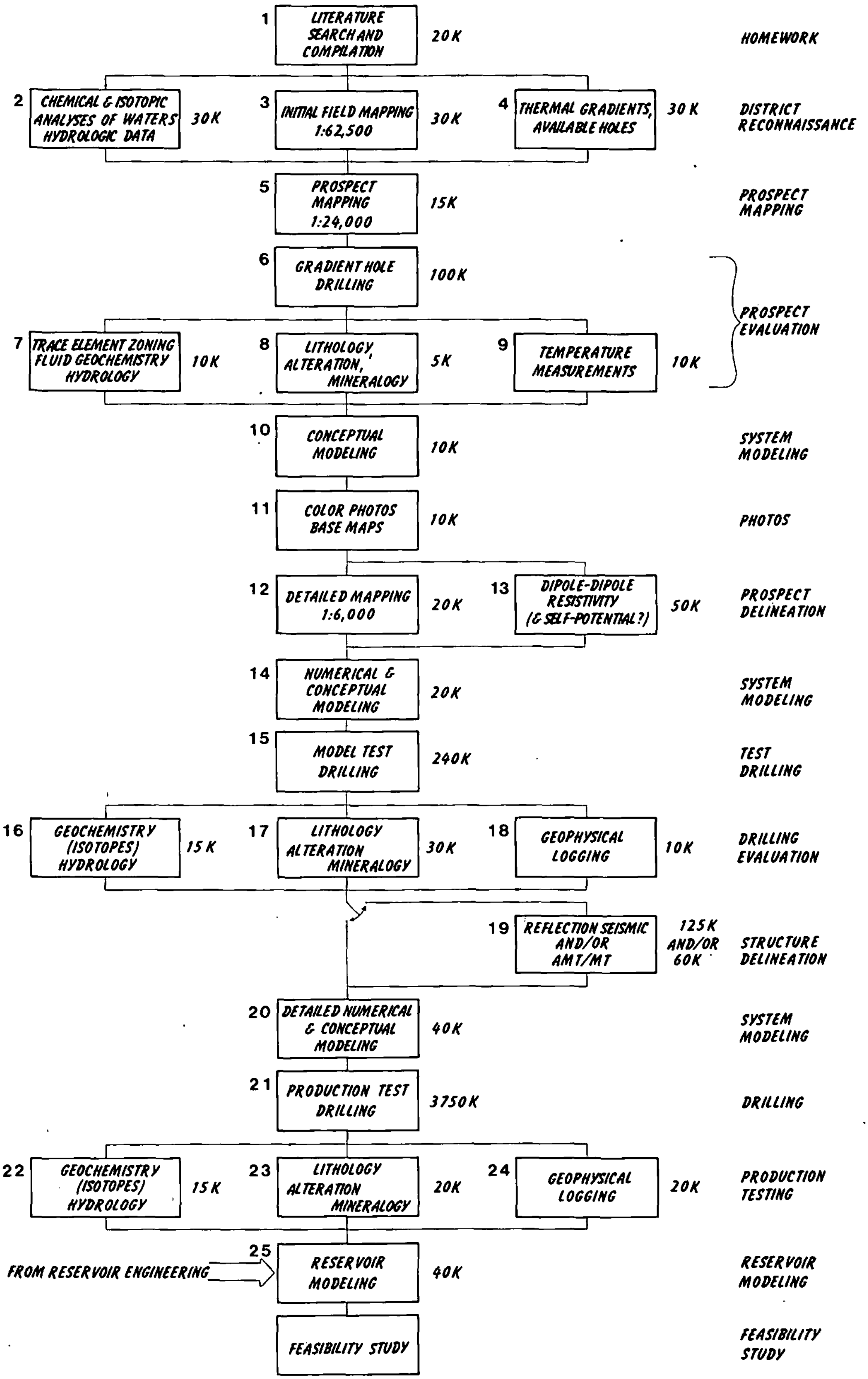


FIG. 6—Suggested high-temperature hydrothermal exploration strategy. Numbers at left of blocks indicate operating sequence. *K* numbers at right of blocks indicate estimated dollar cost in thousands.

interpreting subsequent drilling and geophysical and geochemical surveys. Our experience with data collected by companies participating in DOE's Industry Coupled Case Study Program has been that the completion of a detailed map at this early stage in the exploration program might have suggested to some companies that they not drill thermal-gradient holes at structural intersections or run resistivity lines along major structures; topographic access may dictate otherwise. We shall assume, for the purposes of the subsequent discussion, that only the top-priority prospect will initially warrant detailed investigation.

Drill Gradient Holes, Lithology and Alteration, Temperature Measurements, Geochemistry (Fig. 6, Boxes 6-9)

It is customary to drill about 20 holes 30 to 160 m deep in each high-priority prospect indicated earlier. The problem of cold-water overflow reducing near-surface gradients is generally recognized and is serious. Nevertheless, the gradient measurements in these specifically drilled holes are, perhaps, the most fundamental data to be acquired in the early stages of hydrothermal exploration.

Although temperature measurements are the principal product of these drill holes, additional data can be acquired at relatively low cost. Thermal-conductivity measurements on cores or chips will permit the gradient measurements to be converted to heat flow. Lithologic logging of the holes may give important information concerning hydrothermal alteration and mineral deposition, and can be tied with the surface mapping to give valuable insight into the structural geology. Trace-element analyses of cuttings can be done at small cost to investigate the possibility of geochemical zoning (Ewers and Keays, 1977; Bamford, 1978). Determination of depth to the water table and chemistry of waters encountered will begin to develop a hydrologic data base which will prove to be of great value in subsequent stages of exploration.

Conceptual Modeling (Fig. 6, Box 10)

Completion of the shallow-temperature measurement program is a major milestone in the history of a prospect. This is the appropriate time for the explorationists to formalize their target concepts with the development of a conceptual model. The process should integrate the prospect-specific geologic mapping, geochemical, alteration, and thermal-gradient information and relate these to the broader reconnaissance data base. The output of the process is a target model consistent with the data; some contradictory information will now become apparent. Parameters identified may include lateral extent, depth, heat-source types, and temperature. The options for testing the model in the most efficient manner should be evaluated prior to proceeding. A maximum of 2 man-months, at a cost of less than $10,000, would be required for this activity.

Obtain Color Air Photos and Base Map (Fig. 6, Box 11)

In areas where adequate stereo air-photo coverage and good base maps are available this step will be unnecessary. However, when dealing with an area with complex structural and alteration patterns, it is often most efficient to obtain low-altitude, color aerial photography. These photos provide an excellent base for detailed geologic mapping and can be used to generate detailed topographic base maps.

Detailed Mapping 1:6,000 (Fig. 6, Box 12)

Mapping in greater detail than 1:24,000 may not be necessary, but many added details may be required to answer specific structural questions or to unravel complex alteration patterns. In general, the purpose of this step is to understand the geologic setting as completely as possible prior to initiating the expensive surveys and drilling indicated in the latter half of the exploration process.

Dipole-Dipole Resistivity Survey (Fig. 6, Box 13)

A dipole-dipole resistivity survey should be planned to extend the results of surface geologic mapping to depth. Typically, survey lines are oriented as nearly perpendicular to geologic strike and structures as possible. The dipole length may range between 150 and 600 m to reach the appropriate compromise between lateral resolution and the increased response to features at depth. A dipole separation of 300 m seems to be preferred by the industry in the Basin and Range province. The data should be recorded to at least n = 6 (sixth separation) to allow confidence in subsequent interpretation to depth.

An option not generally exercised is the recording of induced polarization (IP) data along key profiles of the survey (Chu et al, 1980). This may be warranted if trace-element or lithologic studies suggest sulfide zoning which may be related to the geothermal system, or if this parameter can further discriminate between geologic units at depth. The cost of these added data depends on the increased recording time and local noise levels. We do not advocate routine inclusion of IP measurements. A maximum of $50,000 would be required for contract services for the basic resistivity survey, providing 60 line-km of control and numerical modeling of the data. A self-potential survey may be included for fluid-flow information.

Numerical and Conceptual Modeling (Fig. 6, Box 14)

Numerical modeling should be applied to two data sets to test and subsequently modify the conceptual model. The shallow-temperature hole data should be combined with measured or assumed thermal conductivity to produce a heat-flow map. A better definition of the heat source may be apparent after attempts to model this distribution of heat flow by means of forward calculations, or inversion.

A detailed modeling of the resistivity data can be completed using contract services or two- and three-dimensional computer programs now available (Killpack and Hohmann, 1979). A definitive intepretation of resistivity structure to depths of about one-fifth the extreme electrode separation will often be possible. Especially useful outputs from the process are the location of Basin and Range faults and areas of low resistivity associated with hot conductive fluids and altered rock. Although the reservoir itself may be too deep to detect, zones of leakage to the surface may be delineated. These geometric models place new constraints on the conceptual model, as does the more detailed geologic mapping. The model is updated, and serves as the basis for siting intermediate-depth drill testing. The cost, suggested at $20,000, is justified by the commitment of the subsequent drilling.

Model Test Drilling and Logging (Fig. 6, Box 15)

The northern Nevada studies indicate that most companies drill two or more 500 to 800-m slim holes which are referred to variously as deep geothermal-gradient holes, stratigraphic-test wells, or as model test-drill holes. These holes serve to evaluate (a) shallow cold-water overflow or mixing and (b) shallow thermal aquifers as at Desert Peak, Nevada (Benoit, 1978). They also serve to provide a preliminary test of the conceptual model of the geothermal system. We recommend three such holes at an estimated cost of $80,000 each. Although practice varies from company to company, we recommend temperature, resistivity, gamma, and SP logging rather than acquisition of a full suite of logs.

Isotopes, Chemistry, Hydrology (Fig. 6, Box 16)

The model test drilling yields cuttings and fluids which permit one or more of the following: (a) isotopic and chemical geothermometric predictions of temperature in the reservoir, (b) the possibility of identifying the source of recharge to the system, and (c) estimation of the permeability of the reservoir by water/rock ratio analyses (Elders et al, 1978). An understanding of the hydrology of the system can be improved by such inexpensive studies.

Lithology and Alteration Studies (Fig. 6, Box 17)

Lithologic logging is important in determining the subsurface geologic relations. Logging should emphasize the correlation of cuttings with units delineated during the geologic mapping. With this information, geologic cross sections can be drawn and conceptual models of the geometry of the system' refined. By relating the cuttings to the surface geology, the three-dimensional structural setting can be defined. Fault zones may appear as areas of gouge or mylonite. Often faults are the focus of areas of hydrothermal alteration. However, many times the fault zones are unspectacular in cuttings and must be delineated on the basis of known geologic relations, such as attenuation and juxtaposition of units, which can only be explained by faulting.

The geologic cross sections drawn at this time should integrate all of the data sets accumulated. It is particularly important that the geologic, geochemical, and geophysical models be compatible. Discrepancies in interpretation should be rationalized or eliminated.

Geophysical Logging (Fig. 6, Box 18)

Thermal measurements will be made in the model test drilling. For a small additional investment, SP, resistivity, and gamma logs can be run to provide additional stratigraphic control. This type of logging is commonly done in the uranium exploration industry and numerous low-cost logging units are available. However, most of these units are not designed to operate in high-temperature environments. Velocity and density logs could also be obtained, at a significant increase in cost, to assist in the design or interpretation of any subsequent reflection seismic survey.

Reflection Seismic and Audio Magnetotelluric/Magnetotelluric (AMT/MT; Fig. 6, Box 19)

In our strategy we have allowed for the possibility of using either or both of the reflection seismic and AMT/MT methods to assist in mapping structures or fracture systems; 25 km of seismic reflection data of $5,000 per line-kilometer and 30 AMT/MT stations at $2,000 per station are used in the estimate. In some places one or both methods will be inapplicable and hence this box can be bypassed or limited to one method.

Detailed Numerical and Conceptual Modeling (Fig. 6, Box 20)

The target concept is again updated prior to deep drilling in our strategy. Refinements in the numerical models may be possible through hydrology and chemical geothermometry, and through stratigraphic drilling and seismic data; 2 man-months and computer support may be required for this third update of the integrated numerical and conceptual model.

Production Test Drilling and Logging (Fig. 6, Box 21)

Known production test wells in the Basin and Range province have ranged from 382 m at Thermal Power Co. Utah State 72-16 at Roosevelt Hot Springs to 2,939 m at Phillips Petroleum Co. Desert Peak well B-23-1. Deeper drilling to 4,000 m is rumored. If one assumes three production test wells of 1,525 m at an average cost of $1,250,000 (including box 24, full suite logging and brief flow test), then the cost of box 21 is $3,750,000 and this seems to be a typical expenditure.

Isotopes, Chemistry, and Hydrology (Fig. 6, Box 22)

All activities of box 16 are repeated here. Additionally, down-hole temperatures and pressures and their variations during the brief (24 hour nominal) flow test are available to provide further assessment of the reservoir.

Lithology and Alteration Studies (Fig. 6, Box 23)

Lithologic logging of the cuttings from deep drilling should again concentrate on correlating the lithologies with the surface mapping, identifying structures, and characterizing alteration assemblages. The results will provide data needed to draw geologic cross sections through the prospect area and may define small-scale structures that control fluid flow. These cross sections must now be compatible with relations shown by surface mapping, deep- and intermediate-depth drill results, and numerical modeling of geophysical surveys completed. Obviously, discrepancies in the interpretation of various data sets will be present and must be rationalized by remodeling or collection of additional data.

Characterization of alteration assemblages has been shown to yield important information on the location of production zones and the permeabilities of individual units (Browne, 1970, 1978). In addition it is often possible to document the chemical and thermal history of the system by using alteration assemblages (Browne, 1978) and fluid inclusion results (Burruss and Hollister, 1979).

Characterization of the mineralogy of test holes is crucial in facilitating the interpretation of geophysical well logs (Glenn and Hulen, 1979).

Geophysical Logs (Fig. 6, Box 24)

A thorough study of the suite of geophysical logs, well-coordinated with geochemical and lithologic studies, is mandatory. The results are an improved assessment of reservoir temperatures, fracture porosity and permeability, location of hot and cold fluid entries, and the identification of various reservoir-rock properties. For $20,000 we envision digitizing and replotting the various logs to a common depth scale with lithology and cross plots for unit discrimination and physical property evaluation. One man-month of interpretation time by an experienced well log analyst for each of three well tests is expected.

Reservoir Modeling (Fig. 6, Box 25)

The last update of the model considered here is a product consistent with the drilling results, the physical properties determined from the geophysical logs, and the surface geophysical and geochemical data. We do not necessarily imply a rigorous multidata-set numerical-model solution, but rather models from individual different data bases which are now internally consistent, or largely so.

Through flow testing and geometric modeling a preliminary reservoir model is available as the main input to the feasibility study. A decision to enter production implies continued monitoring of key variables and the modification of the reservoir model.

CONCLUSIONS

In the previous section we have presented our recommended strategy for exploration for high-temperature hydrothermal resources in the Basin and Range province and our justification for this choice of strategy. It is an expensive strategy, costing between $680,000 and $865,000 per prospect prior to production test drilling. We justify such large expenditures on the basis that we wish to minimize the risk of a poorly placed production test well when such wells often cost $1,000,000 to $1,800,000. The ratio of predrilling costs to the cost of the first hole therefore is approximately 0.5 under this strategy.

Research in exploration and assessment technology is expected to lead to introduction of new methods (e.g., controlled source electromagnetic methods), reintroduction of old methods, and more cost-effective use of some methods. Hence the strategy we recommend will be updated by a more cost-effective one when new or improved technology becomes available and when we make the next major step in developing conceptual models of high-temperature convective hydrothermal systems. Further, the strategy may evolve from the current one which is primarily directed to convective hydrothermal systems with surface manifestations to one primarily directed toward blind systems.

The broadly experienced geothermal exploration manager may wish to differ with our recommended strategy for various reasons including personal preference, budgetary constraints, time and land position constraints, and environmental or legal constraints. Our intent is not to force uniformity in exploration but to offer our recommendations based upon our collective experience and observations. The newcomer to geothermal exploration is expected to benefit more from this manuscript than the veteran geothermal explorationist.

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FINANCING GEOTHERMAL DEVELOPMENT

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What has always interested me in the geothermal industry is that "Exploration and Development," as in the title of this Short Course, are always linked together. In practice, however, and especially from the financial aspects of the business, there is a great difference in each of these. In discussing the various options available for the overall geothermal implementation process, I should like to stress the need for parallel development in the financing of both the exploration and the development phases. I must also stress the critical need for involving one's financial personnel and/or out-side financial advisors from the earliest planning stages. In addition, I must point out that the ability to finance a project to completion (through to the beginning of cash flow) is the net result of the successful completion of all of the previous phases of that project. A successful financing is the bottom-line criterion that bespeaks the project's ultimate feasibility. I say this because, in order to finance a project successfully, *the prospective investors must understand* all of the risks and mitigating measures involved prior to their supplying the required funding. Let me discuss the building blocks upon which our industry is based.

I. INTRODUCTION

The first of these is, of necessity, the exploration phase, the scope of which includes general reconnaissance, leasing, preliminary exploration, deep drilling, testing, and development drilling functions. A resource company must first decide that it is in the geothermal business and it must allocate funding to engage in preliminary reconnaissance activities. Leasing, and the attendant expenditure of funds, then takes place. Further monies are spent in site-specific exploration (geology, geophysics, gradient drilling, etc.) before a decision is made to commit the substantial funds necessary for deep production drilling. Based on a successful completion of the deep well, extensive testing must take place before deciding whether step-out drilling is warranted in order to bring the field to a desired production level.

This brief synopsis tells only half the story, however. Geothermal is a capital-intensive industry. The utilization of the resource requires the construction of a power plant, agribusiness or industrial facility in addition to the investment in drilling. Since these are site-specific utilization investments, the investor in this phase of development must be assured that the resource on which the facility is being built will last as long as it takes to recover his investment. As a result, the investor is sharing the risk of the reservoir's projected performance through time, in some cases as long as thirty years. There are few oil companies that know or care how to own and run a utility or a dehydration plant. The idea of having to invest significant funds or guarantees beyond the normal scope of their ongoing business is hardly appealing either. For example, if a resource company invests $20 million in the development of a resource but then has to spend an additional $50-60 million to develop it to the point of cash flow - that's a lot of dollars to bet on a single reservoir. And only the limited number of the largest of companies could participate in this game. It is clear that the utilization phase also requires the investment of risk capital, but it appears that the sources thereof will most likely be different.

Now that we've defined the different phases of geothermal development process through to cash flow, let us discuss for a moment the types of markets that geothermal resources are active in. Previous speakers have discussed these, so I will summarize the differences between geothermal for electric and for direct-use applications. It is most important to note that the electric market requires generally a higher temperature of geothermal resources (300° F plus) and results in an energy product, electricity, that can be transmitted over long distances. Non-electric or direct-use geothermal applications have generally focused on temperatures below 300°F (although higher temperatures can be used in industrial and agricultural applications) and the energy has to be consumed within a fairly close proximity to the site (five to ten miles). A further comparison demonstrates that electric projects may require minimum capital investments (re-

C. Summary. Electric commercialization is most efficiently achieved when both the exploration and development phase are integrated financially and a construction program appropriate to the resource in question is developed. The financing of such projects can be streamlined and the net result, the cost of electricity, be achieved on the most cost-effective basis possible.

I. DIRECT-USE DEVELOPMENT PROJECTS

A. The Exploration Phase has similar risk characteristics as drilling for electric with one important difference: The depth of the resource, and therefore the cost of reaching it, is significantly smaller. This results in a lot of differences in the direct-use field as compared with the electric. Many more and smaller companies can be and are involved in direct-use projects, often for their own utilization. The variety of companies is much greater because BTU production can be used for any industry requiring process heat, be it agriculture, dehydration, space heating, etc. Many more non-electric prospects appear to have been identified, and once development is planned, a much shorter turnaround time to cash flow can be expected. This appears to be the result of the minimal environmental impacts of such projects as well as of the significantly smaller capital investment (and lead time) necessary to start-up the project. Shallower and less expensive production wells can be drilled more quickly. Depending on depth, temperature, and flow rates desired, completed non-electric production well cost could run from as low as a few thousand to as much as $250,000. In contrast, an average electric production or injection well to 7,000 feet could run from a million dollars to two million or more. Sources of funds for non-electric production well drilling are essentially the same as outlined in Section IIA, with one further addition. Given the significantly lower cost threshold of entry, an end-user such as a food processor or agricompany might be willing to invest in shallow production drilling themselves if the cost savings or back-up system potential appeared favorable enough.

B. The Utilization Phase for direct uses involves the same types of risks and has available to it all the same sources of funding as described in Section IIB above. A detailed paper will be coming out soon describing sources and types of funds available to direct-use projects. This information is contained in Section Seven on "Financing" of the Workshop on Direct Utilization of Geothermal Energy conducted by the GRC/OIT in Klamath Falls, Oregon in February 1979. I shall basically restrict my comments on this topic to the fact it is generally easier to finance a small project with a quick turn-around to cash flow as opposed to a large project with a long lead time to cash flow where delay and environmental hazards are inherently much greater. Since geothermal can furnish the energy for a wide variety of different businesses, evaluation and analysis of each of these different businesses should not concentrate primarily on the geothermal aspect alone. Overall management capability, economic viability, process and technological risks, marketing, and business structure - all have to be exhaustively reviewed. In this context, geothermal energy is but one component in a processed product and is but one additional variable - that of the fuel supply - to be assessed in a business with many variables. In non-electric, if the resource fails, the option may exist to retrofit to a conventional fuel source, in electric development, if the resource fails, the project fails.

In summary, based on the availability of recently enacted tax benefits, and based on the environmentally and economically desirable aspects of lower temperature geothermal resources, it appears that these projects offer desirable investment opportunities, although on a smaller scale. In fact, at-risk loan capital should become much more rapidly available to the commercialization of such direct-use quality geothermal resources than for electric, because options do exist for the use of the facilities on a commercial basis even with failure of the resource.

IV. CONCLUSIONS

In both the electric and direct-use sections of this paper, I have maintained a parallel structure in discussing the kinds of capital available to the exploration and development phases. Because the successful commercialization of a previously unutilized geothermal resource depends on obtaining different kinds of investment capital for each of the phases, I strongly recommend that one not be undertaken without planning for the other. Integration will save both time and significant amounts of money, thereby enhancing the project's potential for profitable implementation.

First Geothermal Demonstration Project Workshop

Pocatello, Idaho

October 18-19, 1978

COOPERATIVE AGREEMENT No. ET-78-F-07-1727

COOPERATIVE DEMONSTRATION PROJECT

GEOTHERMAL HEATING OF DOUGLAS HIGH SCHOOL

Douglas School System
District No. 51-1
Ellsworth A. F. B., S. D. 57706

WORKSHOP PRESENTATION
Pocatello, Idaho
October 18, 1978

Principal Investigator:	F. J. Issler, Jr. Facilities Engineer Douglas School System
Presentation by:	Dr. Dan D. Carda Research Associate Engineering and Mining Experiment Station S. D. School of Mines and Technology

OUTLINE

1. Generalized discussion of South Dakota and adjacent states.
2. Madison Aquifer system under the State of South Dakota.
   - location of three other geothermal projects
3. Generalized vertical cross-section of the geothermal area.
   - flow characteristics of the Madison
   - extent of the Madison Aquifer
4. Stratigraphic column of South Dakota.
   - identification of various strata
5. Location of the project for the Douglas High School.
   - 35 mm slide presentation
6. Cross-section of well, drilling problems and potential solution.
   - synopsis of present problem
   - possible plan of action utilizing directional drilling
7. Utilization of geothermal energy--Douglas High School.
8. Question/answer period.

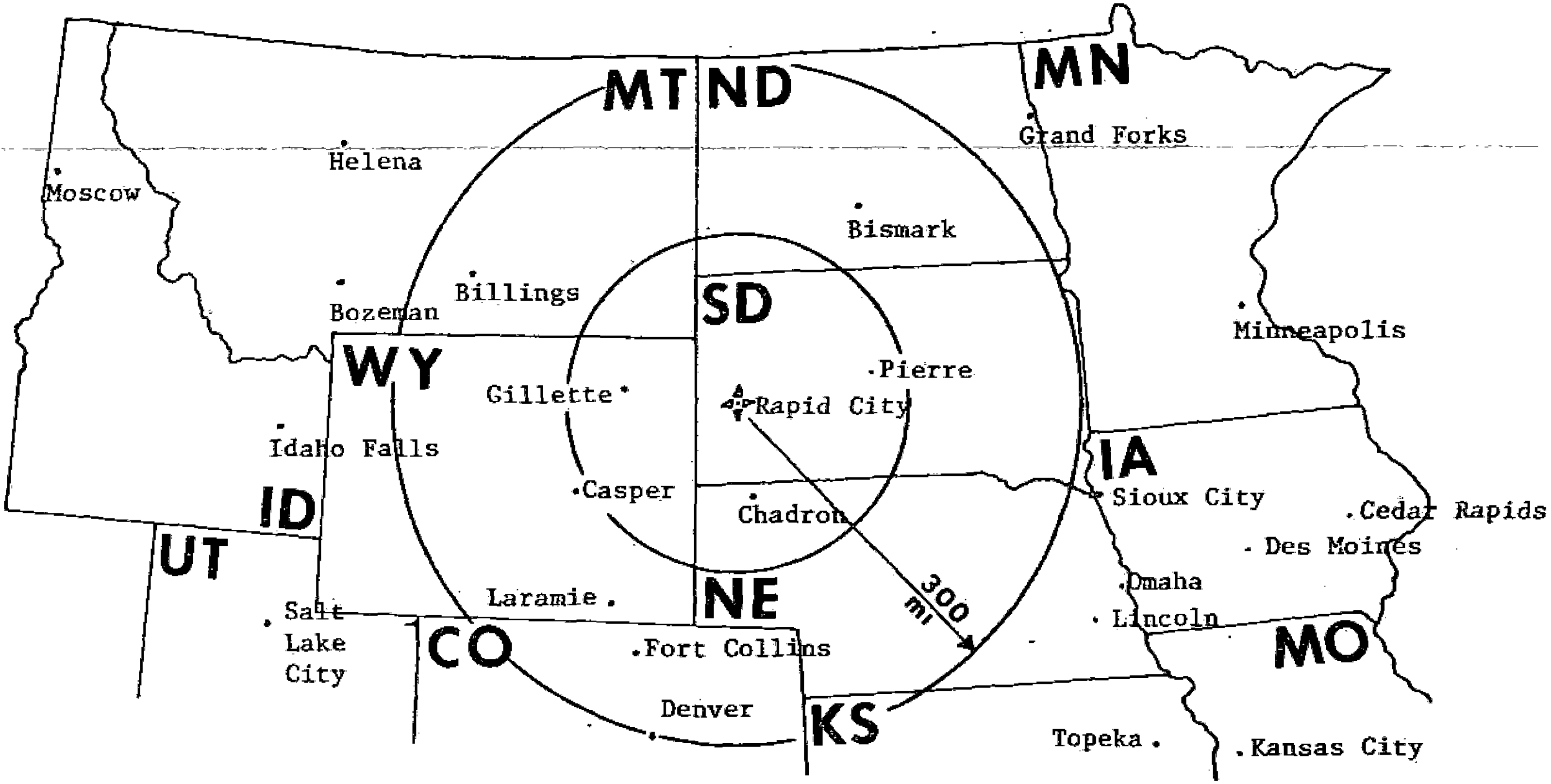
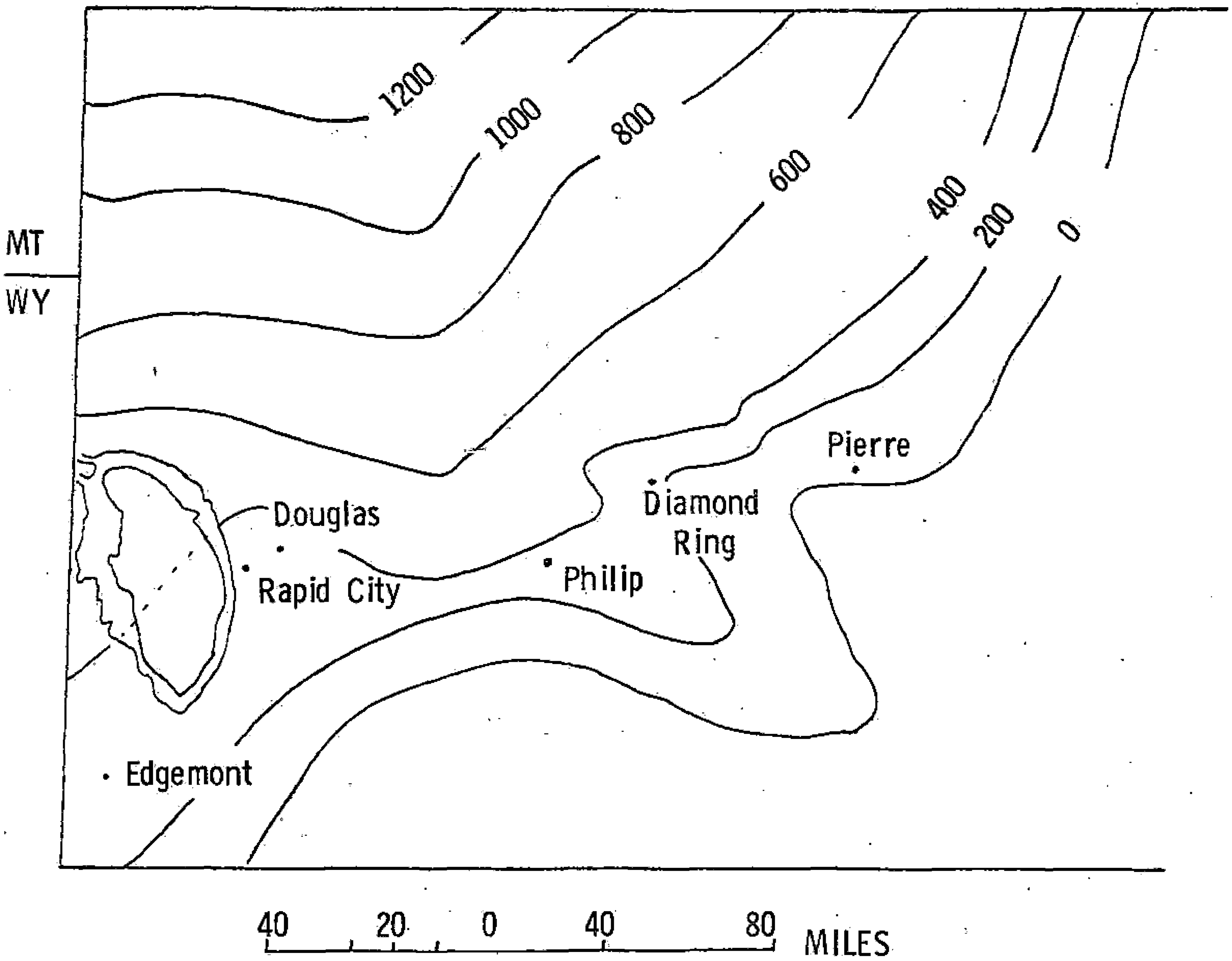
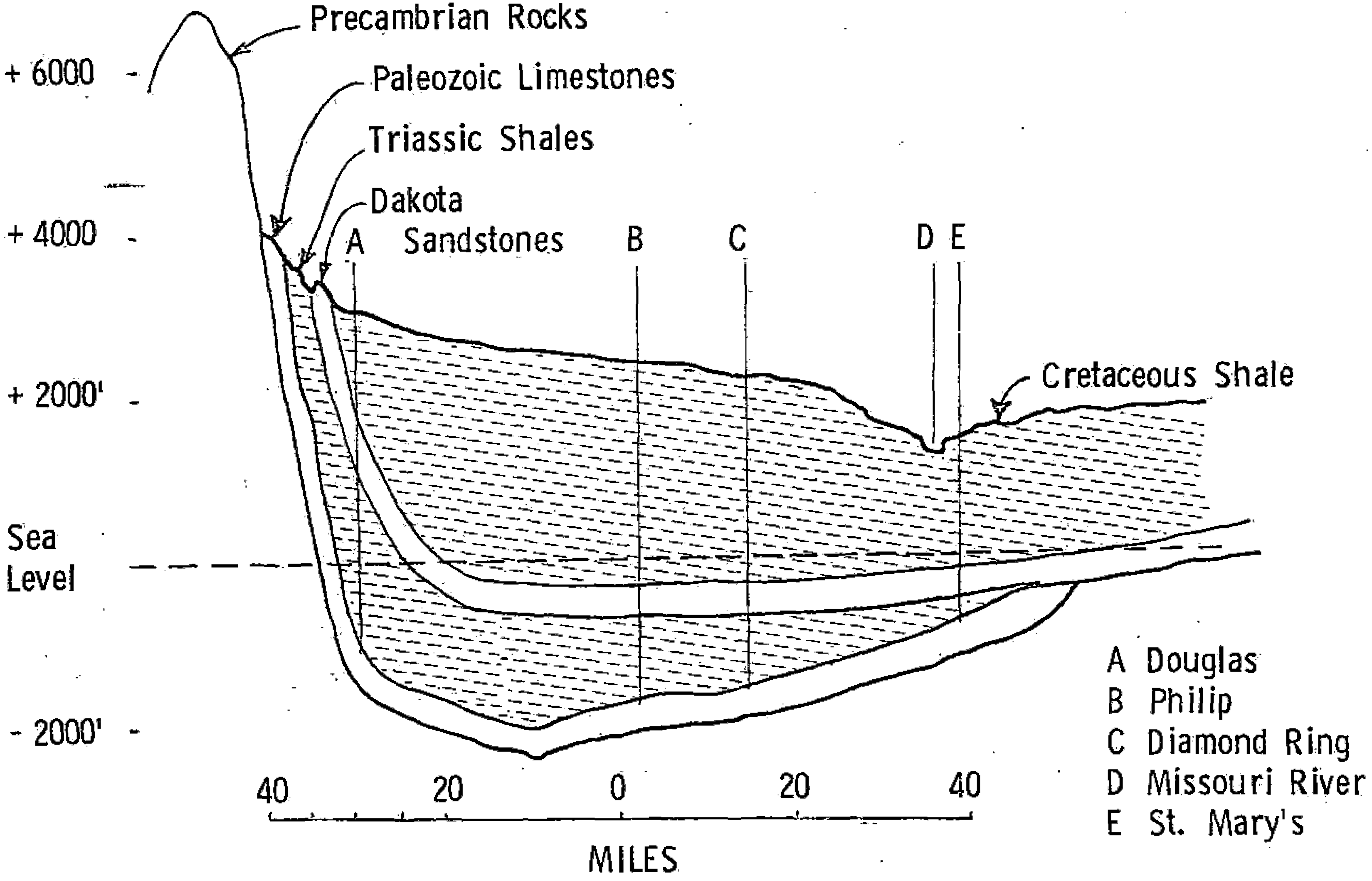


Figure 1. Index Map of Rapid City in the Upper High Plains Region.

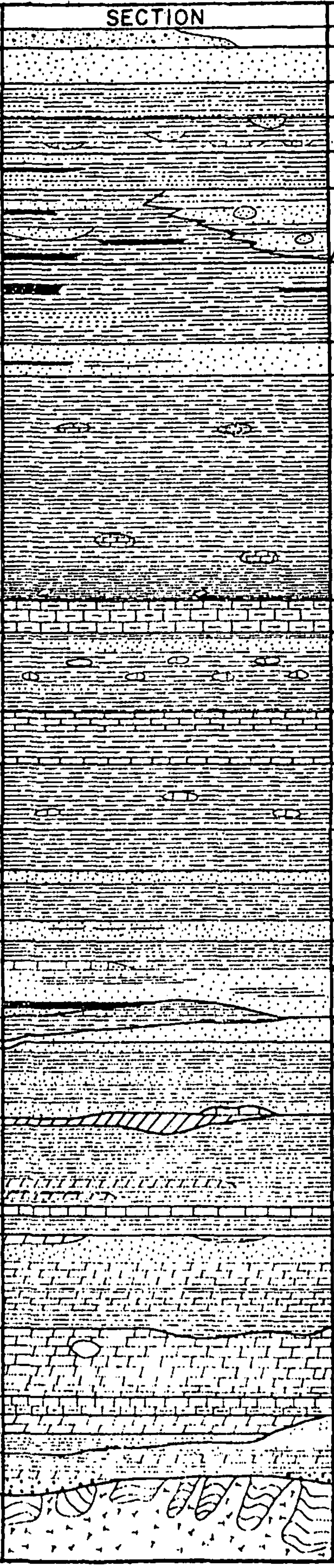


Extent and Thickness of Madison Limestone in South Dakota

GENERALIZED CROSS-SECTION OF SOUTH DAKOTA WITH VERTICAL SCALE EXAGGERATED



GENERAL OUTCROP SECTION OF THE BLACK HILLS AREA

		FORMATION	SECTION	THICKNESS IN FEET	DESCRIPTION
QUATERNARY		SANDS AND GRAVELS		0-50	Sand, gravel, and boulders.
TERTIARY	PLIOCENE	OGALLALA GROUP		0-100	Light colored sands and silts.
	MIOCENE	ARIKAREE GROUP		0-500	Light colored clays and silts. White ash bed at base
	OLIGOCENE	WHITE RIVER GROUP		0-600	Light colored clays with sandstone channel fillings and local limestone lenses
	PALEOCENE	FORT UNION FORMATION: TONGUE RIVER MEMBER		0-425	Light colored clays and sands, with coal-bed farther north.
		CANNONBALL MEMBER		0-225	Green marine shales and yellow sandstones, the latter often as concretions.
		LUDLOW MEMBER		0-350	Somber gray clays and sandstones with thin beds of lignite.
— ? —					
CRETACEOUS	UPPER	HELL CREEK FORMATION (Lance Formation)		425	Somber-colored soft brown shale and gray sandstone, with thin lignite lenses in the upper part. Lower half more sandy. Many loglike concretions and thin lenses of iron carbonate.
		FOX HILLS FORMATION		25-200	Grayish-white to yellow sandstone
		PIERRE SHALE Sharon Springs Mem.		1200-2000	Principal horizon of limestone lenses giving teepee buttes Dark-gray shale containing scattered concretions. Widely scattered limestone masses, giving small tepee buttes Black fissile shale with concretions
		NIOBRARA FORMATION		100-225	Impure chalk and calcareous shale
		Turner Sand Zone CARLILE FORMATION Wall Creek Sands		400-750	Light-gray shale with numerous large concretions and sandy layers. Dark-gray shale
		GREENHORN FORMATION		(25-30)	Impure slabby limestone. Weathers buff.
		GRANEROS GROUP		(200-350)	Dark-gray calcareous shale; with thin Orman Lake limestone at base.
		GRANEROS GROUP: BELLE FOURCHE SHALE		300-550	Gray shale with scattered limestone concretions. Clay spur bentonite at base.
	LOWER	GRANEROS GROUP: MOWRY SHALE		150-250	Light-gray siliceous shale Fish scales and thin layers of bentonite
		GRANEROS GROUP: NEWCASTLE SANDSTONE		20-60	Brown to light yellow and white sandstone.
		GRANEROS GROUP: SKULL CREEK SHALE		170-270	Dark gray to black shale
		INYAN KARA GROUP: FALL RIVER [DAKOTA (?)] ss		10-200	Massive to slabby sandstone.
		INYAN KARA GROUP: LAKOTA FM: Fuson Shale		10-188	Coarse gray to buff cross-bedded conglomeratic ss, interbedded with buff, red, and gray clay, especially toward top. Local fine-grained limestone.
		Minnewaste ls		0-25	
				25-485	
JURASSIC		MORRISON FORMATION		0-220	Green to maroon shale. Thin sandstone.
		UNKPAPA SS		0-225	Massive fine-grained sandstone.
		SUNDANCE FM Redwater Mem Lak Member Hulett Member Stockade Beaver Canyon Spr. Mem		250-450	Greenish-gray shale, thin limestone lenses Glauconitic sandstone; red ss. near middle
		GYPSUM SPRING		0-45	Red siltstone, gypsum, and limestone
TRIASSIC — ? —		SPEARFISH FORMATION Goose Egg Equivalent		250-700	Red sandy shale, soft red sandstone and siltstone with gypsum and thin limestone layers. Gypsum locally near the base.
PERMIAN		MINNEKAHTA LIMESTONE		30-50	Massive gray, laminated limestone.
		OPECHE FORMATION		50-135	Red shale and sandstone
PENNSYLVANIAN		MINNELUSA FORMATION		350-850	Yellow to red cross-bedded sandstone, limestone, and anhydrite locally at top. Interbedded sandstone, limestone, dolomite, shale, and anhydrite. Red shale with interbedded limestone and sandstone at base.
MISSISSIPPIAN		PAHASAPA (MADISON) LIMESTONE		300-630	Massive light-colored limestone. Dolomite in part. Cavernous in upper part.
DEVONIAN		ENGLEWOOD LIMESTONE		30-60	Pink to buff limestone. Shale locally at base.
ORDOVICIAN		WHITEWOOD (RED RIVER) FORMATION		0-60	Buff dolomite and limestone.
		WINNIPEG FORMATION		0-100	Green shale with siltstone
CAMBRIAN		DEADWOOD FORMATION		10-400	Massive buff sandstone. Greenish glauconitic shale, flaggy dolomite and flatpebble limestone conglomerate. Sandstone, with conglomerate locally at the base.
PRE-CAMBRIAN		METAMORPHIC and IGNEOUS ROCKS			Schist, slate, quartzite, and arkosic grit. Intruded by diorite, metamorphosed to amphibolite, and by granite and pegmatite.

1963

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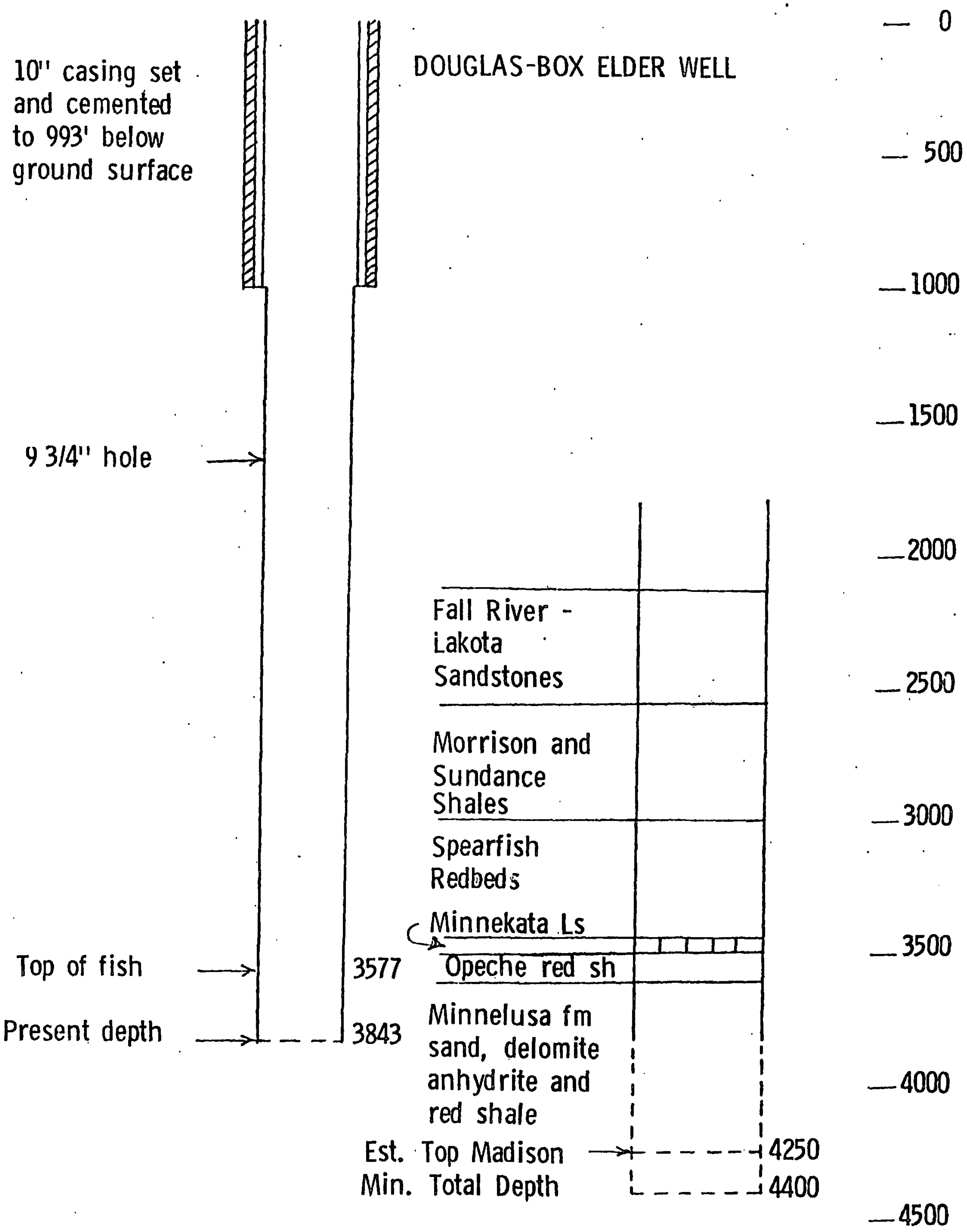
RAPID CITY, SOUTH DAKOTA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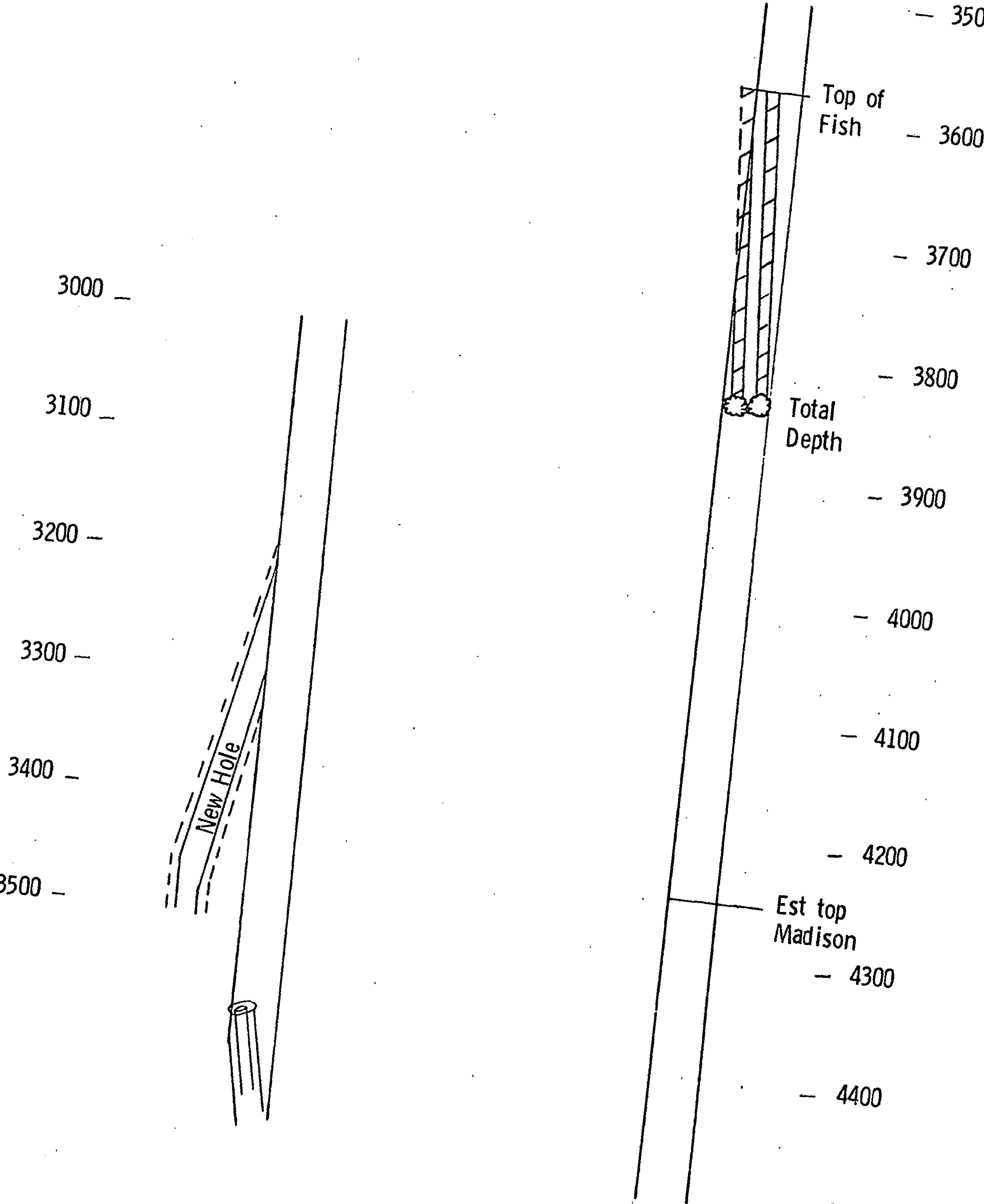
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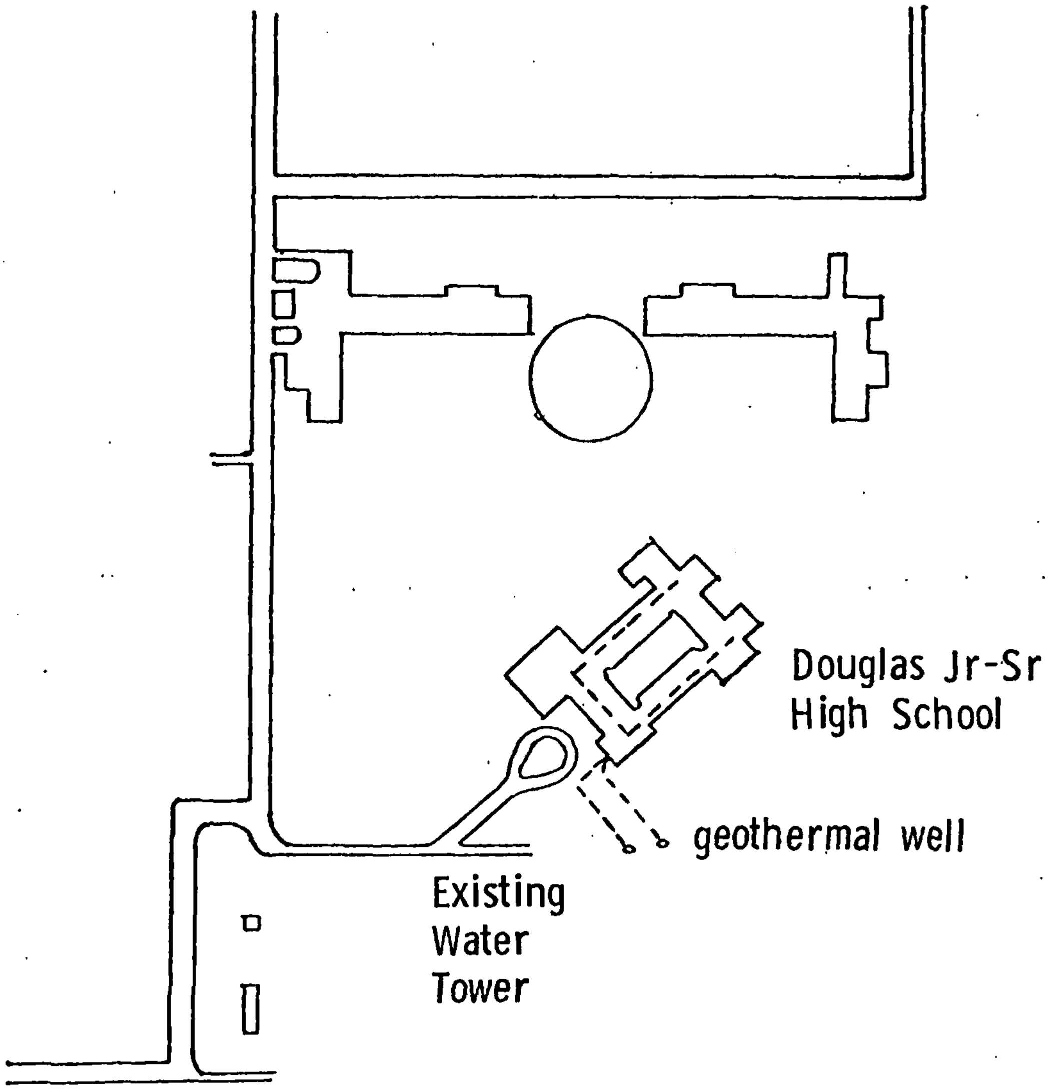

Plan of Douglas geothermal system.

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FORCED GEOHEAT EXTRACTION FROM SHEET-LIKE FLUID CONDUCTORS

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1977

(1) Introduction

Geoheat is now being extracted for electrical power generation from a number of resources in thermally active regions. The most notable examples are The Geysers, California; Larderello, Italy, and Wairakei, New Zealand. Common to all these cases is that the energy is being extracted from natural hydrothermal resources on the basis of free flowing boreholes. This type of operation may be termed as free geoheat production.

Large scale space heating by geoheat has been carried out in Iceland for more than three decades. The Reykjavik District Heating System, which now supplies energy for domestic heating for more than 100,000 people is a low-temperature operation where large scale resource stimulation by borehole pumping is being applied.

The free and stimulated production methods as described above are based on the presence of natural fluid conducting openings in the resource formations and on a natural recharge of the withdrawn fluid. One can also envision forced geoheat extraction systems (FGES) with an artificial recharge of the heat extracting fluid which flows to some extent through artificial openings created by hydraulic fracturing or other pressurizing operations. For the operation of such systems to be successful, the openings have to provide adequate contact areas or contact volumes between the fluid and the rock such that a sufficient amount of heat can be extracted from the hot formations.

In the following, we will discuss a number of economical and physical aspects of FGES with emphasis on heat extraction from sheet-like natural fluid conductors in volcanic formations such as sufficiently open (conducting) fault zones, dikes and formation contacts. We envision applications of our results in some regions in the western U.S., the Pacific Northwest, in particular. Our work has been supported by ERDA under grant E(45-1)-2227.

(2) Limitations on geoheat transport

Thermal waters and natural steam are bulky heat carriers which cannot be transported economically over long distances. In the case of power generation the limits are of the order of a few kilometers only. For direct uses such as space heating, the maximum distances may in extreme cases amount to a few tens of kilometers. At the present state-of-art where only natural convective type sources are being harnessed, geoheat utilization, non-electrical uses, in particular, are therefore severely limited by the low tranportability. The major convective sources are not favorably located with regard to the heat market. There is consequently a great interest in the possibility of extracting geoheat at suitable temperatures over much wider areas than has been possible so far.

(3) FGES in regions of moderately high to normal heat flow

The FGES which we envision involve the circulation of a heat extracting fluid through hot formations at depth between sets of injection and production boreholes. The principal factors that have to be considered in the design of such systems are the following,

(1) thermal properties of the formations
(2) fluid conductivity at the depth of interest
(3) drilling and equipment costs
(4) pumping power required to provide the necessary penetration and contact area
(5) fluid losses, scaling.

(4) Minimum contact area

The size of the fluid-rock contact area required to produce a sufficient amount of hot fluid to amortize a given system investment depends critically on factors (1) to (5) above. The minimum economic area can be estimated on the basis of an idealized model. We assume that the circulating fluid is water absorbing heat from the rock in uniform and unidirectional flow through an infinitesimally thin fracture in a large volume of homogeneous rock which is isothermal at the initiation of the process. Using theoretical results by Bodvarsson (1974), the contact area as a function of plant investment and value of the energy produced can easily be calculated. The results for a single borehole-pair producing heat for building heating are shown in Fig. 1 and the corresponding results for electrical power generation are shown in Fig. 2. In both figures the useful life of the system is assumed to be 20 years, the interest on capital 8% and the operational and maintenance costs are 10% of capital per annum. Other factors are given in the figures. In the electrical case, the required power per borehole pair amounts to a few MW.

(5) Suitable fluid conductors

There are two main possibilities of realizing FGES of the above type, viz., by using (a) natural subsurface fluid conductors or (b) artificial conductors obtained by hydraulic fracturing. The second possibility is now under thorough investigation including field testing by the Los Alamos Scientific Laboratory Dry-Hot-Rock Group in Los Alamos, N.M. (ERDA, 1976). In this note we will concentrate on the natural conductors. The results for the minimum contact area given in Fig. 1 and 2 will obviously apply to both cases (a) and (b).

The natural fluid conductors which have the potential of providing sufficient fluid-rock contact and some relevant data are listed in Table 1 below.

Due to great horizontal extent, major open fault zones and basaltic dikes have very large wall surfaces which in a sufficiently hot environment could be used for heat extraction provided an adequate and sufficiently uniform longitudinal fluid conductivity is available. It is to be emphasized that the fluid conductivity can be enhanced by an increased injection pressure.

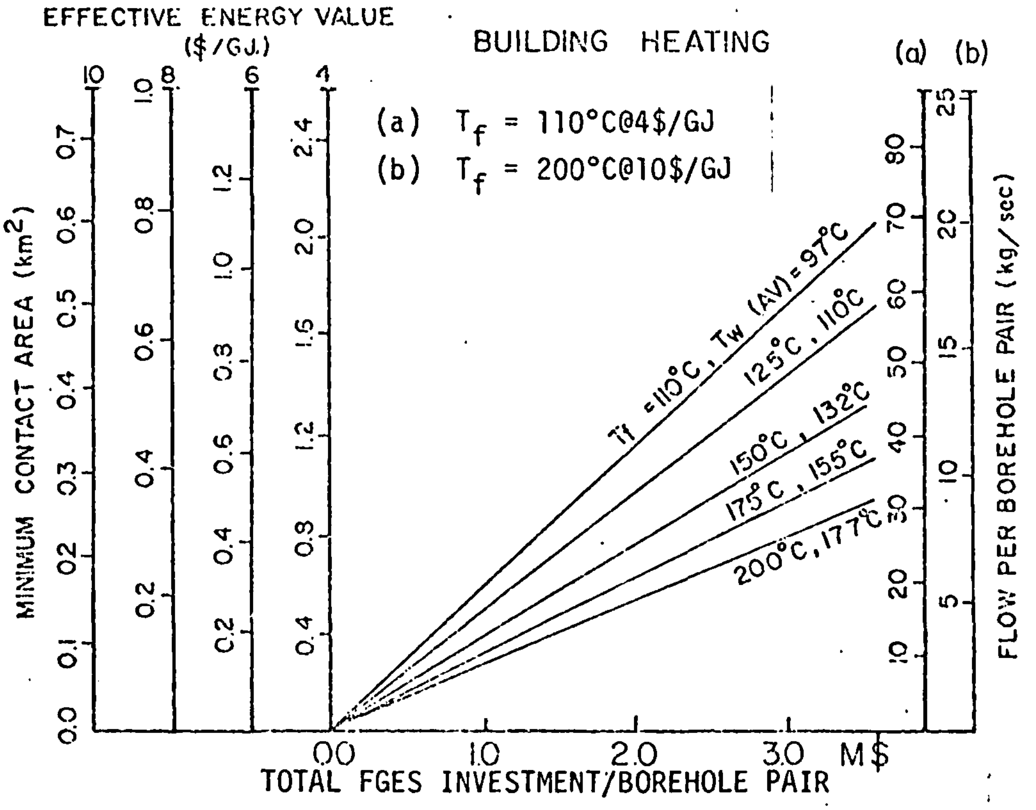

Figure 1. Minimum contact area/borehole pair for building heating.

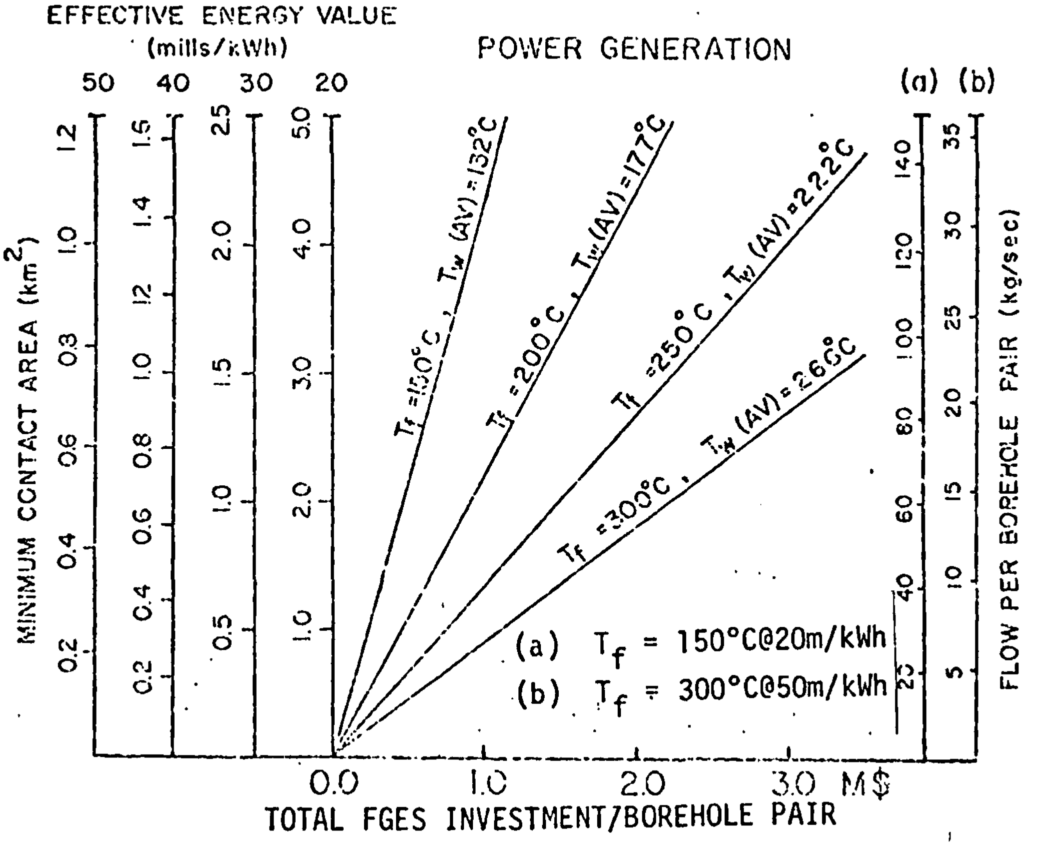

Figure 2. Minimum contact area/borehole pair for power generation.

k = 2.6 W/(m·deg)
ρ_r = 2700 kg/m^3
C_r = 1000 J/(kg·deg)

T_f = formation temperature
T_w(AV) = average water temperature

Table 1

Potential Fluid Conductors

Type	Field observations on large scale fluid conductivity	Role in geoheat extraction
(1) Fault zones	Many major geothermal systems are controlled by faults, e.g. in the Basin and Range Province.	Borehole production obtained by intersecting fault zones.
(2) Basaltic dikes in flood-basalt areas	Many geothermal systems in Iceland are controlled by dikes.	Boreholes in Central North Iceland produce by intersecting dikes.
(3) Other intrusions	Few data available, but columnar structure possibly indicative of conductivity.	Some production in Iceland appears to be obtained from thin basaltic sills.
(4) Formation contacts	Lava-bed contacts are major aquifers in the flood-basalt plateau of Iceland.	Major production in South-Western Iceland obtained from lava-bed contacts.
(5) Sedimentary horizons	Many major sedimentary basins contain large volumes of thermal water.	Large scale forced geoheat production from sedimentary basins in France (DGRST, 1976).

(6) Factors affecting the efficiency of FGES

The estimates given in Fig. 1 and 2 are based on an idealized model. Deviations from the assumed conditions will in one way or an other affect the results and will have to be considered carefully.

First, rock temperatures are generally not uniform. The water may therefore flow along rock surfaces where the temperature varies in the direction of flow. Second, the load on FGES will vary considerably, in particular, in cases where the heat is to be used for building heating. A varying production rate will usually be required in such cases. A somewhat more elaborate computer modeling indicates that these two effects will not be of major importance and can quite easily be taken into account.

Of greater concern is the rather complex interaction of three phenomena affecting the flow of thermal water in subsurface natural conductors, viz., (i) natural flow channeling, (ii) thermoelastic effects and (iii) buoyancy of convective effects. The quantitative theory of these effects in the natural environment is both uncertain and basically difficult. By nature, these flow phenomena are non-linear effects.

Table 2 has been designed to furnish a very brief qualitative overview of the adverse influence of the above three flow effects on the design factors listed in section (3) above.

(7) Experimental preliminary design of a sheet-controlled FGES

The fluid conductors under (1) to (4) in Table 1 appear suited for the type of FGES under consideration. The basically horizontal conductors such

Table 2

Adverse flow phenomena

Type of phenomena	Potential effects Inefficient heat extraction	Pumping power	Water losses
(1) Non-uniform conductivity, flow channeling	Potentially major factor	High pumping pressure may be required to overcome non-uniformity.	Can be a major factor in channeling injected cold water out of the heating zone.
(2) Thermoelastic effects	Enhances channeling of water colder than the rock.	Narrowing of fractures carrying water hotter than the rock requires increasing pumping pressure.	May increase water losses by enhanced channeling.
(3) Buoyancy and convection	Enhanced channeling in down-flow systems		Downward convective penetration of cold water may enhance losses.

as the formation contacts and intrusive sills have, however, very frequently the disadvantage of not being directly observable. Lack of field data can in such cases greatly reduce the possibilities for arriving at a rational design of the heat extraction system. This type of difficulty is of much less concern in the case of the quasi-vertical conductors, such as (1) and (2) in Table 1, where surface outcrops can be inspected. Quite frequently the position of such conductors can be mapped with considerable precision.

We have therefore chosen to base our first attempt at the design of a FGES on the assumption of a sufficiently open quasi-vertical conductor such as a basaltic dike or a fault zone. We make the ad hoc assumption that such a conductor is available. Depending on the position of the injection-production boreholes, the main flow in systems of this type can be vertically up (Fig. 3), vertically down (Fig. 4) or quasi-horizontal. Considering the various phenomena indicated in Table 2 there appear grounds for assuming that the up-flow systems will exhibit the highest degree of flow stability and thereby achieve the most favorable condictions for heat extraction.

A preliminary experimental design of a multihole upflow FGES is shown in Figure 5. The system is to produce water in the temperature range 130-100°C for building heating purposes. The system is envisioned to operate in an environment where the geothermal gradient is 50°C. The effective contact area per borehole pair is to amount to 0.5 km^2, the flow per hole is 25 kg/sec and the effective thermal power relative to a effluent temperature of 40°C is 3.1 MW.

(8) Epilogue

Having come to the conclusion that the estimated subsurface dimensions of the FGES under consideration are not unreasonable, our principal task will be to demonstrate that nature complies with our basic assumptions.

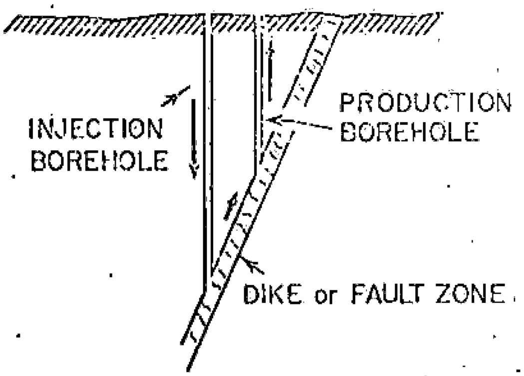

Figure 3. Upflow system

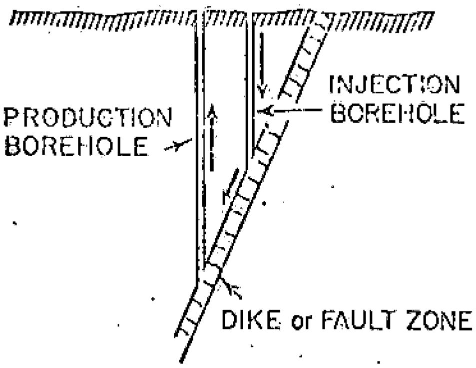

Figure 4. Downflow system

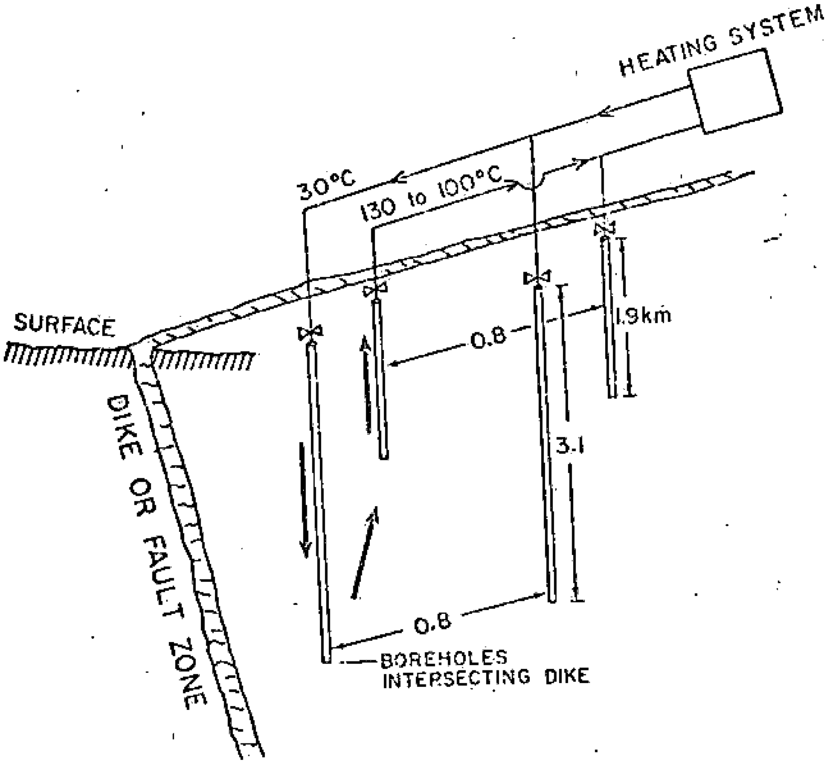

Figure 5. An experimental design of a multihole FGES system for building heating. The flow per borehole pair is 25 kg/sec.

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15 GEOTHERMAL WATERS

Geothermal Rm.

By

G. W. GRINDLEY[1] and G. J. WILLIAMS[2]

Geothermal waters and metallogenesis

Whether or not geothermal steam be regarded as a "mineral" in the true sense, this Chapter is included as a tribute to those scientists and engineers of the Department of Scientific and Industrial Research and of the Ministry of Works who have brought a unique geothermal-steam electric-generating project to fruition. Of particular interest in this geological Volume, however, are the accompanying scientific investigations which have contributed to an understanding of near-surface hydrothermal metasomatic processes, wherein magmatic and meteoric waters meet. There is an obvious genetic link between these processes and those which resulted in the highly profitable Tertiary volcanic gold-silver mineralization of the Hauraki goldfields—a link that could provide, for years to come, a series of fascinating studies.

GEOTHERMAL WATERS AS A SOURCE OF POWER[3]

Introduction

Geothermal energy may be defined as the heat contained in the rocks and interstitial water of the earth's crust due to the geothermal gradient—together with the natural heat flow per unit area, these factors are critical. A mean value for the geothermal gradient in continental areas is generally taken as 30°C/km (1°C/110 ft). This value may be lower in some sedimentary basins that have been, or are being depressed relatively rapidly—and may be higher in mountainous regions that have been or are being elevated relatively rapidly. Magma may be formed and injected upward by strain release during tectonic movements at depths of 50-60 km; or at shallower depths—where the geothermal gradient is inevitably steeper. The geothermal gradient may be further steepened by upward injection of magma into the crustal rocks and cause fusion of these rocks at depths ranging from 10 to 25 km—this may result if the geothermal gradient is steepened sufficiently. Volcanism, plutonism and steep geothermal gradients are therefore intimately associated.

Due to varying geothermal gradients within different parts of the earth's surface, the heat flow varies from place to place. The mean heat flow is commonly taken as 1.1 x 10^{-6} cal/cm^2 (Bullard 1963). The heat flow at the surface also depends on the efficiency of heat transfer from depth, and also on the heat-transfer mechanism. Convective heat-transfer by upward movement of hot water, vapour or magma is efficient and gives a greater heat flow at the surface than purely conductive heat transfer, where little mass movement of the heat-carrying medium takes place. This is most easily appreciated in active volcanic areas, where heat flow is considerably augmented by eruption of lava and ash and by vigorous hot-spring and fumarolic activity. Both convective and conductive heat-transfer normally operate in conjunction, but for large heat flows convective mechanism must dominate. In 1958, the heat flow at Wairakei was approximately 5.5 x 10^{-4} cal/cm^2 or 500 times the accepted mean for the earth (Fisher, 1964). It is unlikely that this heat flow was concentrated from an area 500 times as large at a depth of 8 km, where the maximum temperature of 265°C would be attained under a normal geothermal gradient (Healy 1964). It seems inescapable that a large heat source and an efficient convective transfer of heat to the surface are required in large hydrothermal fields, especially if they have been active for a very long time.

It is apparent that exploitation of geothermal energy depends on rapid transfer of heat to the surface in a convenient form for conversion to power. The most rapid heat-transfer mechanism available is molten rock or magma—which may be erupted at temperatures as high as 1,100°C and in voluminous quantities. Although experimental drilling has been carried out at Kilauea lava lake on the island of Hawaii on the extraction of heat from newly-formed lava, a successful method of heat extraction has yet to be devised. Kilauea lava lake, which was filled by an eruption in 1959, was estimated to contain about 2 x 10^{9} kWh of potentially recoverable energy—sufficient to operate a 100,000 kW plant for 10 to 20 years (Rawson, Bennett, 1961)—a significant resource. Geothermal development to date has depended on the extraction of heat carried in the more conventional form of steam or hot water or a mixture of both. Consequently, it is necessary in geothermal investigation to consider not only the heat flow but also the presence of water or steam in the rocks. Efficient extraction of geothermal energy, therefore, requires:

Rocks at high temperature
Permeable sub-surface aquifers or fissured zones that yield large quantities of steam or hot water when drilled

Hydrothermal fields

Geothermal development has as yet been confined exclusively to the hydrothermal fields, of which the most obvious surface indications are hot springs, fumaroles, geysers and steaming ground. Hydrothermal fields can be broadly classified into

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five groups on the grounds of their relation to the heat source and the nature of the heat-transfer mechanism. The distribution of four of these broad groups in New Zealand is shown in Fig. 15-1: they are briefly described below.

Direct volcanic exhalations

Fumaroles and hot springs are commonly found in the craters or on the flanks of active volcanoes. Such springs are thought to be heated directly by magmatic steam exhaled directly from the magma chamber at the volcano roots. The springs are generally strongly acidic and the steam has a relatively high gas content (3 to 5 per cent). Variable quantities of sulphur dioxide, hydrogen and hydrochloric acid may be present in the gases as well as carbon dioxide and hydrogen sulphide. Heat flows vary but are generally larger than in acid springs associated with alkaline chloride fields. For example, the heat flow from the crater lake on Mt. Ruapehu is about 55,000 kcal/s, and this may be trebled during periods of increased activity (Mr R. R. Dibble, pers. comm). Ketetahi springs on the north flank of Tongariro, and White Island (Plate XXXIV) in the Bay of Plenty are other New Zealand examples (Hamilton, Baumgart *et al.*, 1959). Because of relative inaccessibility and proximity to potential eruptive centres, these springs and fumaroles heated directly by magmatic steam are of little interest for geothermal development.

Low intensity fields in decadent volcanic districts

Hot springs are found around the margins of many quiescent and extinct volcanoes and in extinct or decadent volcanic districts where the geothermal gradient is still substantially higher than normal following volcanism. Such springs are thought to derive their heat supply by downward penetration of meteoric water to comparatively shallow masses of hot volcanic and sedimentary rocks. Around an extinct volcano, a convection system may be set up with hot water rising axially and spreading laterally near the surface, and meteoric water descending around the margins. Since the volume of hot rock accessible to the descending water is not great and cools rapidly close to the surface, such hydrothermal fields may not rise notably in temperature with depth. Because of the low intensity of activity and the absence of a direct magmatic contribution, the waters are not highly mineralised, and all the dissolved constituents can be explained by leaching of the country rocks during passage of the heated water to the surface. New Zealand examples include the numerous, medium to low temperature, moderately to weakly mineralised springs of Waikato, Coromandel Peninsula, Hauraki Graben, Northland and outlying islands which are associated with late Tertiary and early Quaternary basaltic; andesitic and rhyolitic volcanism. Similar thermal springs are found around the flanks of the Lyttelton early Quaternary basalt volcano on Banks Peninsula in Canterbury. The Ngawha field in Northland (Fleming, 1945) is associated with late Quaternary basaltic volcanoes and lava flows and small rhyolitic and andesitic cones, and is the only one of these fields that has been considered seriously for geothermal power development. The hot springs at Ngawha emerge where there are several thousand feet of impermeable Cretaceous marine sediments. The maximum temperature is 83°C, the heat flow is about 8,000 kcal/s, and geothermal prospects depend entirely on the discovery of a suitable aquifer by drilling. Maximum temperatures in the low intensity fields may be insufficient for power generation where temperatures greater than 200°C are normally required. However, other uses for low pressure steam in the drying of timber, salt making, the heating of greenhouses and for central heating, seem to be worth investigation.

High intensity fields in active volcanic districts

The most extensive hydrothermal fields with a high heat flow are in active volcanic districts and are fed from relatively deep-seated plutonic sources—probably cooling batholiths or zones of granitization. Some geologists believe that large magma bodies are formed within the crust by large-scale crustal foundering and melting along narrow, tectonically-controlled zones of high heat flow. Crustal melting on an important scale may have taken place in many acidic volcanic provinces where large volumes of ignimbrite, pumice, pyroclastics and rhyolite lava have been erupted (Healy, 1962). The capacity of the individual heat sources in such areas may be extremely large, and where permeable near-surface formations allow deep penetration of meteoric waters, large convection systems may be set up, allowing effective transfer of heat to near-surface aquifers. Maximum temperatures in such systems are commonly high (200 to 300°C), the volumes of hot rock and interstitial water may be large and the surface heat flows considerable. Several such hydrothermal fields are known in the Taupo Volcanic Zone between Lake Taupo and the Bay of Plenty (Figs. 15-1, 15-2). These hydrothermal fields, fed by convective heat transfer from large semi-permanent acidic magmas, provide attractive potential geothermal power opportunities. Of this general type are the Wairakei, Waiotapu, Rotorua and Kawerau fields, all of which have been exploited for geothermal energy. The major assets of such fields are the great heat capacity of the source and the relatively high permeability of the pumiceous volcanics deposited in the large volcano-tectonic basins so typical of this active tectonic and volcanic zone.

High temperature steam fields from active plutonic sources

A few hydrothermal fields that have been exploited produce dry steam instead of a steam-water mixture. The chief example is the well-known Italian field of Larderello, but the Geysers in California is also a dry-steam field: dry steam has been located in the southern part of the Wairakei field. White (1961) suggested that the differences between the dry steam fields and the more common hot-water fields are due principally to the relation between heat supply and the supply of meteoric water. If the entry of meteoric water deep into the system is restricted by rocks of low permeability, the heat supply may be great enough to vapourise the small amount of interstitial water to dry steam. At Larderello, permeable formations containing dry steam are overlain by thick impermeable shales which effectively restrict the entry of meteoric water into the aquifer. At the Geysers in California, dry steam is tapped in a steep-dipping transcurrent fault-zone traversing otherwise impermeable rocks (McNitt, 1961). At Wairakei, the lowering of hydrostatic level produced by exploitation has produced local pockets of accumulated dry steam: in the south of the field, a large output of dry steam was tapped in a subsurface fault fissure. Whether this steam was produced by drying out of the aquifer or from a steam trap at greater depth has yet to be determined. The dry steam fields, therefore, differ from the more common hot-water fields, only in that the dominant method of heat transfer is by ascending steam rather than hot water. Isotopic studies (Craig, Boata and White, 1956) indicated that the dry steam is dominantly vapourised meteoric water and not of direct magmatic origin; Marinelli (1963) produced good evidence favouring a deep-seated acid magmatic intrusion as the heat source at Larderello.

Non-volcanic hydrothermal fields

Although there is a world-wide association of hydrothermal activity and volcanism, this is by no means universal. No volcanic rocks are known at the Californian Geysers or Larderello, where the heat source is believed to be a deep-seated intrusive body, and in certain zones of active tectonic uplift, hotter rocks have been brought closer to the surface and the geothermal gradient steepened without associated volcanism. In New Zealand, the hot springs of the Southern Alps appear to be a result of recent rapid uplift of the Alps along the line of the Alpine Fault. This uplift has been estimated at between 6 and 9 miles in late Pliocene and Quaternary times (Mason, 1962), amounting to approximately 1 ft of uplift in 150 years. Since the Alpine rocks are relatively impermeable and conductive, heat transfer to the surface is slow, and it is not surprising that a steep geothermal gradient has resulted. This is shown by the numerous small hot springs in many of the river valleys scattered through the mountains. Temperatures range from 40 to 85°C and discharges are generally between one and ten litres per second. All the springs are associated with faults, some with major transcurrent faults such as the Hope and Awatere Faults, and others with minor crush-zones. They are believed to originate by downward percolation of meteoric water to the hot rocks at shallow depth with subsequent uprise along fault zones to the surface. The springs are only weakly mineralized and close to surface waters in composition (Morgan, 1908).

Somewhat similar hot springs are found in the North Island Axial Ranges to the east of the Central Volcanic Region. These springs—Tarawera, Waiohau and Waiau—are related to active transcurrent faults traversing Mesozoic greywackes and are of low temperature and weakly mineralised. Further northeast in Raukumara Peninsula, Te Puia and Morere Springs discharge from sandy sediments associated with diapiric anticlines of incompetent early Tertiary bentonites and Cretaceous shales. These are low temperature (50 to 55°C) springs with a high mineral content; the relatively high content of calcium chloride and sodium iodide is typical of mildly thermal, connate waters or meteoric waters rising from considerable depths through thick marine sediments. Neither the Alpine or East Coast springs can be considered as potential geothermal resources, though they may be useful for recreational and therapeutic purposes.

Geothermal fields

Three hydrothermal fields—Wairakei, Waiotapu and Kawerau—have been exploited to varying degrees as sources of geothermal energy; the investigation of two others, Orakei Korako and Ngawha, in under way. The Taupo and Rotorua fields have been drilled for hot water for use in swimming baths, central heating, timber drying and greenhouses. Apart from Ngawha in Northland all the above fields lie within the Taupo Volcanic Zone (Figs. 15-1 and 15-2).

Wairakei

Investigations on the Wairakei field (Plate XXXV) have been going on for 15 years and a power station of 192 MW capacity[4] is now operating Extension to 250 MW or 280 MW is possible within the next few years. Both high (200 p.s.i.) and intermediate (80 p.s.i.) pressure steam are used in back-pressure and steam-condensing turbine-generator units. Numerous publications have appeared over the years describing the physical, geological, chemical and engineering aspects of the investigation—Grange *et al.* (1955), Banwell (1963, 1964), Healy (1956, 1964), Studt (1957, 1958), Steiner (1953), Ellis and Wilson (1960), Grindley (1957, 1961, 1963) and Smith (1958). Important references appeared in a series of 28 papers contributed to the United Nations Conference on New Sources of Energy (e.g. McNitt, 1961).

The hydrothermal field is underlain by an acid volcanic sequence consisting of Recent pumice cover, Wairakei Breccia, Huka Falls Formation, Haparangi Rhyolite, Waiora Formation, Waiora Valley Andesite, Wairakei Ignimbrites and Ohakuri Group (Grindley, 1956). The stratified volcanic sequence is draped over a basement horst and thickens both eastwards and westwards into adjoining

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[4] Plant factor 70-90%; load factor 80-90%; peak output about 175MW.

volcano-tectonic depressions. The bulk of the steam production is obtained from a thick aquifer of pumice breccias (Waiora Formation) between 1,300 and 2,500 ft thick, capped by lacustrine shales of the Huka Falls Formation. The Ohakuri Group (lying below the ignimbrites) constitutes a lower aquifer which has been little exploited by drill-holes. Hydrothermal water up to 265°C in the Waiora aquifer is fed through linear fissures in the underlying ignimbrites, principally at the crest of a small structural dome. These fissures are believed to be related to active north-east striking, predominantly normal faults, with a small dextral transcurrent component. Major zones of heat liberation have been localised by intersection of secondary north-westerly cross-faults. Fossil, hydrothermal mud-flow conglomerates intercalated in the mid-Pleistocene Huka Falls Formation suggest that hydrothermal activity at Wairakei is at least 0.5 million years old. As mentioned earlier, siting of successful drill-holes involves a search for permeable zones at high temperature. Since sub-surface fault zones have proved excellent producing zones, most production holes have been sited to intersect them.

Waiotapu

An investigation of the Waiotapu field was undertaken between 1956 and 1958, seven wells being drilled[5].

This field is underlain by an acid volcanic sequence consisting of the following units in downward succession:

Earthquake Flat Formation
Maungakakaramea Dacite
Huka Group (lake beds)
Rangitaiki Ignimbrites
Huka Group (pumice breccias)
Waiotapu Ignimbrites
Paeroa Ignimbrites
Ngakoro Andesite
Ohakuri Group
Haparangi Rhyolite

The general sequence is similar to that at Wairakei, except that the Huka lake beds are thin at the surface and the underlying aquifer is thinner and not as effectively capped. Consequently temperatures and pressures are lower, and the Huka aquifer at Waiotapu is unsuitable for steam production (except at very low pressures). Deeper drilling undertaken to find a lower aquifer was only partly successful. A succession of ignimbrite sheets of rather low permeability was drilled in the three deep holes, but despite record temperatures (275 to 295°C), outputs from the thin aquifers encountered were disappointing. Further, the bicarbonate content of the water caused the wells to be blocked up with calcite within a few months. No deep fissured zones were encountered, and it was felt that utilisation may depend on finding them. The hydrothermal field lies at the northern end of the upper Quaternary Taupo-Reporoa Basin; better results may yet be achieved by drilling towards the southern end of the field where the aquifers are expected to be thicker, and where a group of intersecting dextral-normal and sinistral-normal faults may mark one of the major fissured zones feeding the hydrothermal field.

> According to Grindley (1963): "Nothing so far discovered at Waiotapu has contradicted the theory, developed by the writer at Wairakei (Grindley, 1957), that the hot water in the thermal areas is fed from directly below along a relatively few, near-vertical, active fault zones. The essential factor in continuing hydrothermal activity is the continuity of active faulting. If the faults cease to move, the fault zones eventually become blocked by mineral deposition, pressures build up in the near-surface strata, and hydrothermal explosions result. This appears to have happened over much of the Waiotapu field and accounts for the lack of success, compared with Wairakei, in tapping feed zones along faults".

Kawerau

The Tasman forest-product mills at Kawerau use geothermal steam to supplement conventional steam boilers fired by mill wastes and coal. Both intermediate (100 p.s.i.) and high (200 p.s.i.) pressure steam are used in two steam generators and a turbo-electric generator. Ten wells have been drilled in the field. Four of them feed the generating sets at the mill, and were deepened from 2,000 to 3,000 ft in 1960 after the original wells had practically ceased producing as a result of cold-water incursion and calcite deposition. The best well has an output superior to most of those at Wairakei—with a maximum temperature of 285°C (Dench, 1962).

The Kawerau hydrothermal field is underlain by an acid volcanic sequence consisting of the following units:

Recent alluvium
Haparangi Rhyolite
Huka sandstones and breccias
Andesite and Ignimbrite

The general sequence is thus similar to that at Wairakei and Waiotapu. The steam production originally came from the Huka aquifer above 2,000 ft in depth, but since deepening, production has come from fissured zones in the underlying andesite. Production is variable depending on the thickness and permeability of the andesite. The andesite 'aquifer' appears to be sealed by mudstones and the future of the field may depend on the effectiveness of this mudstone cap-rock in preventing eventual cold-water incursion into the lower producing zones. Present discharge from the field is approximately twice the natural heat flow prior to drilling (20,000 kcal/s), but little fall in output has so far been noted.

Effects of exploitation

Only in the geothermal field of Wairakei has exploitation gone on long enough for the results to become obvious. It had previously been assumed that the natural heat flow would provide a reasonable yardstick for estimating the safe rate of extraction, geothermal resources being estimated on this basis (Grange, *et al.*, 1955). A total minimum potential of 200 MW was estimated for the Taupo Volcanic Zone. Over the past few years, it has become apparent that the natural heat flow can be exceeded—by how much and for how long is

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[5] Waiotapu geothermal field: *Dept. Sci. Ind. Res. Bul.* 155.

not yet known. At present, the 1951-52 natural heat flow at Wairakei (102,500 kcal/s) is being exceeded by a factor of about six. In 1958 when the natural heat flow from the field was re-assessed, practically no change was noted even though discharge from the field through bores was 160,000 kcal/s (Fisher, 1964). Since 1958, bore discharge has increased to almost 600,000 kcals/s and the natural heat flow has certainly not diminished appreciably although no further precise measurements are available. The major effect of exploitation has been a reduction in water discharge at the surface accompanied by an increase in steam escape. A similar trend is apparent in the shallower drill-holes and is brought about by lowering of the hydrostatic level, boiling of water in the pores of the rocks and in fissures, and replacement by steam. The total fall in aquifer pressure at sea-level datum was approximately 200 p.s.i. from 1954 to 1964, corresponding to a fall in actual water level of approximately 570 ft (at a water density of 50 lb/cu. ft.). The fall in aquifer pressures extends beyond the vicinity of the production area, and is apparent throughout the whole hydrothermal field, even in those parts little exploited by drill-holes.

The fall in aquifer pressure reduces the pressure drive in drillholes and leads to loss in output and eventually to degradation from the high-pressure (200 p.s.i.) class to intermediate-pressure (80 p.s.i.). This first takes place in the shallower holes with low bottom-hole pressures, and in low-permeability holes where draw-down of aquifer pressures during discharge is substantial (up to 450 p.s.i.). In high-permeability holes, especially those drawing on substantial fissures near the well-bottom, the effects of fall in aquifer pressure are least critical—such wells have the longest productive life. These results demonstrate the importance of accurate hole siting so as to intersect the fault-determined fissure zones at deep levels in the aquifer where pressures and temperatures are high.

The natural effect of the fall in aquifer pressures is the formation of steam at progressively lower levels in the aquifer. This is unavoidable and indeed necessary for the extraction of heat from the aquifer. Because minerals tend to become concentrated in the water phase, steam separation on a large-scale encourages mineral deposition and thus reduces permeability. When steam separation takes place within the solid casing (as in the early stages of exploitation), the deposits of calcite and silica can be reamed out and the well reconditioned without permanent loss in output. If, on the other hand, mineral deposition takes place in the aquifer below the casing, steady and irreparable deterioration in output may result. Mineral deposition is suspected to be a prime cause (the others are loss in temperature and working head) governing the life of geothermal wells. At Waiotapu, mineral deposition has led to the temporary abandonment of geothermal investigations and at Wairakei, although this is not nearly so serious a problem, it may contribute to the steady deterioration of output observed in most wells that have been operating more than a year or two. At present, the drilling of at least five new wells per year is required to keep the steam supply at a level sufficient for the power needs of the station.

Recharge of the aquifer appears to be slow, for considerably more water is being extracted than is being replaced naturally. In fact, the pressure drop is expressed by a linear rather than by an exponential curve when plotted against time with constant discharge. The pressure fall is directly proportional to the cumulative mass discharge above a base figure comparable with the original discharge. The linear pressure fall may be more apparent than real due to the short time the field has been producing at peak capacity, but certainly bears out the observation that the overall permeability of the aquifer is low. This low permeability is partly due to compaction of the soft pumice breccias, but it may mainly be due to cementation by hydrothermal minerals. Except on the margins of the field, the slow rate of recharge allows time for recharge water to become heated to aquifer temperatures before being extracted in drill-holes. In 1964, temperatures in the lower part of the aquifer (below sea-level) had not fallen more than 10°C since exploitation began. Such falls in temperature as have been observed appear to be due to the falling enthalpy of the formation water following separation of steam. In the higher, more permeable parts of the aquifer, temperatures have risen due to the presence of separated steam. This steam being under pressure below the confining mudstones, tends to exclude the influx of colder formation water from outside the hydrothermal field. The large difference in viscosity between hot water (0.1 centipoise) and cold water (1.0 centipoise) favours more rapid movement of hot water and preferential recharge of the aquifer by less viscous, hotter water from below. Aquifer pressures are therefore still high in the surrounding region, except in restricted regions where replacement water is being drawn down along faults or through exceptionally permeable formations.

Production trends

Present indications are that much of the replacement water is hot and is being fed from below the Wairakei Ignimbrites along fault planes; further exploitation should aim at increasing this flow. Deeper drilling into the fault fissures and into the underlying (Ohakuri) aquifer has, therefore, been recommended (Grindley, 1965). Deeper drilling is also considered desirable to investigate the origin of a large output of dry steam, that was tapped by an exploratory hole in the south of the field. This discharge which was tapped unexpectedly in a sub-surface fault fissure, amounts to over 500 Klb/hr and is at present discharging "wild". The theory has been advanced that a dry steam trap may exist in depth in this area, possibly below the Wairakei Ignimbrites, and when the "wild" hole is tamed, deeper drilling on the fissure zone should follow.

The final design of the Wairakei power station depends on the trends in availability of the high-pressure and intermediate-pressure steam and the waste hot water separated at the well-heads. In the original plan (Smith, 1958) it was proposed to flash the hot water in flash tanks to produce low-pressure steam (0.5 lbs/in^2) to feed the final stage condensing turbines. This plan has not yet eventuated because of uncertainty in respect of the supply of hot water. If the supply appears to be adequate for the life of the station, the station capacity could be boosted to 250 or 280 MW by utilization of the hot water. An alternative use for the hot water would be as replacement water for artificial injection into the aquifer to maintain formation pressures. If, on the other hand, the field gradually changes to a steam field, as current trends in enthalpy seem to suggest, production may still be boosted beyond the present 175 MW by transmission of readily available extra-intermediate-pressure steam to the power house.

At present, there is no certain method for estimating the ultimate capacity or the best extraction rates from the Wairakei geothermal field. Experience over 40 years at Larderello has shown similar production trends. Hydrostatic levels have fallen drastically (by several hundred metres), shallow wells have gone out of production and deeper drilling has proved necessary to maintain output (Chierici, 1961). At Larderello, however, cold-water incursion has proved to be a lesser problem than at Wairakei, principally because of the effectiveness of the thick capping shale in restricting the inflow of meteoric water into the aquifer. The temperature of the steam has, in fact, risen by 40°C and become superheated due to its long passage through fissures in low-conductivity, hot rocks to reach the drill-holes. Even so, a production ceiling has been reached at Larderello at present drilling depths, above which it has been found impracticable to increase output. This ceiling is the equivalent of 350 MW of generated power.

Future trends at Wairakei are likely to be comparable—continually falling aquifer pressures, gradually rising enthalpy, deterioration in the production of shallow and marginal wells, and an increasing need towards production from greater depth. Problems of field management will arise for the Wairakei geothermal field is a unique experiment. With intelligent and careful planning of future exploratory and production drilling it does not seem unreasonable to hope that present production rates can be maintained or even exceeded. The pioneering work at Wairakei will undoubtedly assist in the exploitation of other hydrothermal fields in the Taupo Volcanic Zone; as knowledge increases, the results of this pioneering work should lead to more accurate evaluation of geothermal resources in the years to come.

CHEMICAL CONSTITUENTS OF GEOTHERMAL WATERS[6]

Wairakei

According to Wilson (1959) the steam at Wairakei is accompanied by six times its mass of hot water which is mainly a 0.3 per cent solution of NaCl. Significant lithium contents amounting to 12 p.p.m. were found during the earlier investigations—owing to the low atomic weight of Li this element is much more important in the water than calcium—on a mole concentration—and nearly as important as potassium. "It was calculated that the value of the lithium in the water rejected, was about the same as that of the electric power that could be generated from the steam".

Both high and low pressure bores exist, the former probably coming from fissures in the ignimbrite, and the latter from hot water in permeable volcanics: respectively the well-head pressures are 200 and 70 p.s.i.

Gas

Wilson noted that of the gaseous constituents from the condensers, the mixture of hydrogen and methane is roughly equivalent in calorific value to town gas. The daily output of a major gas works may be, say, 3 million c.ft. per day, whereas Wilson gave the combined yearly output of these gases from Wairakei at 11.3 million c.ft. He added that "The output of methane is about equal to the yearly output from the oil wells at New Plymouth.

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[6] Abstracted by G. J. Williams from Wilson (1959).

TABLE 15-1.
CONSTITUENTS OF WATERS FROM GEOTHERMAL BORES, WAIRAKEI[7]

	High pressure bores (p.p.m.)	Int. pressure bores (p.p.m.)	Annual amounts produced[8]	Assumed value	Annual value
NaCl	3,064	3,128	113,000 tons	£5/ton	£565,000
KCl	378	291	11,700 tons	£30/ton	£351,000
Na_2SO_4	55	50	2,000 tons	—	—
NaF	17	16	620 tons	—	—
$CaCO_3$	34	50	1,300 tons	—	—
LiCl	83	77	6,720,000 lbs	8s 0d/lb	£2,340,000
RbCl	4.1	3.4	328,000 lbs	3s 6d/lb	£137,000
CsCl	2.8	2.8	230,000 lbs	(as pollucite)	£334,000
H_3BO_3	146	158	5,400 lbs	£20/ton (borax)	£166,000
SiO_2	395	344	14,200 tons	—	—
As_2O_3	5.5	5.7	537,000 lbs	£85/ton	£10,800

[7] Wilson (1959).

[8] At possible full development of the order of 280,000 kW.

Water

The constituents of the bore waters at the final stage of construction of the power units are set out in Table 15-1. Wilson pointed out that the amount of boric acid is about the same as that recovered at Larderello[9] in Italy, but that it could be recovered economically only if it were found desirable to concentrate the Wairakei water for the recovery of other constituents, "It would be less uneconomic to recover boric acid from the ash of Waikato coals (which are relatively high in boric acid content)". Wilson thought that if it would seem to be economic to win lithium from the water[10] it might also be possible to extract the sodium and potassium chlorides together with the rubidium and caesium salts. He added that mixed K-Rb-Cs carbonates have some use in glass manufacture.

Chloride water in other thermal areas[11]

Wilson noted that the most important thermal areas contain underground chloride water, the main exceptions being Ketetahi and Tikitere. Data for the various areas are set out in Table 15-2 from which Wilson noted that only Tokaanu, Waiotapu and Taupo Spa have concentrations of chloride comparable with those at Wairakei—only at Tokaanu is the chloride content higher than at Wairakei.

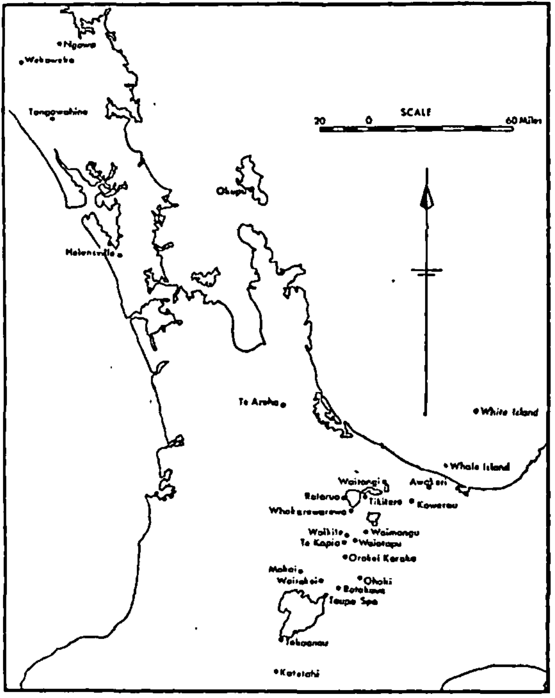

Fig. 15-2. Hot springs in northern areas (Wilson, 1959).

TABLE 15-2.

CONTENTS OF SODIUM CHLORIDE, POTASSIUM CHLORIDE AND LITHIUM IN WATERS OF THERMAL AREAS OF THE NORTH ISLAND[12]

	NaCl %	KCl %	Li p.p.m.	Mole ratio Na/Li
Tokaanu	0.462	0.032	24.0	23
Waiotapu				
Champagne Pool	0.291	0.030	8.0	43
Bore No. 6	0.218	0.030	6.6	39
Wairakei				
Champagne Cauldron	0.271	0.019	11	29
H.P. bores	0.314	0.038	13.5	27.5
Taupo Spa	0.257	0.013	11.5	27
Kawerau				
Bore	0.173	0.015	7.25	28
Onepu Spring	0.107	0.009	2.9	44
Ohaki	0.226	0.015	9.5	28
Waimangu	0.155	0.015	4.0	46
Rotokaua	0.128	0.009	3.8	37
Rotorua				
Whakarewarewa	0.119	0.012	3.4	38
Rotorua town				
Rachel Spring	0.137	0.006	2.35	69
Bore	0.145	0.006	3.0	57
Kuirau	0.081	0.005	2.5	39
Kuirau bore	0.088	0.008	2.4	43
Orakei Korako	0.085	0.006	3.9	28
Waitangi	0.077	0.004	1.7	47
Waikite	0.046	0.006	1.9	29
NORTHLAND				
Tangowahine	1.17	0.050	10.5	132
Wekaweka	0.64	0.009	5.7	133
Okupu (Great Barrier Island)	0.65	0.055	50	15.5
Helensville	0.152	0.004	2.3	80
Ngawha	0.175	0.011	5	42

[12] Wilson (1959).

NEAR-SURFACE HYDROTHERMAL METASOMATISM

Wairakei

Stratigraphic succession

Steiner (1953) studied hydrothermal alteration in the rocks penetrated by the geothermal-steam bores at Wairakei. He found that hydrothermal alteration had significantly altered the flat-lying tuffaceous and arenaceous rocks, but that it has not appreciably altered inter-bedded argillaceous rocks.

TABLE 15-3.

STRATIGRAPHIC SEQUENCE REVEALED BY DRILL HOLES SHOWN IN FIG. 15-3, WAIRAKEI[13]

	Thickness in ft	
	Western holes	Eastern holes
Recent cover	0-240	0-240
Upper Wairakei lapilli tuff	115-231	absent
Chalazoiditic vitric tuff	0- 4	absent
Lower Wairakei lapilli tuff	81-280	absent
Altered chalazoiditic vitric tuff	3- 30	absent
Diatomaceous mud- and silt-stones	absent	200-240
Huka Formation	197-729+	

[13] Steiner, 1953.

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[9] Which was, of course, originally exploited for its boric acid content rather than for power.

[10] He pointed out that the concentration of Li is 130 times greater than that in sea water; Rb—15 times; Cs—11,000 times; F—10 times; B—6 times; I—30 times; and As—1,100 times.

[11] For White Island see Wilson, *in* Hamilton and Baumgart (1959).

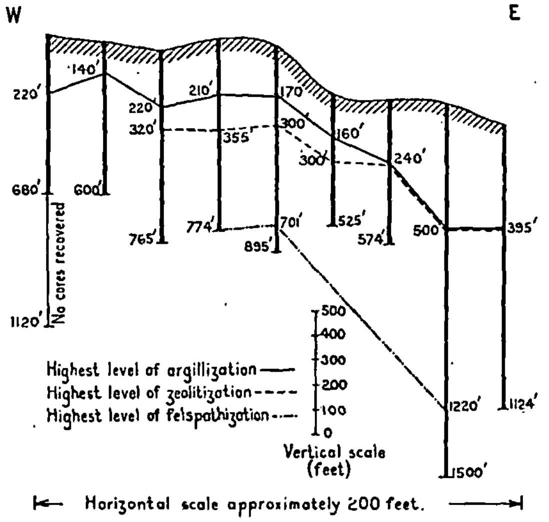

Fig. 15-3. Hydrothermal metasomatic zonation along line of geothermal steam bores, Wairakei (Steiner, 1963).

TABLE 15-4.

COMPARISON OF ALTERED AND UNALTERED ROCKS, WAIRAKEI[14]

	A	B	C	D	E
SiO_2	73.86	72.05	69.20	75.93	73.47
Al_2O_3	13.53	15.46	14.40	12.84	14.56
Fe_2O_3	1.35	0.48	0.58	0.34	1.75
FeO	1.53	1.47	2.19	1.07	0.66
TiO_2	0.37	0.34	0.51	0.21	0.29
MgO	1.28	0.84	0.58	0.22	0.24
CaO	2.22	2.93	1.00	1.45	1.36
Na_2O	1.61	1.87	0.93	4.00	4.31
K_2O	3.13	2.74	10.16	3.65	2.99
P_2O_5	0.09	0.15	0.08	0.02	0.09
MnO	0.16	0.06	0.10	0.05	0.09
BaO	0.04	0.10	0.07	0.13	0.11
ZrO_2	—	0.01	—	0.04	0.01
FeS_2	0.78	1.32	0.15	0.01	0.02
Cl	—	0.05	0.01	tr.	—
H_2O+105°C	4.06	6.30	0.97	0.35	1.18
H_2O—105°C	2.76	4.48	0.14	0.04	0.44

A—Argillized zone: Wairakei lapilli tuff at 230 ft
B—Zeolitized zone: tuffaceous sandstone with ptilolite at 419 ft
C—Felspathized zone: tuffaceous sandstone with adularia at 701 ft
D—Fresh obsidian from Whakapoungakau Mountain, east side Lake Taupo (Grange, 1937)
E—Fresh ignimbrite, Waihaha (Grange, 1937).

The line of bores shown in Fig. 15-3 went to a maximum depth of 1,500 ft within which depth the stratigraphic succession shown in Table 15-3 was found. In more detail the material penetrated is as follows:

A Recent cover of clay with pumiceous and rhyolitic sands.

The Upper and Lower Wairakei lapilli tuffs have the composition of plagioclase rhyolite; the phenocrysts in decreasing order of abundance are andesine plagioclase, quartz, hypersthene, and hornblende. Magnetite and rare apatite are accessory minerals. The ground-mass consists of glass shards and pumiceous streaks and lapillae; there are elliptical bodies up to 1 cm in diameter of rhyolitic glass fragments (chalazoide).

The chalazoiditic vitric tuff, and its altered counterpart lower in the series are embedded in a matrix consisting of the same material.

The diatomaceous mudstones consist of clay with some detrital oligoclase, quartz and volcanic glass.

The Huka Formation consists of sedimentary beds including claystones, mudstones and siltstone embedded in vitric tuffs and pumiceous sandstone. Their dominant contituent is montmorillonite-like material; there is also some carbonaceous material.

Steiner recognized in downward succession the following hydrothermal metasomatic zoning (as shown in Fig. 15-3):

Sulphuric acid leaching
Argillization
Zeolitization
Felsphatization

These zones are shown in chemical form in Table 15-4.

Zone of sulphuric acid leaching

Secondary minerals characteristic of this zone are kaolinite (Chapter 20), alunite (Chapter 14) and opal: of the primary constituents only quartz phenocrysts survive. A few grains of leucoxene represent primary titanomagnetite. At 32 ft alunite appeared and persisted to 50 ft scattered through the rock. Some pyrite was detected at this depth, but below 80 ft montmorillonite-like clay and pyrite are characteristic constituents. At 90 ft the appearance of siderite witnessed a profound change in the character of the hydrothermal alteration manifested mineralogically by the absence of kaolinite, opal and alunite. It is evident that kaolinite, opal and alunite are superficial. It was suggested that the sulphuric acid solutions form by the oxidation of H_2S vapours by oxygen entrained in descending meteoric water.

Zone of argillization

The dominant form of alteration within this zone is the conversion of glass and pumiceous threads into clay minerals of the montmorillonite group—with superimposed alterations represented by zeolitization and felspathization. At high levels the argillization is accompanied by the introduction of pyrite, occurring in cubical crystals with octagonal faces in contrast with the pyrite which appears in the Huka Formation with pyritohedral faces. Plagioclase remains unaffected by argillization—except locally by the formation of calcite. The ferromagnesian minerals are reduced to clay in some drill holes, and in others are unaltered.

Zone of zeolitization

Ptilolite is the characteristic zeolite: it fills pores in the pumice. Heulandite was only occasionally identified[15]. "The fact that plagioclase remains unaltered in rocks containing ptilolite points to alkaline solutions, which, apart from being rich in soda and lime, contain an excess of silica".

Zone of felspathization

This zone is characterized by the presence of secondary adularia, which was identified in several bores, commonly containing some sericite. "The

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[14] Stiener (1953).

[15] See also notes on zeolites in Chapter 14.

replacement of adularia is generally associated with the development of titanomorphite, minute granules of which are scattered throughout the rock and rarely enclose remnants of titaniferous magnetite. Secondary quartz is another common hydrothermal mineral accompanying the formation of adularia. Prehnite, probably of hydrothermal origin, has been identified in one of the cores . . . . containing adularia and titanomorphite; the vertical range is less than 23 ft". Ptilolite is not present in the cores containing adularia, it presumably being destroyed during the replacement of soda and lime by potash.

Waiotapu

Later, Steiner (1963) studied hydrothermal metasomation in the Waiotapu geothermal field, where the exploration bores were sunk to greater depths than those at Wairakei—the deepest bottomed at 3,282 ft. Steiner was thus able to study deeper zones and discuss the relation between sodic and potassic metasomatism.

Stratigraphy

"A sequence of ignimbrite sheets with interbedded sedimentary rocks is a characteristic feature of the explored vertical range . . . . volcanic rocks of relatively low permeability make up in average 70 per cent of the total thickness penetrated by three deep holes . . . . and thus predominate over sedimentary permeable, water-bearing rocks. This may be contrasted with the great thickness—about 1,700 ft—of permeable sedimentary and pyroclastic rocks overlying the ignimbrite sheets at Wairakei". All rocks with the exception of the Maungaongaonga dacite are rhyolitic, and the sedimentary material contains mainly rhyolitic material.

Hydrothermal minerals

In this region, Steiner noted that the primary minerals behaved as follows under hydrothermal influences:

> Quartz alone is resistant to attack
>
> Pyroxene and hornblende are always completely altered, even if plagioclase remains unaltered
>
> Partly altered biotite sometimes occurs alongside fresh plagioclase
>
> Plagioclase is thus less susceptible to alteration than pyroxene, hornblende and biotite
>
> Magnetite is the most susceptible of all the primary minerals
>
> Acid volcanic glass is readily altered—its susceptibility being comparable with that of pyroxene and hornblende

Susceptibility to alteration in decreasing order is therefore: magnetite, pyroxene and hornblende, biotite, plagioclase, and quartz. The sub-surface zonation of hydrothermal metasomatism is discussed below.

Epigene sulphuric acid alteration

Near the surface glassy siltstones, sandstones and a dacite are generally unaffected by hydrothermal alteration except for the formation of pyrite, although in three holes, sulphuric acid alteration was found to be characterized by the formation of alunite for a depth of not more than 100 ft. The alunite replaces felspar, and together with opal, fills interstices; carbonates are absent. Thus, as at Wairakei, alunite and opal result from an epigene process rather than from ascending hydrothermal solutions.

Hypogene alteration

Steiner recognized both potassium silicate alteration and albitization associated with the formation of calcite and occasionally wairakite. The former alterations are characterized by hydromica and potassic felspar, replacing primary soda-lime plagioclase. On the other hand conversion of primary soda-lime plagioclase into albite is commonly associated with the crystallization of calcite—occasionally with the formation of wairakite.

Origin of alteration pattern

In the cores of several holes, an association of potassium silicate alteration with steeply-dipping pyritized veins was discovered. Steiner presumed that alkaline solutions rose along pre-existing fissures to bring about potassic metasomation:

> "Since vein filling tends to seal off fissures, it is evident that hydrothermal solutions which brought about the potassic alteration must have arrived before the vein-filling fluids. In fact, petrographic evidence indicates that the fissures at Waiotapu are filled mainly with pyrite and quartz, and are thus largely sealed off as channelways for ascending hydrothermal solutions".

Steiner concerned himself with the relationship between potassium and sodium metasomatic influences. He seemed to regard the former, associated as it is with pyritized veins, as having been formed from ascending solutions along the fissure: "This seems to be the logical explanation of the occurrence at shallow depth of the potassic alteration, requiring a comparatively high temperature . . . .".

Albitization was occasionally noted overlapping potassic metasomatism. Steiner was inclined to the view that albitization was brought about independently and mostly at a later stage than the potassic alteration. He associated the former with a gaseous phase consisting mainly of CO_2 and H_2S rising from depths greater than those explored by the bores—these gases heated the pores of the rocks and becoming dissolved in ground-water, he believed the combination now to be attacking the rocks to bring about albitization of the soda-lime plagioclase. "The presence of CO_2 is reflected in the formation of calcite which is an abundant hydrothermal mineral in the albitized zones at Waiotapu".

Metal-bearing near-surface hydrothermal metasomatism

Ngawha

There has been some argument as to whether the cinnabar at Ngawha is still forming, but at least there can be no argument that it formed at the surface.

It is noted in Chapter 13 that Henderson (1944) believed cinnabar to be currently forming from thermal waters at Ngawha. He stated that "Some waters also contain arsenic, mercury and gold in very small amount, and sinter containing mercury edges some of the hot pools, which are still probably depositing cinnabar". Fleming (1945) examined several separate thermal exudations in this area and noted that:

> The waters have a higher boron content than any others in New Zealand (1,400 p.p.m.)
> They are consistently high in chloride
> Bicarbonate is present even in the most acid water analysed and much more abundantly in most alkaline waters
> The ammonia content is relatively high
> Sodium greatly exceeds potassium in all analyses
> The silica content is relatively low
> The calcium content is relatively high

He considered that alkaline conditions were more prevalent at an earlier stage in the history of Ngawha, as indicated by the widespread occurrence of sinterized deposits and the deposition of cinnabar. He noted that two springs rich in sulphates are still active in this area. Fleming quoted overseas references to the effect that cinnabar forms only from hot alkaline waters, and came to the conclusion that the present acid conditions at Ngawha are a later development, though he thought it possible that the acid waters now play a part in reducing the sulphide to native mercury: "certainly no mercury could be contained in solution in any of the Ngawha waters analysed"—a statement which is contradictory to that of Henderson who believed that cinnabar is being deposited at the present time.

Metallic constituents of thermal waters in Rotorua-Taupo area

In Chapter 8 (p.125) it is noted that certain geyser waters of the Wairakei and Taupo areas (Bell, 1907) contain metallic constituents such as antimony, gold and silver, and that a mineralized rock containing an appreciable amount of gold and silver had been formed in a branch of the Tarawera River. It is therefore desirable that the additional chemical work necessary to recognize any metallic constituents in the waters obtained from geothermal steam bores should be undertaken[17].

Hauraki goldfield

It is very clear that the gold-silver mineralization of the Hauraki goldfield is derived from the Tertiary volcanic rocks of the Coromandel Peninsula. The propylitization in the First Period andesites is explained chemically in Table 8-5 (Finlayson, 1910) in which it will be noted that an increase of potash is characteristic. Adularia occurs in the Waihi veins (see footnote, p.95, in which it is explained that this mineral was vernacularly known as valencianite).

There appears to be no chemical data relating to the late Tertiary gold-silver sinterous mineralization in the Third Period (rhyolitic) rocks: this mineralization must have been very shallow indeed; if not at the surface itself. A chemical study of the alteration of these rhyolitic rocks, combined with a study of the metallic constituents of the water from the geothermal steam bores might well produce information of considerable metallogenetic interest.

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[17] The results obtained from the Niland geothermal bore sunk to a depth of 5,232 ft close to the Salton Sea in California are fascinating. The alkali metal components of the water from this bore are greatly in excess of those from Wairakei (Table 15-2)—but the bore was much deeper. A line of Quaternary pumiceous rhyolite and obsidian domes was mapped near this geothermal area. "The well tops a very saline brine which has an unusually high potassium content, and perhaps the highest lithium and heavy-metal content known for natural waters. During a production test, the brine deposited in discharge pipes was astonishingly high in silver, copper and other scarce elements normally concentrated in ore deposits. Considerable evidence favours the geologically fascinating possibility that this brine is man's first sample of an 'active' ore solution of the type that probably formed many of the world's economic concentrations of ore metal in the geological past"—note by D. E. White of U.S. Geol. Survey, E. T. Anderson of O'Neill Geothermal Inc., and D. K. Grubbs of Univ. of Virginia.

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DEC 23 1976
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FINAL

THE GEOTHERMAL ENVIRONMENTAL ADVISORY PANEL

DRAFT

GUIDELINES FOR ACQUIRING ENVIRONMENTAL BASELINE DATA ON FEDERAL GEOTHERMAL LEASES

U. S. GEOLOGICAL SURVEY
DISTRICT GEOTHERMAL OFFICE
RECEIVED
JUN 28 1977
SALT LAKE CITY, UTAH

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DEC [illegible] 1976
AREA GEOTHERMAL SUPERVISOR'S OFFICE
CONSERVATION DIVISION
U.S. GEOLOGICAL SURVEY
MENLO PARK, CALIFORNIA

UNITED STATES DEPARTMENT OF THE INTERIOR
MENLO PARK, CALIFORNIA

GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

O : Interested Parties DATE: December 14, 1976

ROM : Geothermal Environmental Advisory Panel

JBJECT: Guidelines for acquisition of Environmental Baseline Data on Federal Geothermal Leases

The attached document was prepared as a consequence of regulations implementing the Geothermal Steam Act of 1970, specifically Title 30 CFR 270.34, which includes in subsection (k) "A requirement for the collection of data concerning the existing air and water quality, noise, seismic and land subsidence activities, and ecological system of the leased lands covering a period of at least one year prior to the submission of a plan for production".

The purpose of these guidelines is to aid lessees in the development of plans to meet this requirement in an orderly and timely manner. Whenever possible the Panel recommends that plans for baseline data acquisition be started as soon as it becomes apparent that a commercially developable resource has been identified. In addition to assuring that lessees are adequately forewarned of the need for advance planning to meet the requirement, the guidelines are designed to provide as much consistency as possible in the data acquired and to provide a framework that will aid the Supervisor in evaluating plans received.

It is emphasized that these guidelines in no sense modify the responsibility of the Area Geothermal Supervisor, Conservation Division, USGS, who, in cooperation with the surface management agencies, (typically BLM or USFS) retains the sole responsibility for approving plans to meet these requirements. The guidelines therefore comprise a set of recommendations prepared for the assistance of both the lessee and the Supervisor. Furthermore, it must be noted that these guidelines are not regarded as a rigid or absolute set of standards. In general, they are presumed to represent the typical range of baseline data appropriate for large-scale geothermal development, generally for electric power. But even for such applications they provide only "guides" in the true sense, because each "Plan" should be prepared on a site-specific basis, so as to be adapted to the nature and scope of the operation proposed and to the particular terrane and ecologic setting involved. In order to accommodate the development of small, localized, or low temperature heat sources, particularly for non-power uses, plans of vastly smaller scope may suffice; in many cases the necessary data may be available from existing sources. This flexibility in scope is accommodated by the exercise of the Supervisor's discretion to accept plans appropriate to the specific situation.

Initial drafts of the guidelines were prepared by a Working Group chaired by Robert Scott. Subgroups dealing specifically with water, air, and biological data were under the chairmanship of J. H. Feth, Dave Jesson, and W. M. Spaulding. Membership of the Working Group was as follows:

Robert Scott, Environmental Protection Agency,
Chairman

Robert Conover, Solicitors Office
Edward Horton, U.S. Forest Service
Joel Robinson, Union Oil Company
Warren Smith, Union Oil Company
John Feth, U.S. Geological Survey
Samuel R. Jewell, AMAX, Inc.
F. Phillip Sharpe, U.S. Bureau of Reclamation
David Jesson, Environmental Protection Agency
Hamilton Hess, Sierra Club
Ralph Longaker, Pacific Gas and Electric Company
Willard M. Spaulding, U.S. Fish and Wildlife Service

Final revisions were made by the Panel as a whole, and responsibility for the content rests with the Panel rather than with the Working Group. It is a pleasure to acknowledge the importance of the diverse points of view represented on the working group, and to thank each member personally for his generous contribution of time and thought. Final revision by the Panel required extensive study and effort, and this too is gratefully acknowledged.

Max D Crittenden Jr

Max D. Crittenden, Jr.
Chairman

CONTENTS

1.0 INTRODUCTION

1.1 Purpose

These guidelines are developed to assist geothermal lessees and operators in complying with Federal Regulation 30 CFR 270.34 (k) which states that a plan of operation shall include "A requirement for the collection of data concerning the existing air and water quality, noise, seismic, and land subsidence activities, and ecological system of the leased lands covering a period of at least one year prior to the submission of a plan for production."

The purpose of collecting environmental data is to provide a baseline representing selected physical, chemical and biological conditions prior to significant disturbance by lease operations against which later environmental data can be compared. This comparison will provide a basis for determining the net environmental change attributable to the operations on the leasehold at any subsequent time.

The purpose of these guidelines is to aid those involved in the exploration for geothermal resources in meeting the requirements for baseline data in a timely manner. Where unit operations are involved these guidelines should apply to the entire unit in the same way as to an individual leasehold. Their timing is designed to coordinate with the generalized scheme of phased operations outlined in orders issued or to be issued by the Supervisor, Conservation Division, USGS.

1.2 Timing

It is presumed that development of a typical large-scale geothermal resource will pass through a succession of phases. Except where not required by regulations, activities will be carried out under a series of Plans of Operations of the types outlined below:

Plan of Exploration:	Geologic and geophysical surveys Shallow temperature gradient holes Deep exploration drilling
Plan of Development:	Development drilling Permanent roads and pipelines Other facilities
Plan of Production:	Operation of wells and facilities for production and use of geothermal energy

Environmental baseline data must be collected over a period of at least a year prior to the submission of a plan of production. Therefore approval of a program of data collection should be obtained with sufficient lead time to allow the actual collection of data to be carried out within the required one year time frame. To allow for purchase, installation and testing of equipment, this implies a lead time of at least 18 months prior to the filing of a plan of production. Consequently, the design of a data collection program should begin as soon as it is evident that a potentially producible resource has been identified. (See Figure 1).

Ideally, it is recommended both in the interests of the lessee and for the protection of the environment, that collection of data on air, water, and biological conditions commence and occur during the exploration drilling phase following the approval of a plan of exploration. It is also recommended, particularly in areas sensitive to subsidence, that levelling surveys should commence as soon as commercial development appears probable, if possible during the geologic and geophysical testing periods which may pre-date the approval of a plan of exploration. Programs for data collection submitted on this schedule should include relevant information from these prior collections of environmental data. If it is not practical to begin data collection at these early stages, lessees should at the very latest, submit a program for the collection of environmental baseline data at the same time as they file the initial plan for development.

1.3 Scope

The wide differences in geothermal resources require that the Supervisor retain a corresponding degree of latitude as to the scope of activities appropriate to satisfy the requirements for acquisition of baseline data. In the exercise of such latitude it is assumed that the Supervisor will seek the review and recommendation of the Geothermal Environmental Advisory Panel, and will consult with other Federal, State and local agencies having expertise and/or regulatory responsibility.

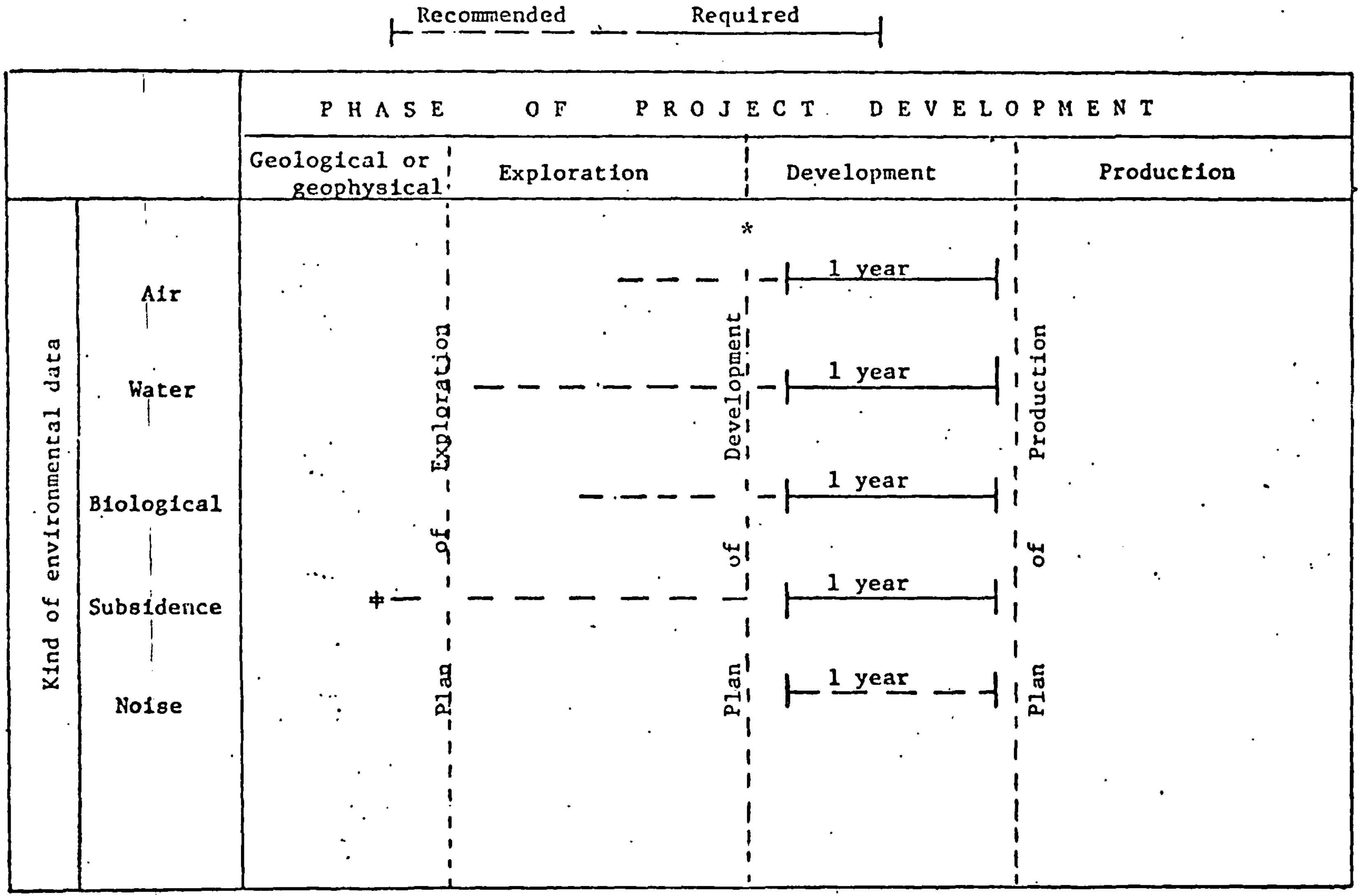
Most of the material that follows is applicable to large scale geothermal development, typically for generation of electrical power. In all areas of extensive development, designs for baseline data acquisition should be site-specific, so as to be adapted to the particular environment involved.

In order to accommodate development of small scale or low-grade heat sources (for example a single well or spring supplying water below 100° C), for small scale use in space or agricultural heating, for development in areas where interaction with the environment will be limited, or for small-scale temporary or experimental facilities, the Supervisor may approve data collection programs of much more limited scope. In some areas these programs may be based largely on existing data.

1.4 Cooperative Studies

In areas with more than one lessee, or in areas of mixed Federal and private land ownership, lessees should be encouraged to cooperate in planning for and acquiring baseline data on a regional basis, and these data may be accepted in lieu of measurements otherwise presumed to be acquired on lease. For certain parameters (eg. air), such regional data may be more significant than those of a more local scale.

Figure 1.--Idealized scheme for collection of environmental baseline data on Federal leased lands



* Lessee submits plan for collection of baseline data.

‡ Recommended particularly in areas sensitive to subsidence (eg. irrigated lands)

Published data and records of other information collected more than one year before the submission of the plan of production, if they adequately disclose the conditions, may be used to supplement data collected specifically to meet these requirements. If the lessee should determine that data applicable to the lease area are being collected by credible agencies or individuals during the required one-year period, he may request that the Supervisor approve inclusion of those data in his data collection plan. The lessee then may not be required to collect duplicate data.

1.5 General Methodology

The basic element in any system for collecting environmental baseline data is a network of sampling stations at which repeated measurements of biological, chemical, or physical parameters can be made. Most stations are fixed and provide a record of changes through time at one specific site. Temporary or mobile stations may also be used to locate points of maximum or minimum impact for a particular parameter, and may be particularly useful as a reconnaissance tool in designing a more permanent net. To be effective, stations not occupied continuously must be identified on the ground so that repeated measurements will be comparable. Parameters that vary on a daily or seasonal cycle should be measured so as to encompass the range of expected variation.

The network design should identify sampling sites that are representative of major parts of the ecologic system to be sampled. If the scope of the program justifies, sites may also be selected to characterize extreme conditions, or those believed to involve unusually severe impact for some specific parameter.

The proposed station network should be shown on a map or maps. Background information and rationale for the proposed network should be included in the program of collection of environmental data that will accompany each plan of development.

The network of fixed stations should be operated in a consistent and uniform manner. Parameter coverage should be as uniform as possible throughout, and should be sufficiently precise to permit detailed and quantitative comparisons from one station to another. Parameter coverage should be extensive enough to characterize the part of the environment being measured in scientifically accepted terms, and to describe problems that may be known to exist. One of the purposes of broad parameter coverage is to identify problems and conditions not previously known in order to separate those environmental impacts that are, in fact, attributable to activities of the lessee from those that result from other causes.

The Supervisor may increase or decrease requirements for baseline data collection at any time if clearly warranted by naturally occurring environmental changes on the leasehold or by significant environmental factors recognized during early phases of measurement. Data collected in accordance with an approved program shall be deemed to be presumptively adequate;

the Supervisor is obligated to demonstrate the inadequacy of the data collection program before imposing additional requirements. Techniques used for collection, measurement, and analysis should be in accordance with the methods prescribed specifically or by reference in the following sections, unless alternatives are specifically approved by the Supervisor.

1.6 Data Reporting

Data should be compiled, analyzed and interpreted in an orderly manner by the lessee. The Supervisor may impose a format for data compilation that is compatible with similar formats for data being compiled on a regional or national basis. The Supervisor may inspect the compiled data at any reasonable time. Of primary importance is the maintenance of uniformity in the data collected from fixed stations or in other measurements or observations. Data analysis and interpretation by the lessee should proceed to the extent warranted by sound scientific judgment. To the extent possible, interrelations within the ecosystem should be determined by the lessee by integration of the various kinds of baseline data collected.

Environmental baseline data and the available interpretation should be reported to the office of the Supervisor on a quarterly basis, in addition to any other report requirements prescribed in 30 CFR 270 and 271. The Supervisor may require additional reporting in cases where usual reporting and interpretation is not adequate.

2.0 DEFINITIONS

2.1 General Definitions

Operations - Any activity on the lease other than casual use by the lessee or others for the exploration, testing, development, production and utilization of geothermal resources.

Plan of Operations - A statement of procedures, materials and equipment used in operations. During the lifetime of a geothermal field, a sequence of such plans will normally be involved unless excepted by subsequent regulations or orders.

1. Plan of exploration may include:
   - a. geologic or geophysical surveys
   - b. shallow temperature gradient holes
   - c. deep exploration drill holes
   - d. disposal of fluids and wastes
2. Plan of development may include:
   - a. development drilling
   - b. construction of permanent roads, pipelines and facilities
   - c. construction (but not operation) of plants for utilization of water or steam

   A program for acquisition of environmental baseline data should be submitted at this stage, or at least 18 months before plan of production is submitted.

3. Plan of Production

   A detailed plan outlining means of utilizing and disposing of geothermal fluids and controlling the related environmental impacts. Baseline data must be acquired for at least a one-year period before this plan is submitted.

Aquifer - A body of consolidated or unconsolidated material in the earth that is saturated with water and capable of yielding water in significant quantities to wells or springs.

Environmental baseline data - Information and measurements adequate to describe the physical, chemical, and biological components of the environment in the lease (or unit) area during at least a one-year period prior to submission of a plan for production.

Geothermal lease - A lease issued under the act of December 24, 1970 (84 Stat. 1566) pursuant to the leasing regulations contained in 43 CFR Group 3200.

GRO - A Geothermal Resources Operational Order issued by the Supervisor as defined in 30 CFR 270.2 (e).

Ground water - Water in an underground aquifer below the top of the zone of saturation.

Hazardous substance - An element or compound which, when discharged into the environment presents an imminent and substantial danger to the public health or welfare, including, but not limited to fish, shellfish, and wildlife.

Lessee - The individual, corporation, association, or municipality to which a geothermal lease has been issued, its successor in interest or assignee, any agent or operator holding authority by or through the lessee.

Operator - The individual, corporation, association having control or management of operations on the leased lands or a portion thereof. The operator, or agent of the lessee, or holder of rights under an approved operating agreement.

Parameter - A quantity or characteristic which describes physical, chemical, or biological conditions such as: temperature, dissolved oxygen, color, count, species composition, or condition of terrestrial or aquatic organisms, stream flow, velocity, or area of channel cross section.

Pollution - The man-made or man-induced adverse alteration of the chemical, physical, biological, and radiological integrity of the environment.

Supervisor - The Area Geothermal Supervisor, Conservation Division, U.S. Geological Survey, or his designee.

Surface water - Any water resource on the land surface, such as rivers, streams, ponds, lakes.

Toxic pollutant - Those pollutants, or combinations of pollutants, including disease-causing agents, which after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will, on the basis of information available, cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction) or physical deformations, in such organisms or their offspring.

Unit - A unit area as defined in 30 CFR 271.2 (e).

2.2 Glossary of terms related to biological data

Aquatic macrophyte - Any aquatic plant that can be seen with the unaided eye, e.g., aquatic mosses, ferns, liverworts, rooted plants, etc.

Critical habitat - Any air, land, or water area including any elements thereof which the Secretary of the Interior, through the Director, U.S. Fish and Wildlife Service or National Marine Fishery Service, has determined is essential to the survival of wild populations of a listed species or to its recovery to a point at which the measures provided pursuant to the Endangered Species Act of 1973 are no longer necessary. Determinations will be published in the Federal Register.

Ecosystem - A biological community including all the component organisms, together with their environment, forming an interacting system.

Endangered species - Any species that is in danger of extinction throughout all or a significant portion of its range. (See Endangered Species Act of 1973, PL 93-205, 87 Stat. 884).

Important organisms - Organisms having significant commercial, recreational, or ecological value, including organisms that may occupy critical trophic levels.

Indicator organism - A species whose presence or absence may be characteristic of environmental conditions in a particular habitat.

Macroinvertebrates - Those organisms visible with the unaided eye and which are retained in a U.S. Standard sieve No. 30 (openings of 1.589 mm).

Periphyton - Aquatic micro-organisms growing on the bottom, or on other submerged substrates.

Plankton - Suspended micro-organisms that have relatively low power of locomotion, or that drift in the water subject to the action of waves and currents.

Priority station - A location in the ecosystem (aquatic, terrestrial, atmospheric) that has the greatest potential for deterioration as a result of its relation to geothermal lease activity.

Proportion of vegetative cover - The proportion of the ground surface under aerial parts of the plants.

Representative station - A location in the ecosystem selected in such a manner that the conditions or parameters measured characterize or approximate those existing over a larger area.

Sensitive habitats - Those portions of an organism's range that are indispensable to the population's survival, welfare, and reproduction.

Threatened species - Any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. (See Endangered Species Act of 1973, PL 93-205)

Transect - Refers to a line or linear band along or within which various parameters of the ecosystem may be measured.

Vegetation type - A plant community which dominates or appears to dominate a geographical region, i.e., grassland, coniferous forest, or tundra.

3.0 AIR QUALITY

3.1 Introduction

3.11 The purpose of the air quality baseline plan should be:

1. to characterize the ambient air quality prior to significant changes associated with geothermal development;
2. to identify substances that may have an adverse effect on the environment and to establish baseline concentrations for these substances;
3. to identify and quantify existing natural and man-made point sources;
4. to collect meterological data necessary for understanding dispersion and conversion patterns;
5. to provide baseline data compatible with later measurements needed to assure compliance with state or regional air quality standards.

3.12 Individual characteristics of each proposed development will largely influence the lessee's air sampling requirements. The plan for data acquisition must be adapted to the specific geothermal resource, terrain, meteorological complexity, proximity to human population and vulnerable natural and economic resources, probable scale of operation, and nature of the development process.

The Supervisor must consequently retain discretion to fix air baseline data requirements appropriate to the particular circumstances, and to judge the adequacy of the lessee's program in close consultation with local, state, and federal air quality agencies.

3.13 Measurement standards and equipment specifications should conform to published EPA Quality Assurance procedures or their equivalent as prescribed by the Supervisor.

3.14 In areas of mixed federal and private land ownership, or one with two or more lessees, lessees should be encouraged to cooperate in the development of programs for acquiring baseline data on a regional basis, if appropriate, in cooperation with local public agencies.

3.2 Identification of components to be measured

3.21 The baseline data plan should include a program for ambient air analysis of hazardous substances anticipated from geothermal operations or pollutants for which there are local, state, or federal standards. At a minimum these should include: particulates, SO_x, NH_3, NO_x, CO, H_2S, and hydrocarbons/photochemical oxidants. In addition, air analyses should be undertaken for other pollutants whose concentrations are known or reasonably expected to warrant establishment of baseline data. These pollutants may be identified by a program which includes:

a. standard analysis of geothermal fluids, (see 4.31A)
b. analysis of gasses where geothermal fluids escape substantially into the atmosphere as a gas or gas-liquid mixture; separate analyses of the gaseous phase at representative wells,
c. analysis of representative naturally occurring gas seeps,
d. examination of existing air quality data.

3.22 The Supervisor, in consultation with the surface management agency, and with federal, state and local air quality agencies, must retain latitude to prescribe, curtail, or suspend measurements for individual pollutants as appropriate in each case, based on data from progressive sampling and on the particular circumstances of projected development in and around the lease area.

3.23 In selecting hazardous substances to be measured and in establishing the number and location of sites and the frequency of measurement, the lessee should consider:

a. downwind, offsite consequences of project emissions,
b. the degree of population exposure and ecosystem sensitivity,
c. topographical and meteorological complexities; seasonal variations,
d. the impact of synergistic effects that may occur,
e. anticipated air quality during ultimate development, including the cumulative impact of both long-term, low-level stack emissions, and secondary or indirect source emissions (for example, traffic to geothermally heated homes or worker traffic; industrial emissions from geothermally heated crop drying; evaporative emissions from ponded brines).

3.24 The Supervisor may require special measurement of ozone and sulfur dioxide levels in agricultural areas where sulfur compound emissions from geothermal activities might raise existing oxidant levels above the damage threshold for vegetation.

3.25 In areas susceptable to fog or dust conditions visibility should be measured.

3.3 Meteorological measurements

3.31 Since meteorological data are necessary as a prerequisite to an adequate program to understand the distribution of pollutants in ambient air, the lessee should gather existing seasonal meteorological information, including temperature, barometric pressure, relative humidity, wind speed and direction, and precipitation. Such data alone may be adequate for small, non-power projects.

3.32 Most extensive geothermal developments will require a network of surface meteorological recording stations in topographically representative positions. If appropriate one station may be placed 50-200 feet above ground at a proposed plant site or area of maximum projected emissions. Each station should be capable of meeting the following requirements: 1) relative humidity or dew point shall have an accuracy of ± 2° F, 2) temperature range: -20° F to 130° F, 3) wind speed starting threshold of 1 mph and an accuracy of 0.5 mph, or 1 percent of the wind speed, whichever is greater, 4) precipitation accurate of ± 0.01 inch, 5) for parameters normally recorded continuously, data should be acquired over at least 75% of the base period.

3.33 For a period of at least one week in each season, temperature inversions should be ascertained by pibals, acoustic radar, radiosondes, wiresondes, or aircraft flights.

3.34 Lessee should locate meteorological stations so that data obtained are adequate to apply to dispersion models if appropriate.

3.4 Data acquisition

3.41 The lessee should assemble existing air quality data, which may be substituted for portions of the lessee's data gathering program if specifically approved by the Supervisor.

3.42 Ambient air quality at fixed stations should be measured continuously for the baseline period (1 year) with 75% recovery of data.

3.43 Temporary or mobile units may be required to measure high local concentrations of air pollutants as well as releases resulting from incidents such as upsets, breakdowns, or blowouts. Spot sampling locations downwind from a well blowout or other hazardous occurrence should also be undertaken for as long a period as circumstances warrant.

3.44 If hydrogen sulfide is found to be present in ambient air in concentrations exceeding 10 ppb, the plan should provide for the installation and servicing of an array of lead acetate tabs (or similar devices) to measure H_2S at wells, natural seeps, and in areas where risk to people or to the ecosystem may be especially acute. Lessee should map these areas of crucial exposure by census. If well testing occurs within the base period the operator should gather data both during well testing and when wells are not being tested. One or more continuously recording stations may be required. The following equipment specifications and reporting requirements are recommended if H_2S measurements are required:

HYDROGEN SULFIDE - MICRO-METEOROLOGICAL STATION

1. H_2S analytical equipment should be capable of a precision of 0.01 ppm (v/v), and accuracy of 5 percent of full scale (v/v), with minimal detectable sensitivity of 0.005 - 0.01 ppm (v/v).

2. Sulfur analyzers should possess dynamic calibration to assure consistency in tolerances.

3. At least one secondary calibrating sulfur analyzer should be used to obtain a breakdown of the various species of sulfur making up the analysis.

4. Data should be processed to yield:

    a. highest hourly average hydrogen sulfide concentration daily
    b. 24-hour average hydrogen sulfide concentration
    c. monthly average hydrogen sulfide concentrations
    d. seasonal average hydrogen sulfide concentrations.

5. Where terrain and climatic factors make them significant, the following additional relations should be determined:

    a. the relation between hydrogen sulfide concentration and wind direction
    b. diurnal variations in hydrogen sulfide relative to micro-meteorological parameters
    c. hydrogen sulfide concentrations related to rain, snow, temperature and dew point or relative humidity

3.45 Lessee shall comply with applicable federal, state, and local standards affecting measuring equipment and techniques for individual pollutants, and lessee should attempt to follow other established design criteria, network strategy, and analytical methodology.

4.0 WATER QUALITY

4.1 Introduction

Procedures recommended for establishing a water-quality baseline on geothermal leases and units are divided into two categories, 1) general, and 2) site specific. These recommendations stem from the principle that detailed knowledge of water quality in the environment and of the geothermal fluid(s) is needed early in any operation, to establish baseline concentrations and to determine which potentially harmful constituents are present. Later, measurements may be limited to those constituents that may adversely affect the environment.

4.2 General sampling requirements

To provide an adequate body of baseline data on water quality, the following procedures and principles are generally recommended for all leases or units:

4.21 Standards

Collection and analysis of water samples should be done according to current methods published by EPA, USGS, "Standard Methods" as summarized in "Recommended Methods for Water-Data Acquisition" (3). Analyses by State-certified laboratories are preferred.

4.22 Sources to be sampled

A. Surface water

Where present, perennial streams and significant intermittent streams should be sampled at or near the upstream and downstream boundaries of the lease or unit. Ponds, lakes, canals and drains, if present, should also be sampled. In areas of complex ownership or development lessees should be encouraged to develop sampling programs on a cooperative basis (1.4 above) taking into consideration differences in topography, geology, land use and access.

B. Ground water

Where present, ground-water sources (springs, seeps, and water wells) on the leasehold should be sampled for analysis as prescribed by the Supervisor. If the leasehold overlies and is upgradient from parts of an aquifer from which water is used for domestic, irrigation, stock, or wildlife supply, the Supervisor may require the lessee to obtain water samples for analysis from that aquifer during the drilling of geothermal wells, even though no wells on the lease hold produce from that aquifer.

C. Geothermal fluids

Geothermal fluids produced under the lease should be sampled for analysis according to provisions of GRO Order No. 4, and as specified below. (see 4.31).

4.23 Frequency and duration of sampling

A. The Supervisor should have wide latitude in determining frequency and duration of sampling during the baseline period.

B. The size, nature, intensity of development, and use of the geothermal resources should be important determining factors.

C. Frequency of sampling of streams should be selected with regard to the regimen and environment of the stream. Quarterly samples may define basic conditions in areas where streamflow is fairly uniform. In areas of significant seasonal variation, times of sampling should be adjusted to determine quality of typical high and low flows and/or of extreme events.

D. Ground-water sources upgradient of lessee's structures should be sampled at least once. Downgradient sources should be sampled at frequencies determined by the Supervisor in light of the chemical quality of geothermal fluids and other conditions and events peculiar to the lease.

E. Natural discharges of geothermal fluids (as from hot springs) should be sampled at least once prior to commencement of exploration drilling, and at least once more during the baseline data period.

F. Artificially produced geothermal fluids should be sampled for analysis when encountered and after there has been enough discharge to assure that the sample is representative of fluid(s) in the producing zone. Thereafter, samples may be required by the Supervisor after any major modification to the well or change in flow characteristics.

4.24 Parameters to be measured

A. Physical

1. Discharge of streams, wells, and springs should be measured each time a sample is taken.

2. Temperature should be determined each time a water source is sampled. Precision should be:

   $0.2^\circ C$ in the range 0° to $30^\circ C$
   $1.0^\circ C$ in the range 31° to $100^\circ C$
   5.0° above $100^\circ C$

3. pH should be determined each time a water source is sampled. For the range 6.0 to 9.0 a precision of about 0.5 pH unit will be accepted. Outside of this range more precise measurements should be obtained.

4. Specific conductance should be determined each time a water source is sampled.

5. Turbidity should be measured on surface-water samples where eutrophication exists or is threatened.

B. Chemical

1. Surface waters

   The first surface water sample from each site should receive a standard analysis. Standard analyses include DO, SiO_2, Ca, Mg, Na, K, alkalinity, SO_4, Cl, NO_3, F, dissolved solids, total P. Thereafter, where specific conductance does not increase by more than 10 percent, repeat analyses may not be required.

2. Ground water

   Ground-water samples from each sampling site should be given standard analysis as required for surface water at least once. Analysis of the first sample from each ground-water source shall include an assay for gross radioactivity.

4.3 Site Specific sampling requirements

The following requirements are to be within the province of the Supervisor and should become part of the required environmental baseline for surface and ground waters when toxic substances have been determined to exist in natural discharges of geothermal fluids or in fluids from geothermal wells, or if the Supervisor has reason to expect that toxic substances exist owing to geologic or other conditions. If the lessee in his plan of operation indicates he intends to use toxic substances, a baseline for such substances should be established prior to their introduction on the lease.

4.31 Geothermal fluids

A. All pre-lease thermal wells and hot springs should be sampled in accordance with 4.23 E above. In addition to the standard analysis the following components are to be quantified by accepted laboratory methods (reference 4)

1. Gases: CO_2, H_2S, SO_2, NH_3, and Rn-222

2. Water: As, Ag, B, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Mo, NH_4, Pb, Se, Sr, and Zn.

B. Analysis of produced geothermal fluids is required under provisions of GRO Order No. 4, section 10, within 30 days of completion of any geothermal well.

C. Analyses of geothermal fluids should include determination of gross radioactivity. If radioactivity exceeds the following values (gross $\alpha > 10$ pCi/ℓ, gross $\beta > 50$ pCi/ℓ) the Supervisor may require specific radionuclide assays of these and other water sources on the lease.

4.32 If water pollution is threatened from sources on the lease other than geothermal fluids the Supervisor should require sampling and analysis of those sources and of the water bodies (surface or subsurface) threatened. Potential sources of pollution include, but are not restricted to, effluent or drainage streams including road culverts, mud pits or other sumps, sanitary facilities, and waste-disposal leachates.

4.33 Biochemical, bacteriological, and organic quality of streams, canals and drains should be determined at the discretion of the Supervisor. In general, stations upstream and downstream from construction sites will be of principal interest. Parameters that may be called for include: BOD_5, TOC, COD, fecal coliform bacteria, and fecal streptococcus bacteria. Pesticide analysis should be required if pesticides have been used extensively on the leasehold.

Leachates of any origin originating on the leasehold should be analyzed for deleterious organic constituents and characteristics.

The Supervisor may require biochemical, bacteriological, and organic quality determinations on runoff from construction sites such as roads and drilling pads if that runoff reaches a body of surface water.

4.34 Samples for determination of suspended sediment may be taken from surface sources at discretion of the Supervisor. The load of any component absorbed on suspended sediment may require quantification.

4.35 Standing surface-water bodies (such as ponds, lakes, or reservoirs) on the leasehold or within the realm of influence from operations on the leasehold should be sampled for analysis to determine water quality prior to operations by the lessee. Dissolved oxygen, BOD_5, pH, specific conductance, temperature, and fecal bacteria may be determined monthly or seasonally.

REFERENCES

1. (U.S.) Environmental Protection Agency, 1971, "Methods for chemical analysis of water and wastes", EPA Laboratory, Cincinnati, OH.

2. Brown, Eugene, Skougstad, M. W., and Fishman, J. J., 1970, "Methods for collection and analysis of water samples for dissolved minerals and gases", U.S. Geol. Survey TWRI, Book 5, Chapter A-1.

3. Federal Interagency Work Group on Designation of Standards for Water Data Acquisition, 1972, "Recommended methods for water data acquisition", U.S. Geol. Survey Special Publ.

4. Presser, T. S., and Barnes, Ivan, 1974, "Special techniques for determining chemical properties of geothermal water", U.S. Geol. Survey Water-Resources Investigations 22-74. (Request from T. S. Presser, WRD, USGS, Menlo Park).

5. "Standard methods for the examination of water and waste water" (latest edition) prepared and published jointly by American Public Health Association, American Water Works Association, and Water Pollution Control Federation.

6. Environmental Protection Agency, 1973, Water quality criteria 1972: EPA=R3-033, March 1973, 594 p.

5.0 BIOLOGICAL DATA

5.1 Review of program design

The adequacy of the design and conduct of the biological baseline data program should be determined by the Supervisor in consultation with surface management agencies, State fish and game agencies, and the U.S. Fish and Wildlife Service.

5.2 Aquatic

The following instructions refer to all surface waters. Although specific sampling techniques will vary, the types of information needed to establish an effective baseline for any aquatic resource are the same. The design of the sampling scheme, specific methods of sample collection and analysis and, in some cases, the frequency of sampling will usually be site specific.

5.21 Station Selection Criteria

A. Priority stations should be established at all points of potential impact and at any location where initial inventories (see below) identify endangered or threatened species or a fishery resource of recognized high value. Points of potential impacts are recognized as, but not limited to, perennial aquatic resources upstream and downstream from areas of intensive environmental manipulation, such as road development, pad preparation, well drilling, retaining ponds and temporary or permanent facilities.

B. Representative stations should be established at a sufficient number of points to document the structure of the aquatic ecosystem.

5.22 Prior to, or concurrently with, selection of the sampling stations, an initial inventory of the floral and faunal components of the aquatic ecosystem should be accomplished in sufficient detail and intensity to identify: 1) the presence of any endangered or threatened species listed in accordance with the Endangered Species Act of 1973, and 2) other species and the relative abundance of those species present in the ecosystem. After compilation of the inventory data, sensitive and/or important organisms will be identified and selected for more detailed study. Selection of these species and the degree to which their population dynamics are quantified will determine the level of resolution in identifying and separating natural population changes from those resulting from geothermal development. In addition to the investigations dealing with individual species, attention should be directed to determining community structure and function in terms of abundance, diversity and biomass of the organisms present. General parameters to be investigated will be determined by the particular species present in the ecosystem and their required habitat. The following biotic groups will generally be represented: periphyton, plankton, aquatic macrophytes, macroinvertebrates, and fish and/or other vertebrates. Specific parameters for the identified sensitive and/or important species will include estimates of such things as abundance, standing crop of biomass, diversity, and intrinsic growth rate (as related to biomass). The required habitat should be inventoried for any listed sensitive and/or important species for which critical life stages have been identified (eg salmonid spawning grounds). Baseline levels of heavy metals should be determined in fish. If determined levels exceed levels indicated in State or Federal water quality criteria, measurements of heavy metal content may be required for baseline purposes in other components of the ecosystem.

5.23 Frequency

The sampling frequencies for the various general parameters (Table 1) are to be used as initial sampling schedules and may be adjusted by the Supervisor on the basis of demonstrated population dynamics.

5.24 Data Interpretation and Reporting

Analysis and interpretation of data should be in accordance with methodologies acceptable within the scientific community. Degree of precision and, where available, accuracy will be reported for the estimates of all parameters. Reports will describe the structure and functional nature of the aquatic ecosystem.

TABLE 1. RECOMMENDED SAMPLING FREQUENCY FOR GENERAL PARAMETERS AND ASPECTS OF THOSE PARAMETERS. a/

COMPONENT	STANDING CROP (in numbers and biomass)	DIVERSITY	INTRINSIC GROWTH RATE (as related to biomass)	REMARKS
hyton	Seasonally	Seasonally	Seasonally	Estimates of net production will be made.
ton	Monthly	Monthly	Monthly	In standing waters only
ic Macrophytes	Semi-annually	Annually	Semi-annually	Estimates of net production will be made.
invertebrates	Seasonally	Seasonally	Annually	
b/	Annually	Annually	Annually	

a/ Sampling frequencies will vary from these basic guidelines depending on the sensitive and/or important species under investigation and the seasonal characteristics of activity.

b/ Natality, and mortality by age class will be estimated annually for fish populations. See chemical sections for sampling frequencies for heavy metals.

5.3 Terrestrial

5.31 Introduction

Baseline studies of terrestrial biology should consist essentially of inventories necessary to establish the identity of flora and fauna within the lease area and in areas likely to be affected by lessee activity. These studies are necessary to identify significant processes and relationships within the ecosystem. The importance of review by people and organizations having acknowledged familiarity with and information on the flora and fauna of the lease site is emphasized. Duplication of efforts should be avoided by making use of existing information whenever possible. For example, universities or agencies having information should be consulted. Such pre-existing data may be included in the data collection program with the approval of the Supervisor.

5.32 Flora

The first step in baseline studies of flora and fauna should be to obtain copies of recent aerial photographs and prepare a vegetative type map of the lease area and adjacent areas of concern. Color aerial infrared photographs are preferred and can be used to delineate and document major vegetative types. The photos should be of a scale satisfactory to reveal individual types within the lease area. Ground verification should be carried out as needed to characterise floral components of each type. Examples of vegetative types identified at this stage include riparian, grassland, desert shrub, woodland, or forest.

A. Station Selection Criteria

The number and location of representative stations or transects should be selected so as to characterize each vegetative type within the lease area. Priority stations shall be selected in areas of special interest based on knowledge of anticipated geothermal development, concern for critical habitat, or for other reasons.

B. Parameters and Methods

Parameters to be identified or measured include the following:

1. Vegetative-types
2. Identification of plant communities within

vegetative types (e.g. pinyon-juniper, creosote bush, oak-mixed shrub, saltbush-greasewood)

3. Measurements of cover density and species composition within plant communities
4. Measurements such as the volumes of seed or forage production as may be related to use by animal species in the area
5. Identify and locate endangered or threatened plant species
6. Identify species and/or communities with special scientific values

Exact sampling methodology and additional parameters will be those relevant to the specific lease area as determined through consultation with knowledgeable individuals and agencies and approved by the Supervisor.

Methods of data analysis will be those generally accepted by the scientific community concerned with the particular parameters. This will be primarily the land administrating agency, the U.S. Fish and Wildlife Service and the State Fish and Game Department.

5.33 Fauna

The baseline inventory of the animal community found on or associated with the lease area should include: identification of species present and their relative abundance and habitat association or preference; the presence of threatened or endangered species; seasonal use patterns and movements of both resident and migratory species; and, if data are available, the identification of "key" indicator species. This initial inventory should include a review and compilation of existing data from sources such as universities, fish and wildlife agencies, check lists, etc. This inventory should be expanded as required to accomplish the objectives.

A. Station Selection Criteria

The number and extent of stations or transects should be sufficient to provide reliable data on particularly sensitive areas, coverage of representative habitats on the lease area, and as the basis for comparability with data collected during the subsequent monitoring phase. Should critical or particularly sensitive species or habitats occur within the lease area the Supervisor may require a more rigorous and extensive sampling program.

B. Frequency

Each station or transect should be sampled quarterly so as to determine seasonal variations in use, nesting/breeding seasons, and relative abundance of species using the lease area.

6.0 NOISE

Ambient noise levels prior to the operations of the lessee constitute the baseline against which later measurements can be compared. In many natural settings remote from the activities of man, sound level measurements available from mamagement agencies or other sources may be acceptable. In areas affected by noise from highways, frequent planes, or other industrial or manmade sources, sound measurements to establish a baseline should be carried out by the lessee. These measurements should be conducted in accordance with the provisions of GRO-4, section 11.

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UNIVERSITY OF UTAH
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MEMORANDUM

TO: Distribution

FROM: John Beebee

SUBJECT: Notes from 30th Geothermal Coordinating Group Meeting, 31st Meeting.

Here are my notes, supplemented by your amendments, corrections, and viewgraphs, from the 30th Geothermal Coordinating Group Meeting. 1980

The 31st meeting will also be held in the Washington, D.C. area, January 14, 15, & 16. At the last meeting it was decided to have this meeting with representatives from the field offices of the Division of Geothermal Energy. The Division of Geothermal Energy promised to brief us on any aspects of their program that would be of general interest. Please let me, or Ogle, know your wishes in this regard.

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NOTES

GEOTHERMAL COORDINATING COMMITTEE
30th Meeting
Washington, D.C.
August 6-8, 1980

Division of Geothermal Energy - Bennie DiBona

Stan Weiss has gone to NASA and has been replaced by Rudy Black, at least until elections. Rudy has geothermal, low head hydro, and uranium enrichment. Environmental aspects of geothermal are elsewhere. We are reassembling the Division after the recent split. In the technology area, we are trying to keep personnel assignments constant. Marshall Reed has returned to Menlo Park. Chuck Bufe of the U.S.G.S. will be responsible for work in subsidence and induced seismicity.

The House geothermal budget is hard to follow. The Senate budget process won't begin until after the general elections. The largest proposed cut is in hydrothermal commercialization activities. This includes technical assistance to interested users and the low to moderate temperature assessments.

There are a lot of direct heat skeptics. We need to build a story that will feed their quad fetish. We are having trouble selling direct heat. We need data to show it is useful. We started to replace the industry coupled program with the low temperature user coupled program. Also, we were too hasty in assuming that the electric industry would go for the high temperature resources.

The House Committee on Science and Technology also wanted $10 million to fund the binary technology power plant. (For the plant, each party will put up around $70 million. The Baca plant is running around $150 million total). They did not want to go over the President's budget. McCormick would not touch the geopressure budget, because it would cause too much trouble with Lindy Boggs. The Division of Geothermal Energy felt it had to keep hot dry rock at $14 million. In addition to hydrothermal commercialization, conversion technology (mainly the Sperry project) was hit pretty hard.

Congress has passed an Energy Security Act, of which Title VI creates a program of loans similar to a previously existing small hydro program. Funding is $5 million for 1981. It isn't clear how this act interfaces with the loan guarantee program.

Jack Salisbury is now working on a new goals statement for the Division of Geothermal Energy. People here just don't believe the current numbers. We aren't going to play this game anymore for hot dry rock and geopressure, but we do need to play it for hydrothermal technology. We are looking at reservoirs and trying to link them with developers. The Interagency Geothermal Coordinating Council was also unhappy with the old goals. The point is that we need a better projection of what might really happen. It is easier for electric than nonelectric. The point is to convince the House Science and Technology Committee that geothermal will contribute a significant number of quads. Unlike solar, and except for the

August 6, 1980

FY 1981 GEOTHERMAL ENERGY BUDGET HISTORY

(Budget Authority in 1,000's)

Operating Expenses	Pres. Budget to Congress	House Sci. Tech. Auth. Mark	Diff.	House Appro. Mark	Diff.
Hydrothermal Commercialization	$ 9,024	$ 6,048	-$ 2,976	$ 3,024	-$ 3,024
Hydrothermal Resources	42,089	33,589	- 8,500	33,589	0
Geopressured Resources	35,800	35,800	0	35,800	0
Geothermal Technology Development	51,890	41,390	- 10,000	39,390	- 2,500
o Component Devel.	(38,390) A/	(28,390)	(- 10,000)	(25,890)	(- 2,500)
o Hot Dry Rock	(13,500)	(13,500)	0	(13,500)	0
Total Operating Expenses	$138,803	$117,327	-$ 21,476	$111,803	-$ 5,524
Total Capital Equipment	$ 1,310	$ 1,310	0	$ 1,310	0
Construction					
Flash Demonstration (#1)	$ 10,911	$ 8,911	-$ 2,000	$ 6,911	-$ 2,000
Binary Demonstration (#2)	0	10,000	+ 10,000	10,000	0
Total Construction	$ 10,911	$ 18,911	+$ 8,000	$ 16,911	-$ 2,000
TOTAL GEOTHERMAL	$151,024	$137,548	-$ 13,476	$130,024	-$ 7,524

A/ Does not include $2.5 million from the Federal Republic of Germany.

Does not include loan guarantee.

Aug. 5, 1980

FY 1981 GEOTHERMAL ENERGY
BUDGET HISTORY

(Budget Authority in 1,000's)

Hydrothermal Resources

Operating Expenses	Pres. Budget to Congress	House Sci. Tech. Auth. Mark	Diff.	House Appro. Mark	Diff.
Resource Definition	$ 19,398	$ 18,398	-$ 1,000	$ 15,148	-$ 3,250
Non-Electric Demonstrations	16,000	10,500	- 5,500	10,500	0
Environmental Control	2,600	2,600	0	2,600	0
Flash Demonstration	1,139	1,139	0	1,139	0
Binary Demonstration	0	0	0	0	0
Raft River Pilot Plant	2,452	2,452	0	3,702	+ 1,250
Geothermal Component Facility	500	500	0	500	0
General Cut	0	- 2,000	- 2,000	0 A/	+ 2,000
Total Hydrothermal Resources	$ 42,089	$ 33,589	-$ 8,500	$ 33,589	0

A/Appropriation figures distribute the HS&T general budget cut within each subprogram.

Aug. 5, 1980

FY 1981 GEOTHERMAL ENERGY
BUDGET HISTORY

(Budget Authority in 1,000's)

Geothermal Technology Development

Operating Expenses	Pres. Budget to Congress	House Sci. Tech. Auth. Mark	Diff.	House Appro. Mark	Diff.
Component Development					
Drilling & Completions Technology	$ 8,250	$ 8,250	$ 0	$ 7,250	-$ 1,000
Conversion Tech.	12,800	9,300	- 3,500	5,300	- 4,000
Reservoir Stimulation	4,500	3,000	- 1,500	3,000	0
Geochemical Engr. & Mtls.	5,005	4,505	- 500	4,005	- 500
Geoscience Technology	7,835	6,335	- 1,500	6,335	0
General Cut	0	- 3,000	- 3,000	0A/	+ 3,000
Total Component Development	$ 38,390	$ 28,390	-$ 10,000	$ 25,890	-$ 2,500
Hot Dry Rock	$ 13,500B/	$ 13,500	0	$ 13,500	0
Total Geothermal Technology Development	$ 51,890	$ 41,890	-$ 10,000	$ 39,390	- 2,500

A/ Appropriation figures distribute the HS&T general budget cut within each subprogram.

B/ Does not include $2.5 million from the Federal Republic of Germany.

Aug. 5, 1980

new program

ENERGY SECURITY ACT*

GEOTHERMAL ENERGY ACT (Title VI)

Provisions

- o Loans for reservoir confirmation
- o Loans for non-electric feasibility studies
- o Loans for construction
- o Reservoir Insurance Program Study

Similar to hydro.

Funding

- o $5 million in FY 1981 and $20 million thereafter for 4 years for reservoir confirmation loans.
- o $5 million in FY 1981 for feasibility studies
- o Funding for construction and for the Reservoir Insurance Program Study not identified

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*Public Law 96-294

electric industry, there is no constituency for geothermal. Parametric studies don't fly.

Industry will begin lobbying for geothermal, but it has a hard time competing for attention with coal gasification, shale retorting, etc. Industry nibbles in with 10mw power plants, not 50 or 500. We are encouraging industry to get the first plant on line at new reservoirs. For example, the Eugene Water and Power Board is thinking of 10mw packaged binary plants for use in N. Nevada (to minimize environmental problems). As a second example, the Division of Geothermal Energy may get money from the Department of Defense for developing power sources for MX.

Of course, there is the possibility that the Senate will restore the funds cut by the House Science and Technology Committee. If not, the Division can use its discretion in reprogramming up to 10% of the budget. Then again, we could cancel a lot of contracts. Some money can be moved because budget categories are not well defined.

The latest estimate, adding all electric plants coming on line, we get 2300mw. Heber would not have gone binary without government funds. San Diego Gas and Electric has a low bond rating to start with. The Baca plant is not research and development.

The Division of Geothermal Energy now has 25-28 on board staff and doesn't have much of a travel budget, or sometimes we don't know what is in it. The staff just can't go to all meetings these days. My own most important job is getting acquainted with Congressional staff, industry, and Department of Energy higher-ups.

Geopressure resource evaluation is very expensive, and this is why the budget is so high. With less than $25 million, you are kidding yourself. Also, geopressure has started looking up in the last few months. By 1983 we should understand the reservoirs. Geopressure suffered from some bad field contractors.

Basic Energy Sciences - George Kolstad

The budget history of Basic Energy Sciences is roughly as follows ($ million).

	1979	1980	1981	1982		
			(Cong.Appd.)	(min)	(med)	(enh)
Total Geosciences (Operating)	6.100	8.082	9.300	9.8	11.0	11.8
Continental Drilling	-----	1.000	1.500	---	----	----
Geochemical Migration	.510	.600	.800	.85	.9	.95
Organic Geochemistry	-----	-----	-----	-----	----	.5
Rock Mechanics	-----	.200	.400			
Equipment	.355	.560	.930	.850	.950	1.000

The National Continental Drilling Program is stalled because of the emphasis on oceanic drilling. However, the DOE effort is progressing at a moderate pace. The money being spent for deep drilling is mostly going into site assessment. At Livermore a drill hole information center has been established encompassing Department of Energy, United States Geological Survey, and Department of Defense holes. It has information on location, availability, contacts, etc. (Nancy Howard) A study is being made (LASL) of the need for a drill core and sample repository. Existing ones tend to start out well but then run out of money for upkeep. How are the cores from the Continental Scientific Drilling Program going to be stored? Distributed? Inventoried? Geothermally-derived cores are stored at the University of Utah.

We are also supporting work on the geochemistry of geothermal materials at Argonne and the migration of heavy element chemical species in geologic strata.

Projects are selected primarily on the basis of two criteria, scientific excellence and relevance. Suggestions come in the form of unsolicited proposals from Universities and national laboratories. We don't have a "directed" research program in the same sense as the Division of Geothermal Energy. For this reason it is hard to shape the "program" to meet clearly-defined goals and benchmarks. On the other hand, that is the nature of basic research.

United States Geological Survey - Al Koven

The U.S.G.S. prefers not to say much at this time. The budget cuts will eliminate the extramural program, stretch out the Cascades and Basin and Range programs and the low temperature geothermal assessment. Marshall Reed is now head of the State Coupled Program for the U.S.G.S.

Department of Energy - Office of Health and Environmental Research - Frank Hudson

One of the Department of Energy Assistant Secretaries, Ruth Clusen, is in charge of environmental aspects of energy development. There are five offices within the secretariat, one of which is the Office of Health and Environmental Research. Originally it was the Division of Biology and Medicine of the Atomic Energy Commission. It amounts to about 32 people and $210 million per year.

In the switch from the Atomic Energy Commission to Department of Energy we went from nuclear problems to problems with everything. We try to balance our program between technology specific problems and more general ones.

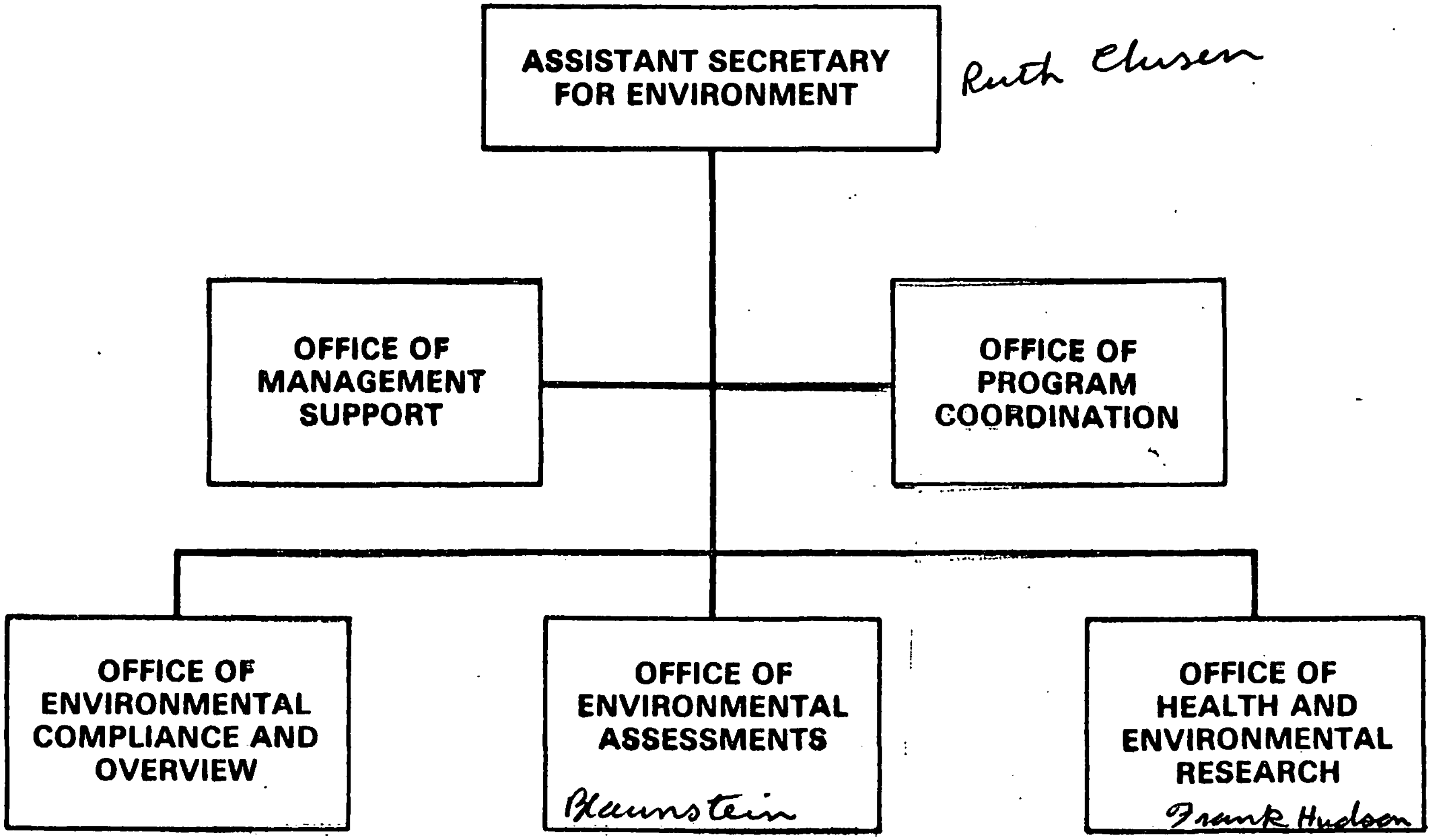
Within the government, we have the following breakdown of agencies and environmental function:

Environmental Protection Agency - Protect and enhance the environment by means of regulation.

Office of Secretary of Environment - Monitor Department of Energy activities to see that they conform to the National Environmental Policy Act.

Office of Health and Environmental Research - Protect health and safety of the taxpayers as we develop energy.

OFFICE OF ENVIRONMENT



ASSISTANT SECRETARY FOR ENVIRONMENT

Ruth Clusen

OFFICE OF MANAGEMENT SUPPORT

OFFICE OF PROGRAM COORDINATION

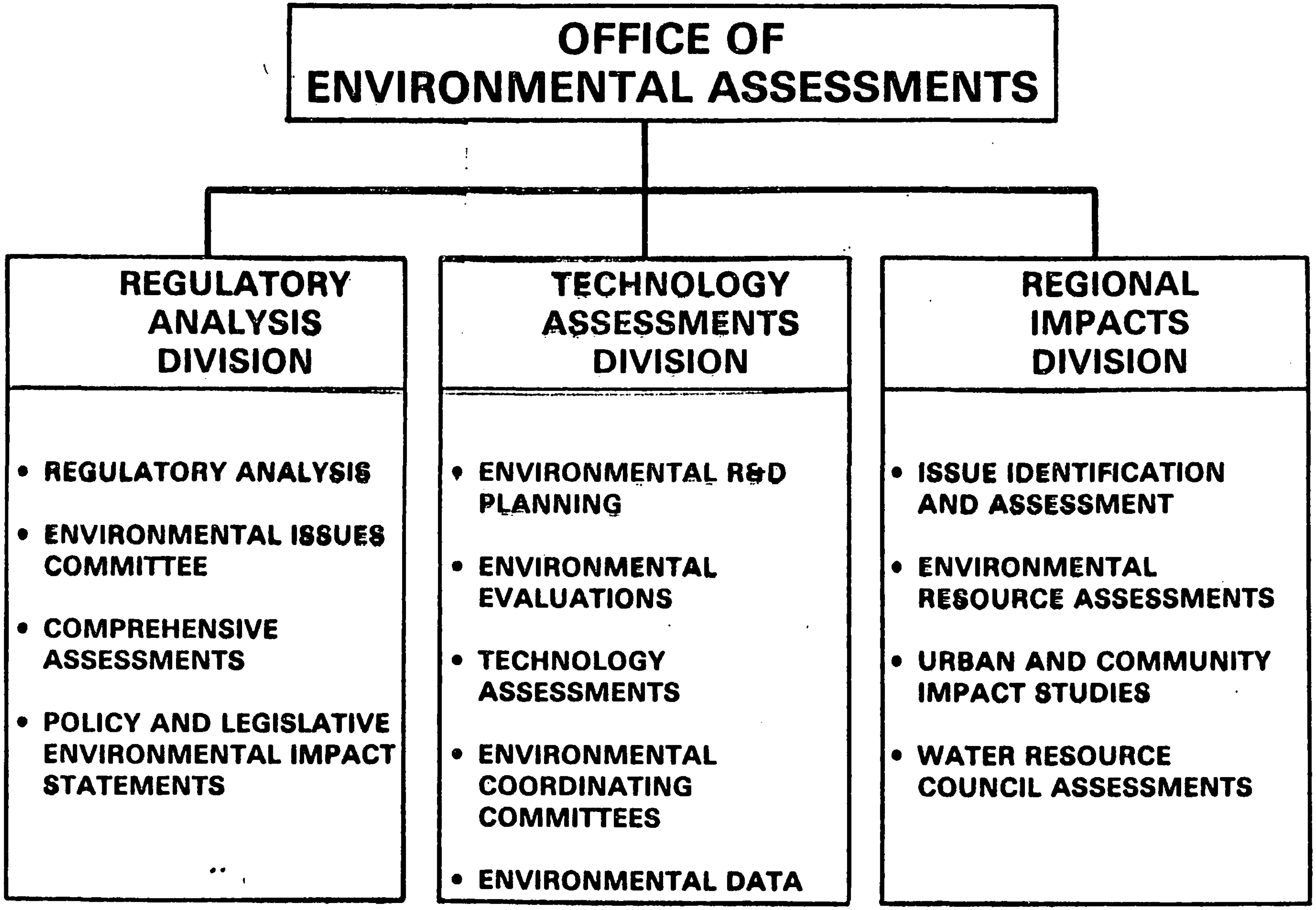
OFFICE OF ENVIRONMENTAL COMPLIANCE AND OVERVIEW

OFFICE OF ENVIRONMENTAL ASSESSMENTS

Blaunstein

OFFICE OF HEALTH AND ENVIRONMENTAL RESEARCH

Frank Hudson



OFFICE OF ENVIRONMENTAL ASSESSMENTS

REGULATORY ANALYSIS DIVISION

- REGULATORY ANALYSIS
- ENVIRONMENTAL ISSUES COMMITTEE
- COMPREHENSIVE ASSESSMENTS
- POLICY AND LEGISLATIVE ENVIRONMENTAL IMPACT STATEMENTS

TECHNOLOGY ASSESSMENTS DIVISION

- ENVIRONMENTAL R&D PLANNING
- ENVIRONMENTAL EVALUATIONS
- TECHNOLOGY ASSESSMENTS
- ENVIRONMENTAL COORDINATING COMMITTEES
- ENVIRONMENTAL DATA

REGIONAL IMPACTS DIVISION

- ISSUE IDENTIFICATION AND ASSESSMENT
- ENVIRONMENTAL RESOURCE ASSESSMENTS
- URBAN AND COMMUNITY IMPACT STUDIES
- WATER RESOURCE COUNCIL ASSESSMENTS

TECHNOLOGY ASSESSMENTS DIVISION

- ENVIRONMENTAL R&D PLANNING
  - ENVIRONMENTAL COORDINATING COMMITTEES
    OFFICE OF ENVIRONMENT
    OFFICE OF RESOURCE APPLICATIONS (DGE)
  - ENVIRONMENTAL DEVELOPMENT PLANS (EDP)
    1977 (DOE/EDP-0014)
    1979 (DOE/EDP-0036)
    1981

- **ENVIRONMENTAL EVALUATIONS**
  - **ENVIRONMENTAL READINESS DOCUMENTS**

    PREPARED BY OFFICE OF ENVIRONMENT

    PREPARED AS INPUT TO DOE DECISIONS

    1978—HYDROTHERMAL ELECTRIC & DIRECT HEAT
    (DOE/ERD-0005)

- **TECHNOLOGY ASSESSMENTS**
  - TO DETERMINE THE DIRECT AND INDIRECT IMPACTS OF A COMMERCIALIZED INDUSTRY
  - STUDIES:
    - PRELIMINARY ASSESSMENTS OF KGRA'S (LLL) GEYSERS, MONO LONG VALLEY, COSO HOT SPRINGS, IDAHO, NEVADA, NEW MEXICO, HAWAII, TEXAS GULF COAST, LOUISIANA GULF COAST, UTAH
    - GEYSERS/SOCIOECONOMIC STUDY (LLL/LBL)
    - IMPERIAL VALLEY (DOE/EV-0092) (LLL)

      (Premier study on what would happen if there was geothermal development).
    - ASSESSMENT OF DIRECT HEAT USES (LLL)

- **ENVIRONMENTAL DATA**
  - TECHNOLOGY/ENVIRONMENTAL CHARACTERIZATIONS (DOE/EV-0072)
    - SYSTEM DESCRIPTION
    - COMPONENTS
    - RESOURCES
    - FUEL
    - COSTS
    - RESIDUALS—AIR POLLUTANTS—WATER POLLUTANTS—LAND USE—SOLID WASTE—WATER USE
  - ENVIRONMENTAL CHARACTERIZATION INFORMATION REPORT (ECIR) – Coal fired power plants : One planned for GT in '81.
    - SYNTHESIS OF ENVIRONMENTAL DATA AND INFORMATION RELEVANT TO A TECHNOLOGY SYSTEM OR PROCESS
    - GEOTHERMAL/HYDROTHERMAL ECIR—1981

Division of Geothermal Energy - Sponsors work on specific technical obstacles to geothermal development.

The Office of Health and Environment is problem oriented: it seeks a better understanding of problems through science. We develop methods for solving problems, e.g. atmospheric transport models. We are the only program in government in health instrumentation and measurement. The office has 80% of its work in national laboratories (including half a dozen small labs) and 20% in universities.

I am chairman of the Geothermal Environmental Working Group. We check to see that all environmental thinking about geothermal meshes. Information comes to this group through Department of Energy funded projects. It is hoped that 1980 and 81 experience will expedite 1990 plant applications.

We have been doing atmospheric studies in complex terrain. This applies to the H_2S problem at the Geysers. The program consists of closely coupled modeling and measurement. Besides this, in 1980 we are finishing up the Imperial Valley work, are looking at ecological problems at the Geysers, and are working at Baca. For the Baca project, the Secretary for Environment had to sign off on the Environmental Impact Statement. This made us a little unpopular.

In the geothermal area, environmental instrumentation is adequate.

In 1980 we (Office of the Secretary for Environment) will spend $2.2 million on geothermal environmental work.

Unfortunately, for 1981 we had to provide a specific list of items to President Carter that would result in a 10% budget cut, but we couldn't cut fossil. The proposal made was to cut out all geothermal environmental work.

On the east coast there are people who want to use geothermal water to help raise clams and shellfish. Where do we learn about the effects of doing this? We would like a method for tracing the movement of ground water. In Virginia and Delaware it is illegal to reinject. There are many questions of water transport between aquifers.

At Raft River the state is asking questions about water transport that EG&G cannot answer. People seeking geothermal permits have trouble getting the required information.

Lawrence Livermore Laboratory - David Layton

The Imperial Valley Environmental Program began in 1975 with the geothermal loop experimental facility. The utilities wanted to know the impact of 500 mw of electric development on Imperial Valley. It has been funded by the Assistant Secretary for the Environment.

The major elements of the program are air and water quality, ecosystem quality, subsidence and seismicity, effects on health, socio-economic effects. The components of the assessment process are a description of the affected environment, characterization of geothermal resources and technologies, identification of impacts and issues, preparation of scenarios, assessments of impacts, and an analysis of controls and mitigation measures.

The energy potential in Imperial Valley is about 6760mw, or 1/3 of the hot water resource of the United States. The land is mostly used for agriculture.

Air quality was measured at 6 stations. Ambient levels of H_2S, SO_2, O_3, NO, NO_x, CO_2, Hg and particulates were measured. Wind directions and velocities were monitored. Geothermal fluids were sampled to determine concentrations of noncondensible gases. Atmospheric transport models were used to simulate the air quality changes from 3000mw of geothermal development, based on no pollution abatement. At 3000mw it was found that the California H_2S standard ($42\mu g/m^3$-hr-avg) would be exceeded at least 1% of the time. To meet the standard, emissions would have to be reduced 82% at the Salton Sea and Brawley. There would have to be a 47% reduction at Heber and E. Mesa. H_2S is one of the chief concerns because of its obnoxious odor.

Contamination of the Valley's surface and ground water could occur due to accidental releases of geothermal fluids. Such water quality impacts are difficult to predict. Agricultural waste water runs into the Salton Sea.

There are several possible sources of cooling water: irrigation water from the Colorado River, waste water from agriculture, and steam condensate. The effects of using these sources on Valley water quality were examined. Low and medium scenarios of energy growth are not affected by water quality considerations. In the high growth scenario, Heber and E. Mesa support 800 and 600mw, respectively, before constraints appear. With medium growth and average hydrologic conditions, toxic levels (to fish) in the Salton Sea will be reached between 1985 and 1990. It will require many years for the sea to reach the 1975 elevation. The use of steam condensate for cooling should be promoted.

Simulation indicates sugar beets will be benefitted by additional H_2S. Alfalfa, cotton, and lettuce will be unaffected. The effect of saline drift from cooling towers can't be determined. It is a problem at the geysers. If land is accidentally flooded with geothermal fluids it will be hard to reclaim.

Subsidence can't be overlooked, even with full injection, because of all the irrigation canals. Imperial county insists on injection to control subsidence. Changes in elevations and slopes must be determined. Downhole compaction should be measured. There has been about 10cm of subsidence in the last 5 years from others causes in the valley. Heber is a good site to get compaction data.

It is unlikely that subsurface injection will trigger earthquakes. Background seismicity should be monitored to determine whether it is affected by injection activities.

The California air quality standard will not protect people from odor. Other gases, ammonia, mercury, radon, benzene, are not problems. Data on occurrence of occupational diseases show the rate at Geysers power plants is very high compared to other utilities. It may be due to toxic chemicals used in the H_2S abatement processes.

At 4500mw, the population of Imperial Valley increases by 30%. The gross economic output from the county could increase by a factor of 3 over the baseline by 2020. Geothermal development will not affect the jobless rate.

The following mitigation measures are available: facility siting, injection, H_2S controls, cooling tower drift eliminators, use of steam condensate for cooling water, containment berms for spills, procedures for reclaiming soils, pressure maintenance to reduce compaction, repair of surface damage from subsidence.

Division of Geothermal Energy - Dave Allen

The accompanying viewgraphs pretty well outline the Division's environmental program. Chuck Bufe will take over seismics and subsidence.

Right now there is no single environmental focus in the Division. At one time there was a person in the division who could represent the whole environmental effort. Federal environmental research seems to be declining. We don't seem to have a good system for centralizing what has been done in environmental research.

(The following random remarks came out of the discussion.) Paul Kruger, at Stanford, is trying to figure out where the radon in geothermal fluids comes from. Seismicity is like radon. Since it is relatively easy to detect, it is interesting. The induced seismicity problem is not unique to geothermal. Can geothermal fluids be disposed in the ocean? The British have been doing it in Wales.

Department of Energy - Division of Technology Assessment/Office of Environmental Assessments (OEA) - Robert Blaunstein

The Office of Technology Assessment determines the environmental issues that arise from a given technology. The Office of Health and Environmental Research generally studies ecological and health effects. OEA carries out impact assessments. The Environmental Protection Agency has an autonomous program. EPA and DOE are beginning to work more closely. The National Environmental Policy Act Affairs (NEPA Affairs) Office certifies that proposed technological initiatives are environmentally safe. The Division of Geothermal Energy develops abatement hardware, while the environmental office assesses the control strategies.

The geothermal environmental budget, in the Assistant Secretary's Office (EV), has been very high. This has been due to the Imperial Valley Environmental Project which is winding down. The Division of Geothermal Energy and EV have worked very closely to develop joint planning programs.

Priorities often change due to high and low level politics, and a confusion of aims at high levels. Budgets have prevented continuation of the Livermore Environmental Program.

General Council's Office - Marty Rogowski

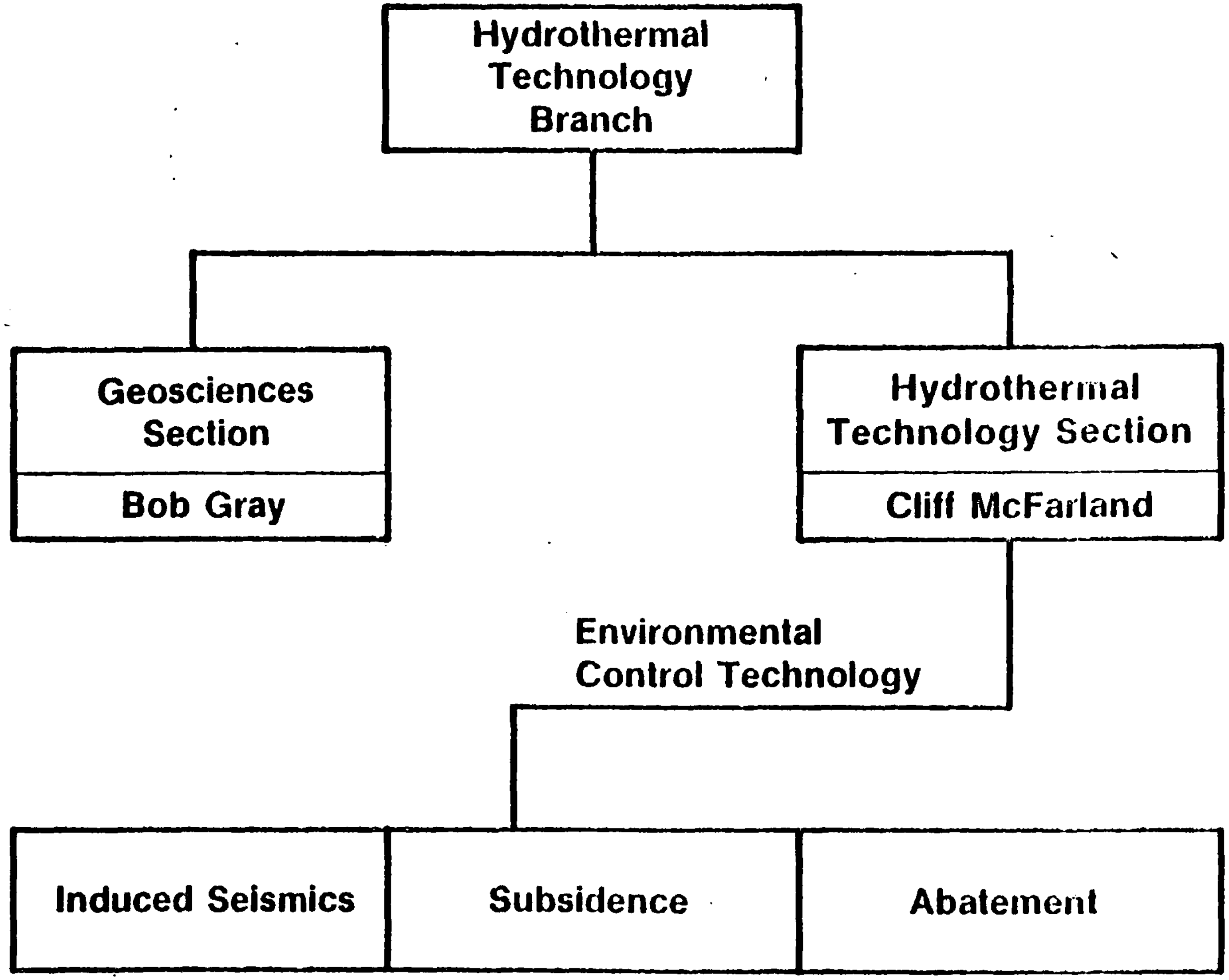
The General Council's Office in coordination with the Office of Environment, advises Ruth Davis on which environmental documents need to be prepared and when. Ruth Davis decides whether a geothermal project is environmentally acceptable.

Division of Geothermal Energy

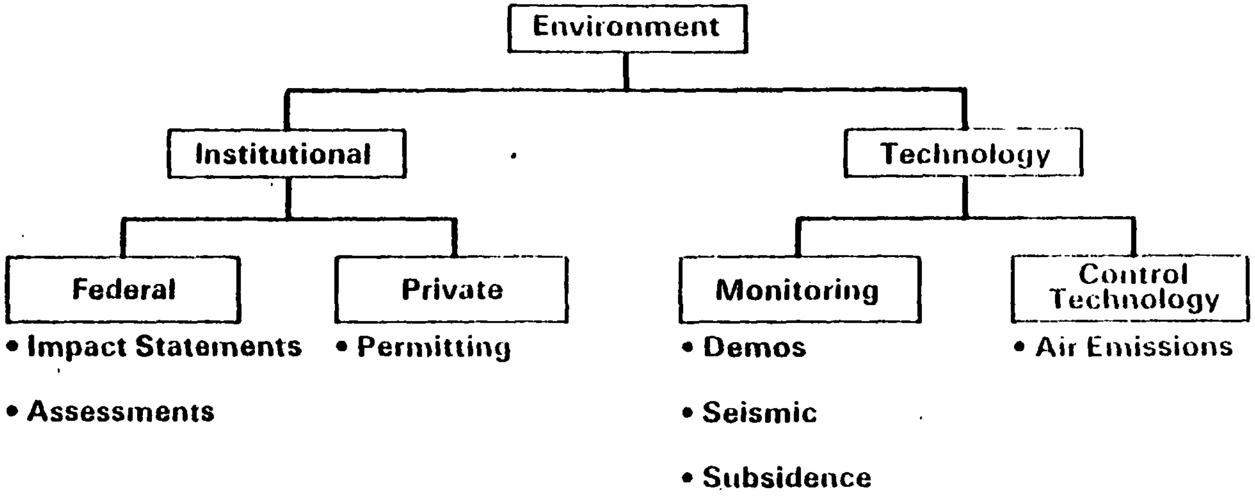
Environmental Control Technology

Briefing Outline

- How Env. Control Fits in D.G.E. (Hydro Thermal)
- Other Players on the Stage
- A Recent Study by Env. Controls Panel And It's Report to I.G.C.C.
- Panel Priorities and Recommendations
- Response to Briefing by I.G.C.C. Chairman
- Status of Reports
- Characterize FY 80 Program
- Glance at FY 81 Intent


Hydrothermal Technology Branch
Geosciences Section
Bob Gray
Hydrothermal Technology Section
Cliff McFarland
Environmental Control Technology
Induced Seismics
Subsidence
Abatement

Geothermal Environmental Considerations



- Environment
  - Institutional
    - Federal
      - Impact Statements
      - Assessments
    - Private
      - Permitting
  - Technology
    - Monitoring
      - Demos
      - Seismic
      - Subsidence
    - Control Technology
      - Air Emissions

Laws and Regulations

- Clean Air Act
- Federal Water Pollution Control Act
- Safe Drinking Water Act
- Noise Control Act
- Toxic Substances Control Act
- Other

- **Players**
- **IGCC - Environmental Control Panel**

Dept. of Energy
  - Environment (EV)
  - Division of Geothermal Energy

Environmental Protection Agency

Dept. of Interior
  - Geological Survey
  - Fish & Wildlife Service
  - Bureau of Land Management
  - U.S. Forest Service

Dept. of Defense (Navy)

Dept. of Agriculture
  - Forest Service

“Controls” Defined

“Technological or Other Methods to Reduce, Terminate or Prevent Detrimental Effects on the Environment”

1. Technological Controls
2. Control Oriented Support Efforts
3. Non-Technological Control Methods
4. Siting

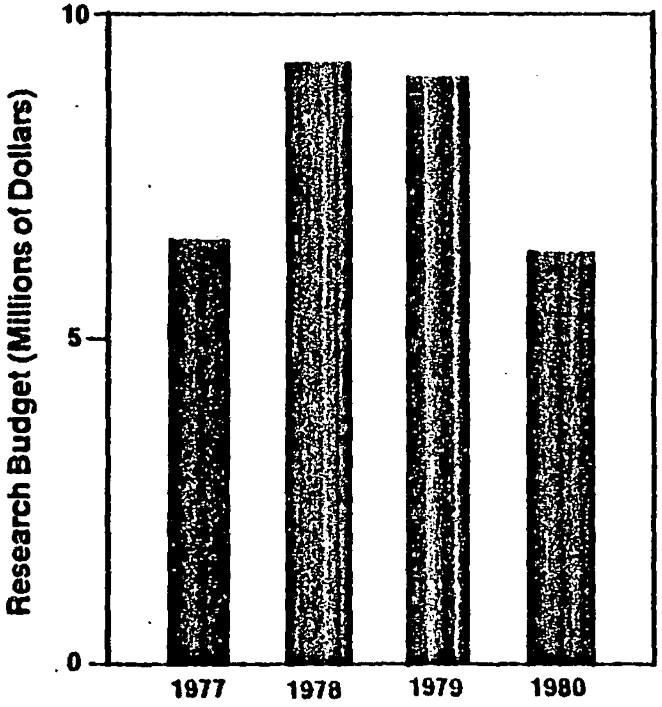
Panel Charter

- Identify Env. Concerns Which May Interfere With Commercialization
- Assess Needs to Control Impact of These Concerns Based on Current Env. Knowledge
- Assess Adequacy of Existing Controls, Tech. and Non Tech.
- Review On-Going Fed. Research Needs
- Recommend Need Modification to Fed. Research Programs to Assure Availability of Adequate Controls on Timely Basis

Approach Taken by Env. Controls Panel

1. Identify Major Env. Concerns
2. Assess Affect of Legislation and Regulations
3. Assess Adequacy of Existing Controls
4. Identify Range of Controls-Related Research
5. Review Scope, Balance, Level of Fed. Controls R&D
6. Recommend Priorities for Research
7. Recommend Modifications in Research Emphasis

Federal Geothermal Environmental Research Program Budget Summary



Federal Geothermal Environmental Research Program Budget Summary Agency[1]

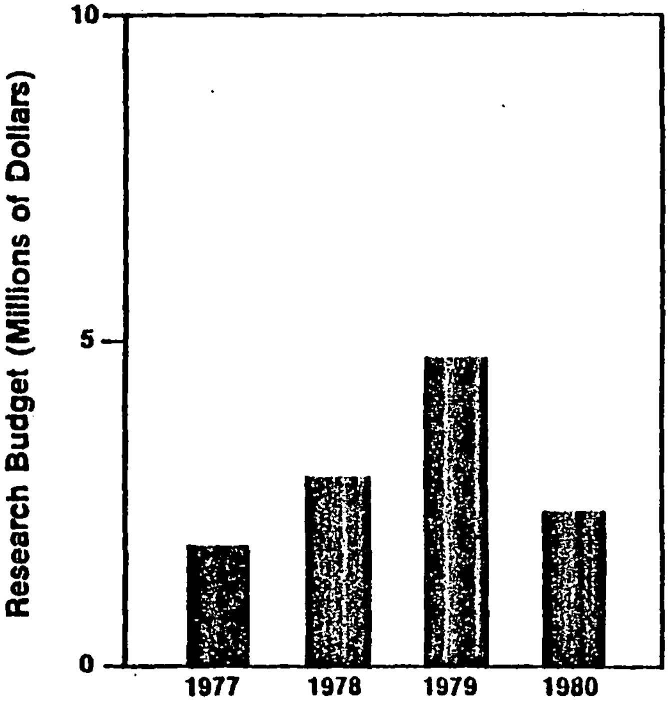
(Thousands of dollars)

	1977	1978	1979	1980
EPA	700	850	850	850
DOI (USGS)	750	750	900	800
DOE	5,050	7,650	7,300	4,700
(DOE/EV)[2]	(3,700)	(4,400)	(3,400)	(3,450)
(DOE/RA)[2]	(1,350)	(3,250)	(3,900)	(1,250)
Total	6,500	9,250	9,050	6,350

[1] Budget Figures Rounded to Nearest $50,000.

[2] DOE/EV - Department of Energy/Environment
DOE/RA - Department of Energy/Resource Applications

Federal Geothermal Environmental Research Program Controls-Related Budget



Federal Geothermal Environmental Research Program Controls-Related Budget by Agency[1]

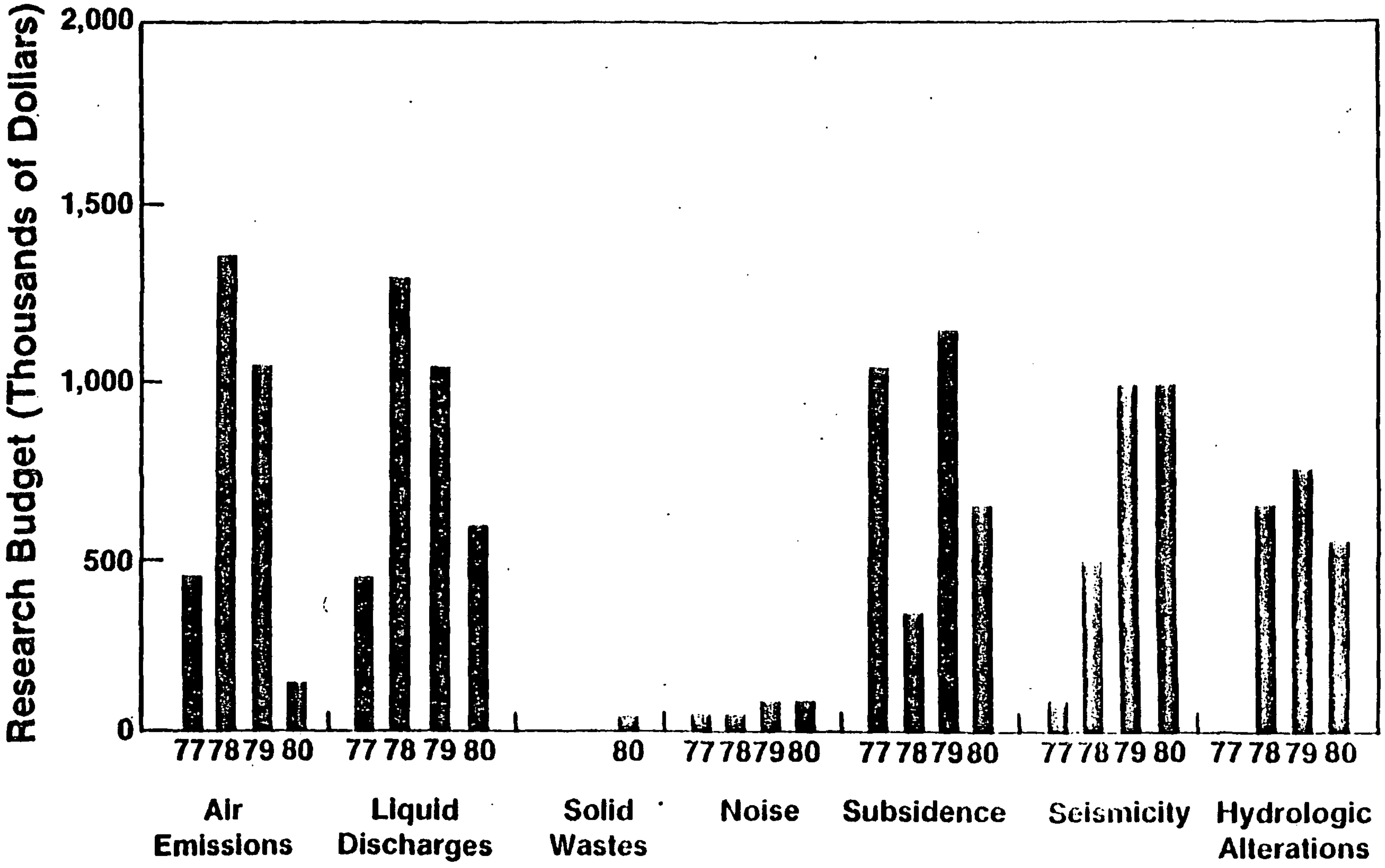
(Thousands of Dollars)

	1977	1978	1979	1980
EPA	300	550	500	500
DOI (USGS)	750	750	900	800
DOE	800	2,650	3,350	1,100
(DOE/EV)[2]	(300)	(600)	(200)	(500)
(DOE/RA)[2]	(500)	(2,050)	(3,150)	(600)
Total	1,850	3,950	4,750	2,400

[1] Budget Figures Rounded to Nearest $50,000.

[2] DOE/EV - Department of Energy/Environment
DOE/RA - Department of Energy/Resource Applications

Federal Geothermal Environmental Research Program Controls-Related Budget By Concern



Top Priorities for Controls — Related Research

Air Emissions

- H_2S Controls for Power Plants
- H_2S Controls of Steam Stacking & Well Emissions
- Non-H_2S Gaseous Emissions

Liquid Discharges/Subsidence

- Injection Monitoring Techniques
- Treatment and Use of Non-Geothermal Waters
- Methods for Subsidence Prevention, Prediction and Control

Solid Wastes

- Solid Waste Characterization & Management Methods Evaluation

Middle Priorities for Controls — Related Research

Liquid Discharges/Subsidence/Seismicity

- Brine Treatment
- Induced Seismicity Identification and Characterization
- Induced Subsidence Characterization

Solid Waste

- Management Methods Development

Other

- In-Line Monitoring
- Chemical & Physical Modeling/Simulation Techniques

Low Priorities for Control — Related Research

- Induced Seismicity Controls Development
- Noise Controls Development

Other Panel Recommendations

- Increased Coordination Through Panel Mechanism
    - Among Key Agencies for Fed. Research Strategy
    - With Industry and Environmental Groups
- Joint Monitoring of Production Sites on Continuous Basis to Develop Better Understanding of Env. Concerns/Controls

EG&G Study — Technology Requirements

To Accelerate Commercialization of Hydrothermal Energy

Background:

- 48 People Surveyed from 5 Industries
  (16 Developers, 9 Utilities, 4 Financiers, 10 A&E, 9 Direct Heat)
- Ranked 26 Technology Requirements to Accelerate Geothermal

Some Results

- Environmental Controls Ranked 10th Among Technology Areas
- 75% of Respondents Felt Non-Technical Issues Are More Important
- "Faster Resolution of Environmental Restraints" Was 4th Most Frequent Non-Technical Issue Mentioned

IGCC Chairman, Dr. Ruth Davis, Response

- Env. Control Panel Provide, at Earliest Possible Date, Specific Recommendations for Areas of Research to Be Done
- Kind of Research
- Levels of Funding
- Suggestions as to Agencies

Present Status

- Panel Report No. 1
  - Briefed to I.G.C.C.
  - Reviewed by Industry
- Panel Report No. 2
  - Project List Being Developed
  - Input from Industry, Others
  - Briefing to I.G.C.C. in September
  - Will be Future, Interagency Program
- Other Working Groups/Regulatory

Induced Seismicity

- High Temp. Geothermal Resources are Often Associated with Active Zones.
- Induced (Man-Made), Indistinguishable from Natural Quakes.
- The Only Recognizable Discriminating Criterion is Correlation With Engineering Activity.
- Seismicity Can be Induced by Massive Withdrawal and Injection.
- Exploitation of Geothermal Resources May Very Likely Result In Local Seismicity and Quite Possible Produce Damaging Quakes.

Induced Seismicity

Present Funding

FY 79 (Carryover)	$305K
Fy 80	$ 50K
Obligated	$355K

Present Obligations (Thru NVO)

1. **Univ. of Nevada (Reno) - Dixie Valley**
   - [redacted] [redacted]
2. **U.S.G.S. - Geysers**
   - **Monitor Seismic Phones & Analyze**
   - **Source Characteristics**
   - **Modeling Study** Est. $180K
3. **LBL - East Mesa**
   - **Single Downhole Seismometer/Telemetry** Est. $5K
4. **Holmes & Narver**
   - **Project Management Service** Est. $35K

Subsidence

- Land Deformation May Follow Removal of Amounts of Fluid From Reservoirs, or Oil and Gas Reservoirs
- Environmental Impact is Significant Only When Subsidence Results In Damage to Man-Made Facilities or Ecosystem Habitat
- One Foot Drop In Ground Level May Not be Significant In Middle of Desert, While Same Adjacent to A Body of Water May Result In Flooding
- Subsidence Will be Controlled by Reinjection, Regulated Fluid Withdrawal and Monitoring Surface and Sub-Surface Movements

Present Subsidence Program

Funding About $850K Distributed → HQ → SAN → LEL → Including Subcontractors

4 Independent Elements

1. Subsidence Characterization
    - Examples of Subsidence and Effects
    - Case Histories (Geysers, Wairakei, New Zealand)
2. Subsidence Mensuration
    - Guidelines for Surface Monitoring Surveys to Establish Background Rates and Monitor Possible Deformation Induced by Geothermal Development
3. Subsidence Prediction
    - Dependent Upon Understanding Response of Geologic Materials and Systems to Natural and Man-Made Stress Fields
4. Reservoir Operating Policy
    - Policy to Minimize Effects of Subsidence

Air Emissions - Abatement

- H_2S Is A Major Environmental Concern
- Offensive Odor More Concern Than Toxicity
- States Vary In Ambient Standards for H^2S
  - .003 PPM (1-Hour Avg.) In New Mexico
  - .03 PPM (1-Hour Avg.) In California
- Problem of H_2S Emissions Focused at Geysers Power Generation Site
- Problem Compounded by Fact that 1st 500 MW was Built Without H_2S Controls - Retrofit
- Other Substances Emitted During Operations
  - CO, NH_3, Radon, Hydrocarbons, Mercury Vapor, and Boron

    None Yet Significant
- 3 Efforts Show Promise for Commercial Scale Application

- "Downstream" (Applied After Turbine)

  (1) Iron Catalyst Process

  - Ferric Sulfate Added to Condesate Cooling Towers, Oxidizing H_2S In Aqueous Phase
  - Noncondensable Gases Ducted into Cooling Towers And Scrubbed by Falling Water
  - Ferric Ions are Regenerated and Sulfur Produced
  - Sulfur Sludge Impure and Presents A Toxic Solid Waste
  - H_2S Removal Efficiency Low (Around 60%)
  - Improvement with Addition of Hydrogen Peroxide And Sodium Hydroxide (Around 60%)

(2) Stretford Process

- Steam Scrubbed with A Regenerable Aqueous Solution Containing Sodium Compounds and an Acid. Pure Sulfur Produced

- Drawback - Although It Can Virtually Remove All H^2S It Contacts, It Cannot Treat H_2S Dissolved In Condensate This Portion Emitted at Cooling Tower Unless Treated This May be Up to 40% of Total

- Thus, Condensate May Require Treatment, Perhaps with Hydrogen Peroxide

- Upstream Process

  (3) EIC Process

  - Only Demonstrated Process Partly Supported By Government Funds
  - Successful Testing of 10,000 Lbs. of Steam/Hr. (1/10th Scale Demonstrated) at Geysers Removing More Than 95% of H_2S from Raw Steam
  - Steam Scrubbed with Copper Sulfate to Produce Copper Sulfide and Ammonium Sulfate Copper Sulfate is Regenerated from Copper Sulfide And Clean Steam Sent to Turbine
  - Commercial Process Could be Possible In 3 Years
  - Process Has Advantage of

    (1) Control of Emissions During Steam Stacking

    (2) Reducing Corrosivity of Steam to Turbine Blades And Other Plant Components

    (3) Control of Ammonia and Boron Emissions

  - Problems
    - Material - Crevice Corrosion During Tests
    - Anticipated Resolved by Titanium Clad Reaction Vessel Delivery of Titanium Critical

UOP (Universal Oil Products) Process

- Applied Research Stage
- DGE Has Funded A Catalytic Absorption System to Control H_2S "Upstream" from Either A Vapor or Liquid Dominated Geothermal Resource

Contract Signed	9/79
Testing Began	11/79
Cost to DOE	$188K
Final Report	9/80

(Extension Contingent Upon Results)

- Project Becoming Involved with Detailed Chemistry And Materials Questions

FY 1981 Program

- H_2S Abatement - Priority
- Injection Monitoring
- Solid Waste
- Subsidence - Implementation
- Seismicity - Monitoring/Anal.
- Analysis - Support
- Bibliographic/Information Base

$2.6 M

It is the Assistant Secretary for Resource Assessment that is responsible for the decision.

An environmental impact statement goes beyond environmental issues, and looks also at socioeconomic impacts. It also goes beyond federal regulations and considers state and local requirements, in an attempt to combine impact statements. It also covers additional scenarios to the proposed action, such as expansion.

One of the major issues at the Baca project was religious freedom. This was a surprise, but it should not have been. Union Oil was not required to be as thorough in these matters as the government.

What do you do to avoid Baca type problems in the future? Preliminary assessments are supposed to do this. The Hot Dry Rock project is worried they will get swept up with the dust raised at Baca. So far, the Indians have made a distinction. As soon as Art Wilbur began work at Baca he aggressively tried to get local involvement, but he was 8 years too late. The National Environmental Policy Act (NEPA) process requires early involvement. At the end of the NEPA process there is sometimes an emotional problem that must be dealt with emotionally.

Often the NEPA process is used with ulterior motives. If the government accepts religious claims on good faith it runs the risk of having numerous projects stopped categorically. The water rights issue at Baca was perfectly real, and there was insufficient data to deal with it initially.

Oak Ridge National Laboratory - Lance Mezga

Oak Ridge prepares environmental impact statements and environmental assessments for the Department of Energy and for the Nuclear Regulatory Commission. Document review and concurrence comes from the Office of Environmental Compliance and Overview. Oak Ridge has prepared assessments for the hydrothermal commercialization program, geopressure, hot dry rock, the Baca project, etc.

The Marlin Torbett et al hospital project required two years to finalize the environmental assessment because of delays in reviewing the document by EV/NAD. A ""Finding of No Significant Impact" was ultimately prepared. The Marlin Torbett project cost the government $100,000 and, in addition, the environmental assessment cost approximately $40,000.

There were six important issues at Baca: (1) Indian religious freedom, (2) depletion of flow of the Jemez River, (3) conflict with possible future public acquisition of the land, (4) endangered species, (5) conflict with a National Natural Landmark and (6) coordination with Federal, state, and local agencies. The Forest Service is currently examining the transmission line corridor.

In conjunction with the California Energy Corporation, the Navy is developing a 50Mw power plant at Coso with a loan guaranty. Oak Ridge is looking at this. If there is a chance of significant impact, an environmental impact statement must be prepared.

ORNL ENVIRONMENTAL
IMPACT SECTION ASSESSMENT ACTIVITIES

- NUCLEAR - FISSION
- NUCLEAR - FUSION
- FOSSIL - COAL, OIL, GAS, SYNFUELS
- GEOTHERMAL
- SOLAR - BIOMASS
- DISTRICT HEATING
- CONSERVATION

NATURE OF ORNL SUPPORT TO THE
DEPARTMENT OF ENERGY
GEOTHERMAL ENERGY PROGRAM

- PREPARE EA'S AND EIS'S
- PREPARE FLOODPLAIN WETLANDS ASSESSMENTS
- ASSIST IN COORDINATING OTHER AGENCY ENVIRONMENTAL REVIEW REQUIREMENTS
- PROVIDE OTHER ENVIRONMENTAL SUPPORT

GEOTHERMAL ENERGY PROGRAMS
ASSISTED BY ORNL

DIVISION OF GEOTHERMAL ENERGY - HEADQUARTERS

- HYDROTHERMAL (INCLUDING DIRECT HEAT APPLICATION)
- HOT DRY ROCK
- GEOPRESSURE

SAN FRANCISCO OPERATIONS OFFICE

- GEOTHERMAL LOAN GUARANTY
- ENVIRONMENTAL SUPPORT FOR BACA GEOTHERMAL DEMONSTRATION PROJECT

HYDROTHERMAL ENVIRONMENTAL ASSESSMENT
PROJECTS -- FY 1980

- MARLIN TORBETT - HUTCHINGS - SMITH MEMORIAL HOSPITAL
- HEBER BINARY CYCLE GEOTHERMAL DEMONSTRATION PROJECT
- BACA GEOTHERMAL DEMONSTRATION PROJECT

GEOPRESSURE ENVIRONMENTAL ASSESSMENT
PROJECTS -- FY 1980

- GLADYS MCCALL WELL TEST
- LAFOURCHE CROSSING WELL TEST
- SOUTHEAST PECAN ISLAND WELL TEST
- WILCOX - TUSCALOOSA SUBPROGRAMMATIC
- SWEET LAKE WELL TEST
- DOW PARCPERDUE WELL TEST

GEOTHERMAL LOAN GUARANTY
ENVIRONMENTAL ASSESSMENT PROJECTS
-- FY 1980

- OREGON TRAIL MUSHROOMS DIRECT HEAT APPLICATION
- SOUTH GEYSERS WELL FIELD DEVELOPMENT
- SOUTHERN CALIFORNIA EDISON HEBER 50MW POWER PLANT
- COSO HOT SPRINGS WELL FIELD DEVELOPMENT AND POWER PLANT
- CRESCENT VALLEY ETHANOL PROJECT/
- SOUTH BRAWLEY EA SUPPLEMENT

Coastal Environments is assisting ORNL in preparing geopressure environmental impact statement and assessments. Louisiana State University and the University of Texas design monitoring programs for every geopressure well for the Division of Geothermal Energy. Open ocean discharge of brine does not appear to be a viable option at this time because of permit requirements. Getting them may cost more than injection.

Many hot springs are national historic sites and depletion of their flow is inevitable in some geothermal projects. At Brady Hot Springs plans were all set to drill an archaeological site.

Lawrence Berkeley Laboratory - Norman Goldstein

Dr. Goldstein discussed subsidence research at Lawrence Berkeley Laboratory. This is summarized in the draft document "Geothermal Subsidence Research Program Plan and Review," LBL-11271, Earth Sciences Division, Lawrence Berkeley Laboratory, University of California, Berkeley, Calif., July 1980. The following viewgraphs, excepted from the document above, outline the Lawrence Berkeley Laboratory program.

Discussion of the Committee

There was a discussion of whether this committee should continue meeting, at least in the present format. The conclusion was that the committee will meet twice next year. The first meeting will be a 3 day meeting in Washington, D.C., in December or January. The Division of Geothermal Energy and the Regional Representatives will meet with the group for at least one day, and the Division of Geothermal Energy will brief the group on the pertinent aspects of its program. In addition, there will be regular laboratory reports. The second meeting will be in some place relevant to geothermal.

Los Alamos Scientific Laboratory - Mort Smith

To remedy the casing-collapse problems in hot dry rock hole EE-1 cost about $8,000 per day rig time plus about $8,000 per day for fishermen and other services. The cost of the unsuccessful Sigma Mesa hole came from the hot dry rock program. The $2.5 million from Japan hasn't come yet. There are very tight financial conditions in the hot dry rock program.

The Sigma Mesa hole was drilled to heat the laboratory. The basement there is at about 10,000 ft. probably overlain by cavernous limestones that might be a good aquifer.

Testing continues on the previously reported hot dry rock loop. At 1300 psi pumping pressure we get 100 gpm flow or 2.5 MW of energy. The temperature hasn't dropped yet, indicating a heat transfer area of at least 120,000 m^2. Eventually we want to create a 1,000,000 m^2 heat transfer surface.

The EE-2 well has a temperature gradient of 64°C/km average; 89°C/Km in the sediments and 53°C/km in the top 1000 ft of basement, increasing steadily with depth to more than 90°C/km at 14,000 ft.

(Geothermal Subsidence Research

Table I The Formal Structure of the Original GSRP (1977)

Elements	Research Category	Projects
A. Characterization of Subsidence	1. Case Histories of Subsiding Areas and Geothermal Subsidence Potential Maps	1. Land Deformation Case Histories 2. Geothermal Subsidence Potential Maps
	2. Field Measurement Programs	1. Criteria to Distinguish Between Potential Subsidence Caused by a Geothermal Project and Subsidence Due to Other Causes 2. Monitor Horizontal and Vertical Displacement
	3. Direct Monitoring Instrumentation	1. Assess the State of the Art of Measurement 2. Develop Prototype Instruments and Conduct Field Tests
	4. Environmental and Economic Effects	1. Data Collection 2. Investigate Effects
B. Physical Theory of Subsidence	5. Physical Processes of Subsidence	Same as Research Category
C. Properties of Materials	6. Indirect Techniques to Estimate Subsidence at Depth	1. Assess Indirect Techniques 2. Develop Prototypes
	7. Laboratory Testing	Same as Research Category
D. Simulation of Subsidence	8. Subsidence Models	Same as Research Category
E. Subsidence Control	9. Reservoir Operational Control Policy	1. Industry Evaluation 2. Guidelines and Procedures

ELEMENT	MONITORING AND MEASUREMENT	PREDICTION	IMPACT ASSESSMENT
CATEGORIES	o Direct monitoring	o Subsidence models	o Case Histories
	o Indirect techniques to estimate compaction at depth	o Physical processes of subsidence	o Environment and economic effects
	o Field (in-situ) measurement		

Figure 2 Current Research Elements and Categories in the GSRP

TABLE II

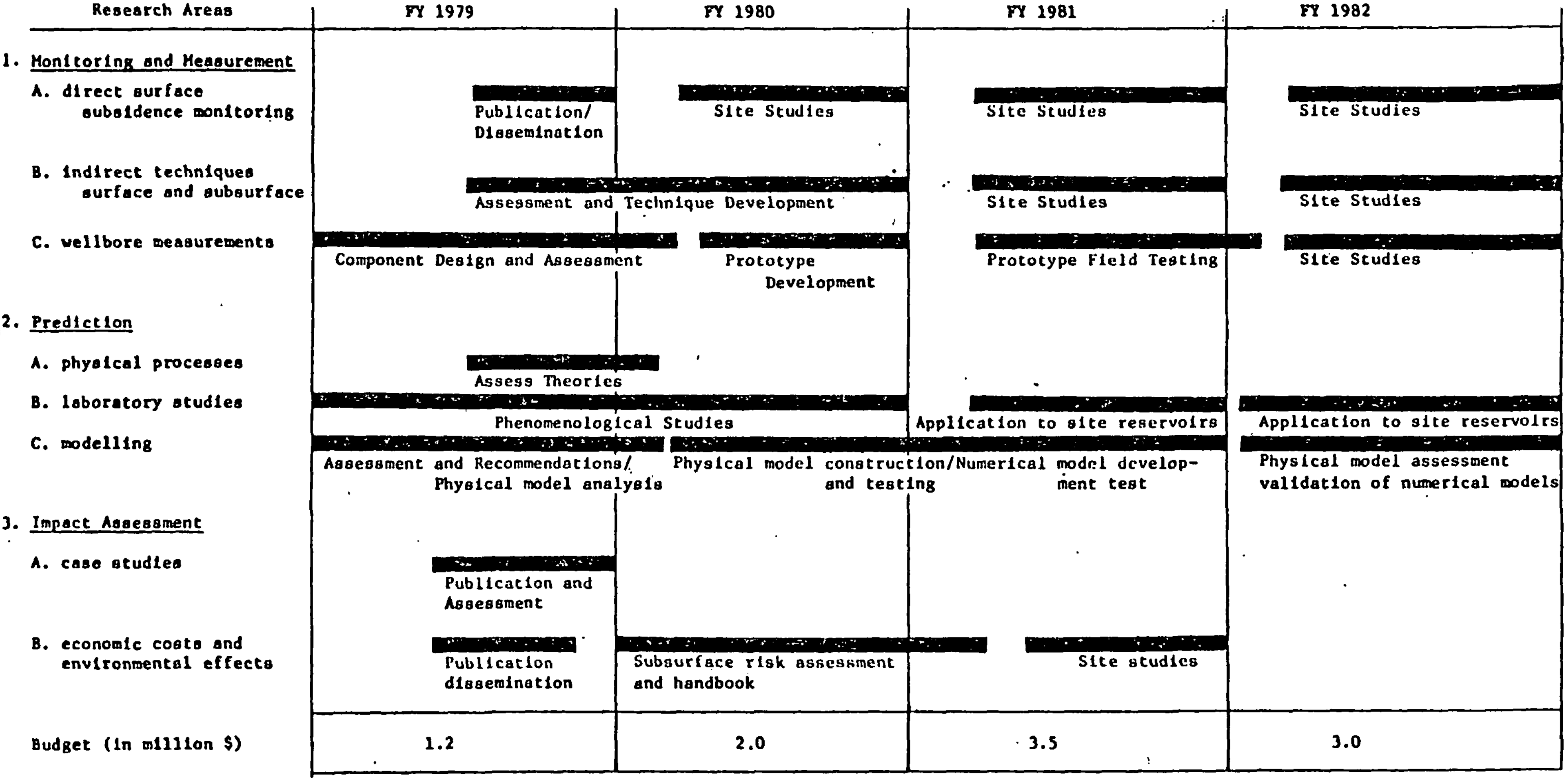
GEOTHERMAL SUBSIDENCE RESEARCH PROGRAM COSTS

($000)

	FISCAL YEAR			
	1978	1979	1980	1981 (estimated)
PROGRAM MANAGEMENT	150	200	130	140
LBL IN-HOUSE RESEARCH	50	125	95	150
SUBCONTRACTS				
PREDICTION	149	503	255	200
MEASUREMENT/MONITORING	189	264	238	230
IMPACT ASSESSMENT	196	22	220*	100
	734	1114	938	820

* Geopressure Subsidence Research

Figure 3 GEOTHERMAL SUBSIDENCE RESEARCH PLAN, FY 1979 THROUGH FY 1982



Research Areas	FY 1979	FY 1980	FY 1981	FY 1982
1. Monitoring and Measurement				
A. direct surface subsidence monitoring	Publication/ Dissemination	Site Studies	Site Studies	Site Studies
B. indirect techniques surface and subsurface	Assessment and Technique Development		Site Studies	Site Studies
C. wellbore measurements	Component Design and Assessment	Prototype Development	Prototype Field Testing	Site Studies
2. Prediction				
A. physical processes	Assess Theories			
B. laboratory studies	Phenomenological Studies		Application to site reservoirs	Application to site reservoirs
C. modelling	Assessment and Recommendations/ Physical model analysis	Physical model construction and testing/Numerical model development test		Physical model assessment validation of numerical models
3. Impact Assessment				
A. case studies	Publication and Assessment			
B. economic costs and environmental effects	Publication dissemination	Subsurface risk assessment and handbook	Site studies	
Budget (in million $)	1.2	2.0	3.5	3.0

TABLE IIIa

RECOMMENDED

SUBSIDENCE PROGRAM FY 1981

HYDROTHERMAL SUPPORT BRANCH

MONITORING AND MEASUREMENT

(1) Establish new or continue ongoing leveling and gravity baseline studies at Heber, Brawley, Baca, and Cerro Prieto geothermal fields in the Salton Trough.

(2) Exercise the new Automatic Seismic Processor (ASP) at geothermal reservoirs and relate seismic data to compaction/subsidence.

(3) Support releveling of the Imperial Valley network.

PREDICTION

(1) Evaluate numerically subsidence potentials at East Mesa, Cerro Prieto, Wairakei, The Geysers using new data on core compressibilities leveling and gravity.

(2) Evaluate creep compaction potential of cores from new wells at the Heber geothermal field.

IMPACT ASSESSMENT

(1) Study the prevention or control of subsidence by means of fluid injection via the TERZAGI computer code.

Table IIIb

RECOMMENDED

SUBSIDENCE RESEARCH PROGRAM FY 1981

ADVANCED TECHNOLOGY BRANCH, GEOPRESSURE GEOTHERMAL

MONITORING AND MEASUREMENT

(1) Establish the rates and distributions of subsidence from natural and cultural activities; compare these to measured/or expected geothermal induced subsidence.

(2) Monitor ground surface deformation and induced seismicity at all new design test wells.

PREDICTION

(1) Study shale dewatering as a contributor of geofluids by means of (a) well data analyses to determine caprock leakage and system compressibilities, and (b) laboratory measurements on cores.

(2) By means of computer simulations and field monitoring, estimate/predict the effect of growth faults on surface deformation under different production/injection scenarios.

(3) Test the accuracy of numerical codes for subsidence prediction by means of iterative calculations using fluid production, rock property data and observed subsidence at the new design test wells.

IMPACT ASSESSMENT

(1) Estimate the immediate economic loss and future (long-term) economic impacts due to subsidence at the design test wells.

(2) Investigate and evaluate cost and feasibility of subsidence mitigation or connection methods; e.g., diking around wells.

TABLE IV

PROJECTS CONTEMPLATED OR UNDERTAKEN DURING FY 1979-80

ELEMENT	CATEGORY	PROJECT	COSTED ($0000)
A. Monitoring and Measurement	Direct Measurement	1. Hostile Environment Development (Sandia et al.)	224
		2. Radioactive Bullet Logging Assessment (University of Texas)	40
	Indirect Measurements	1. Precision Gravity (C.S.U., Long Beach)	25
		2. Seismological Investigations (U.C., Berkeley)	107
Prediction	Theory	1. Theory of Subsidence (Univ. of Illinois & U.C., Berkeley)	63
		2. Assessment of Numerical Codes and Theory (Golder Associates)	286
		3. Compaction and Subsidence Modeling (LBL)	220
	Laboratory Studies and Physical Modeling	1. Creep Tests, Elastic Modeling of Reservoir Rocks (TerraTek)	416
		2. Centrifuge Tests (Colo. Sch. of Mines)	158
		3. Large-Scale Physical Modeling at LBL	not funded
C. Impact Assessment	Case Histories	1. Chocolate Bayou Case Study Supplement (EDAW-ESA)	20
	Environment and Economic Effects	1. Compilation of Environment and Economic Effects at specific Sites	not funded
		2. Subsidence Handbook	not funded
		3. Geopressure-Geothermal Research Plan (EDAW-ESA)	220

Los Alamos is publishing a geothermal gradient map for the United States. The money crunch is causing other contracts for assessment work to be closed out. In response to the recent enthusiasm for electricity, low temperature work is being de-emphasized.

We have a skid mounted binary power plant. We put in 50 gpm of 137°C water and get 60 kw of electricity out. On strict economic grounds, it would be a disaster. The transportation and installation of the unit caused a lot of leaks in the freon system.

In siting the hot dry rock system, it was clear that the geology was less complicated on the side of the caldera furthest from the laboratory, because it was outside of the Rio Grande Rift. Two possible geologic hazards were man-made earthquakes (for which you need a natural fault) and aquifer contamination.

Each Indian Pueblo has a "center of the world", the exact meaning of which is unclear to white people. The laboratory archaeologist (Charley Steen) was unable to find any sites or artifacts at Fenton Hill, which is remarkable.

Fenton Hill had been burned, logged, and otherwise messed up in a way that made the potential impact of hot dry rock look benign to the Forest Service, which issued a special use permit.

There had been a lot of hydrologic investigation in the area. Water quality has been monitored in springs and streams, with no notable result.

The area around Fenton Hill has been saturated with seismographs (with a sensitivity to M_L = .5; -1 for close in quakes). There is a regional net that covers N. New Mexico. Most quakes come from about 20 km west of the site. New Mexico is relatively quiet. We have detected microseismic events associated with opening cracks. Trucks and earthquakes can be seismically distinguished.

An environmental study area surrounds the hot dry rock site. The environmental group at the Department of Energy has funded a case study of the area. Hot dry rock has been pretty benign.

Environmental monitoring has been piggybacked on a lot of experiments and this seems to be very useful.

Johns Hopkins University - Fletcher Paddison

The Department of Energy's Division of Geothermal Energy (DOE/DGE) has an extensive program on the Atlantic Coastal Plain to assess and target geothermal resources, Ref. 1. A complementary program defines the detailed energy markets, the practicality and economics of geothermal energy to satisfy the market demands, Refs. 2,3, and 4. These programs are evoking considerable interest in the potential uses of geothermal energy. DOE/DGE has drilled a deep well in Crisfield, Maryland, that demonstrated availability of geothermal water at 135°F. Reference 5 documents an analysis of the use of this resource for space heating.

A solicitation for a second deep well to be cost-shared and used thereafter for energy production in the Delmarva area was published this spring. There were not as many respondents to the solicitation as had been hoped, and a survey of the expected respondents is in process to identify the reasons. The State of Delaware was awarded the program and a deep (approximately 5000 to 7000 ft) well is planned at Lewes, Delaware, to be used initially by the Barcroft Corporation to recover magnesium hydroxide, an ingredient used in Maalox. Eventually, dependent upon well productivity, other uses may come on line.

Other geothermal activity in the East is as follows.

DOE/DGE is funding the Virginia Polytechnic Institute and State University (VPI&SU) to drill a 1000 ft gradient well at Kings Bay, Georgia, at the Trident Submarine Support Base. If the projected temperatures are interesting and have potential for being integrated into a planned 100 million dollar coal-fired base heating plant, currently under design, the Department of Defense will join with DOE to drill a well to basement to confirm temperature and water availability at depth.

DOE/DGE is funding VPI&SU to drill a slim hole at Cove Point, Maryland, to confirm the availability of water and the temperature near the basement, i.e., 3500 ft. Cove Point is the Columbia LNG Corporation terminal for Algerian liquefied natural gas. Technical assistance studies have shown that deep groundwater can displace large quantities of gas currently used to gasify the liquid natural gas. The temperature of the groundwater is not important, but the permeability of the deep sand formation will dictate how much gas can be displaced with geothermal groundwater. A preliminary analysis of the potential of groundwater is to be found in Ref. 6.

DOE/DGE together with the New York State Energy Research and Development Authority (NYSERDA) is funding the drilling of a deep, i.e., 5000 ft, confirmation well in Montezuma, New York. The Standard Brands, wet corn mill plant, can use geothermal water as a first step in the displacement of oil in the manufacture of fructose corn sugar, Ref. 7.

The market survey of the mid-Atlantic Coastal Plain is complete and the survey of the Southeastern Coastal Plain is just starting.

A current unknown on the coastal plain is the eventual cost of production and reinjection geothermal wells. Oil field drillers can, but do not commonly, use gravel pack and screen completions in wells required in the unconsolidated coastal plain sands, and water well drillers, who commonly use these techniques, are not used to drilling to the depths required for geothermal wells. Accordingly, experience is needed to establish techniques and confidence which will result in cost estimates. Currently the range runs from $35 to $80/ft up to 7000 ft.

The attached viewgraphs list all the geothermal and related programs in the Eastern U.S. active during FY 1980.

<u>References</u>:

1. J.K. Costain, et al, "Evaluation and Targeting of Geothermal Resources in the Southeastern United States. Progress Report," Series VPI&SU-5648 1-7.
2. W.J. Toth, "Geothermal Energy Market Study in the Atlantic Coastal Plain, Definition of Markets for Geothermal Energy in the Northern Atlantic Coastal Plain," APL/JHU GEMS-002, May 1980.

EASTERN GEOTHERMAL PROGRAMS

ATLANTIC COASTAL PLAIN

- RESOURCE EVALUATION AND TARGETING — VPI&SU
- FORMATION OF STATE TEAMS — JHU
  - DELAWARE – FY 80
  - VIRGINIA, MARYLAND } IN PROCESS – FY 81
  - GEORGIA, NORTH CAROLINA, SOUTH CAROLINA, NEW YORK } TO FOLLOW FY-81
- LEGAL, RULES AND REGULATIONS
  - MD GEOTHERMAL RESOURCES ACT – 1978
  - DE GEOTHERMAL RESOURCES ACT – VETOED 1980
  - NCSL LEGISLATIVE WORKSHOPS
    - VA, DE REVISION, MD REVISION } 1980-81
    - GA, NC, SC, PA } TO FOLLOW
- RESOURCE CONFIRMATION AND ENGINEERING — DGE
  - DEEP WELL, 4200 FT, CRISFIELD, MD – 1979
  - SECOND DEEP WELL, 7-8K FT, DELMARVA BARCROFT CO., LEWES, DE — FY 1980
  - DEEP WELL, 3500 FT, COVE POINT, MD — FY 1980
  - GRADIENT WELL, 2000 FT, KINGS BAY, GA — FY 1980
    POSSIBLY FOLLOWED BY WELL TO BASEMENT JOINT DOD/DOE
  - DEEP WELL, 5000 FT, MONTEZUMA, NY – JOINT DGE/NYSERDA — FY 1980
  - USER-COUPLED RESOURCE CONFIRMATION PROGRAM — FY 1981

EASTERN GEOTHERMAL PROGRAMS

ATLANTIC COASTAL PLAIN (continued)

- MARKET ASSESSMENT — JHU
  - AREA NEW JERSEY TO NORTH CAROLINA COMPLETED
    - REPORT IN PRINTING
  - AREA NORTH CAROLINA TO GEORGIA CY 1980
- ECONOMICS OF EASTERN GEOTHERMAL ENERGY — JHU
  - SEVERAL CODES OF VARYING COMPLEXITY AVAILABLE
  - COSTS
    - UTILIZATION FACTOR OF WELL } CRITICAL
    - RESOURCE CHARACTERISTICS } CRITICAL
    - ROYALTY PAYMENTS – NOT A PROBLEM
    - POTENTIAL LITIGATION RE OWNERSHIP – DISINCENTIVE
    - OPTIMIZATION NECESSARY THROUGH CASCADE USE OR PEAKING SYSTEM
    - WELL COSTS NOT ESTABLISHED
- PRDA – GEOTHERMAL UTILIZATION FOOD PROCESSING INDUSTRY, SALISBURY, MD – COMPLETE — CAMPBELL SOUP & BURNS & ROE

TECHNICAL ASSISTANCE

SPACE HEATING

CRISFIELD HIGH SCHOOL, SOMERSET CO., MD
PITTSVILLE ELEMENTARY SCHOOL, WICOMICO CO., MD
NAVAL AIR REWORK FACILITY, NORFOLK, VA.

PROCESS HEAT

MULTI-USE, LEWES, DE
MARICULTURE – OYSTERS AND CLAMS, CHESAPEAKE BAY, MD
VAPORIZING LNG – COVE POINT, MD
CLINTON CORN PRODUCTS – FRUCTOSE, MONTEZUMA, NY

EASTERN GEOTHERMAL PROGRAMS

ATLANTIC COASTAL PLAIN (continued)

– HOT DRY ROCK EASTERN PROGRAM	LASL/CONTRACTORS
DELMARVA STUDY – CRISFIELD TO WALLOPS ISLAND STUMPY POINT, NORTH CAROLINA NEW YORK NEW HAMPSHIRE PENNSYLVANIA AND OHIO NEBRASKA SOUTHEASTERN COASTAL PLAIN WEST VIRGINIA ARKANSAS ILLINOIS/INDIANA	
– USGS/WR – REGIONAL AQUIFER PROGRAM	USGS/WR

EASTERN GEOTHERMAL PROGRAMS

OTHER EASTERN AREAS

- RESOURCE ASSESSMENT PROGRAMS — DGE/STATES/VPI/LASL

DELAWARE	KANSAS	OHIO
ALABAMA	MISSOURI	NEW YORK
ARKANSAS	NEBRASKA	WEST VIRGINIA

- INITIAL DEFINITION OF SELECTED GEOTHERMAL RESOURCES — DGE/GRUY

ILLINOIS	VIRGINIA
IOWA	WEST VIRGINIA
INDIANA	MASSACHUSETTS
MISSIOURI	MICHIGAN

– IDENTIFICATION OF EASTERN COUNTIES WITH RESOURCE AND MARKET MATCH – REPORTED	JHU
– LOAN GUARANTY AND GEOTHERMAL FINANCE BROKER	EG&G
– GEOTHERMAL APPLICATION ASSESSMENT FOR TVA REGION OF SOUTHEAST	ORAU
– TECHNICAL INFORMATION INTERCHANGE MEETING (OCT '80)	JHU
– STATE FACT BOOKS (50 STATES)	JHU

3. William Barron, "Geothermal Energy Market Study on the Atlantic Coastal Plain, A Review of Recent Energy Price Projections for Traditional Space and Process Heating Fuels in the Post-1985 Period," APL/JHU GEMS-007, April 1980.
4. W. Barron, P. Kroll, and W.J. Toth, "GRITS: A Computer Program for the Economic Evaluation of Direct-Use Applications of Geothermal Energy," APL/JHU GEMS-008, June 1980.
5. "The Crisfield, Maryland Well and Geothermal Energy," APL/JHU Letter Report CQO-2544, 12 November 1979.
6. "Report on Technical Assistance for Columbia LNG Corporation," APL/JHU Letter CQO-2850, March 28, 1980. Also summarized in Paper by K. Yu and F.C. Paddison, "Technical Assistance - Hydrothermal Resource Application in the Eastern U.S.," Geothermal Resources Council, Transactions Vol. 4, pp 629-631, September 1980.
7. F.C. Paddison and A.M. Stone, "Geothermal Energy in Cayuga County, New York," APL/JHU QM-80-082, May 28, 1980.

Oak Ridge National Laboratory - John Michel

The vertical fluted tube is a factor of 2 better (in Btu/hr/ft of 1" diameter tube) than conventional smooth heat exchanger tubes. A condenser based on these principles will shortly be installed at the 60 Kw binary plant at Raft River. It will be used both with pure isobutane from a conventional exchanger and with a direct contact heat exchanger that contaminates the isobutane with noncondensible gases and water. A second, much larger condenser is being fabricated and will be used with the Lawrence Berkeley Laboratory 500 Kw binary plant at E. Mesa, Calif.

The Arkansas Power and Light 100 Kw demo plant is on site but the direct contact condenser doesn't work well because of the accumulation of non-condensibles and the problems related to venting.

We have been looking at water requirements for geothermal power plants. The number of acre ft. per mw per year goes down as the resource temperature increases. There is not much difference between flash steam and binary, although in theory binary generation requires more cooling water. As much as $1750 per acre foot has been paid for power plant cooling water, vs $35 per acre ft. for irrigation water.

Oak Ridge has a waste heat applications project, for water around 140°F. We are surveying industry to find potential applications for waste heat. We have a district heat applications and management contract. We are developing advanced heat pumps, including ground source heat pumps. The ocean thermal energy conversion program is taking over ocean geothermal.

Idaho National Engineering Laboratory - John Morfitt

A number of problems have occurred with downhole pumps. The Peerless line shaft pumps worked a few days before developing bearing problems. The REDA pumps worked a few days before developing electric insulation problems.

These were 650 HP pumps working at about 130°C. After being repaired, one pump lasted only 14 seconds. Another failed on the test stand at the factory. It costs about $30,000 to set the pumps. Small (60 HP) pumps work okay if limited experience elsewhere is typical. The manufacturers think they can make the pumps work. We believe quality control may be one of the chief problems.

The 60 KW binary plant is now fully automated and runs 90 percent of the time. It is inexpensive to operate. Geothermal water is used for cooling water, but treatment is necessary to prevent corrosion in the condensers.

Vendor contractor problems will delay the completion of the 5MW plant until October.

The low temperature direct use program has been nearly wiped out by lack of funding. Refrigeration and fluidized bed heat exchanger work has stopped. The Idaho National Engineering Laboratory believes direct use and space heat are more relevant uses of geothermal than electricity.

We are doing a wetlands study to see if surface flooding is an alternative to injection.

Circulate

PNL-SA-14847

SUBJ
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GEOTHERMAL CHEMISTRY IN-LINE INSTRUMENTATION

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April 1987

Presented at the
Geothermal Program Information Meeting,
Washington, D.C., U.S. Department of Energy
April 14-15, 1987

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GEOTHERMAL CHEMISTRY IN-LINE INSTRUMENTATION

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Richland, Washington 99352

ABSTRACT

During Fiscal Years 1986 and 1987, Pacific Northwest Laboratory (PNL) operated under declining budgets to achieve several major milestones:

- A Site Access Agreement with San Diego Gas and Electric Company was signed and since renewed for Fiscal Year 1987. The agreement allows PNL access to the Heber Binary Plant for conducting experiments.
- The PNL field laboratory was moved from East Mesa to the Heber Binary Plant.
- A subcontract was let to a commercial supplier of pH probes to build advanced transistor-based pH sensors.
- A field test determined response of the transistor-based pH probes to Heber brines.
- A filter test was performed to look at scaling tendencies of the Heber plant brine if it were cooled below 150°F.
- Two prototype particle counters based on ultrasonic sound and a laser beam scattering were tested in the laboratory and subjected to one field test.

INTRODUCTION

Geothermal activities at Pacific Northwest Laboratory have always emphasized understanding of brine chemistry as it relates to potential scaling, corrosion, or reinjection problems. Development of instruments to aid in this understanding has been a major goal of all the work. Past work involved extensive corrosion monitoring and instrument testing at the Magma Electric Company East Mesa Plant. Corrosion probes, conductivity meters, redox probes, pH probes, CO_2 probes, particle meters, and leak detectors were all developed and evaluated there.

During 1986, PNL completed a Site Access Agreement to install two trailers on site and test connections on the inlet and outlet brine line at the Heber Binary Demonstration Plant.

In Fiscal Year 1987, tests were started at the Heber Plant. Funding levels limited activities to testing transistor pH sensors, on-line and particle analyzers, and a small study of suspended solids in the geothermal brine at the Heber Plant.

Field Test of Transistor pH Sensor

The pH sensor subcontractor developed five prototype pH sensors and two CO_2 partial pressure sensors. Both probes are based on Ion Sensitive Field Effect Transistor (ISFET) technology. The subcontractor designed and built the probes as well as tested them in autoclaves at their own laboratories.

The first field test was performed by PNL in January 1987. PNL built the test stand connected to the Heber Plant inlet and outlet brine. The test stand could evaluate four probes simultaneously. Capabilities existed for passing plant inlet brine, plant outlet brine, or a buffer solution past each sensor. Buffers of pH 4, 7, and 10 were prepared for the field test. Temperature of any of the fluids could be controlled using the heat exchangers.

Fluid temperatures ranged between ambient (40°F) and the plant inlet brine temperature (350°F).

Of the five pH probes delivered by the subcontractor, three failed early upon exposure to low-temperature (150°F) plant outlet brine. The other two survived a calibration with buffer solutions of pH 4 and pH 7. Both pH solutions were circulated at temperatures of ambient, 145, 240, and 325°F. The two good probes lasted several hours in the plant outlet brine, but failed after less than an hour in the high-temperature brine. Figure 1 shows the laboratory and field calibrations for the pH sensor. The voltage offsets between the field and laboratory data are due to differences in reference electrodes used in the laboratory and the field. The important similarities are the slope of the curves and the gaps between pH 4 and pH 7 lines. The vertical gap between the two calibration lines at a given temperature indicates the mV/pH unit output of the probe. Both of the probes reproduced pH values quite closely in the field to what had been observed in the laboratory.

Subsequent analysis of the failed pH probes indicated the failures were due to a leak in a glass-to-glass sputtered metal seal and were not in the transistor sensor itself. Under the high pressure, water got into the probe and shorted the leads. The subcontractor has indicated a different design could eliminate this seal.

Scaling Tendencies of the Heber Brine

Any time a saturated brine is cooled, various minerals will reach their saturation limit and either crystallize on heat transfer surfaces or remain as particles suspended in the brine. These

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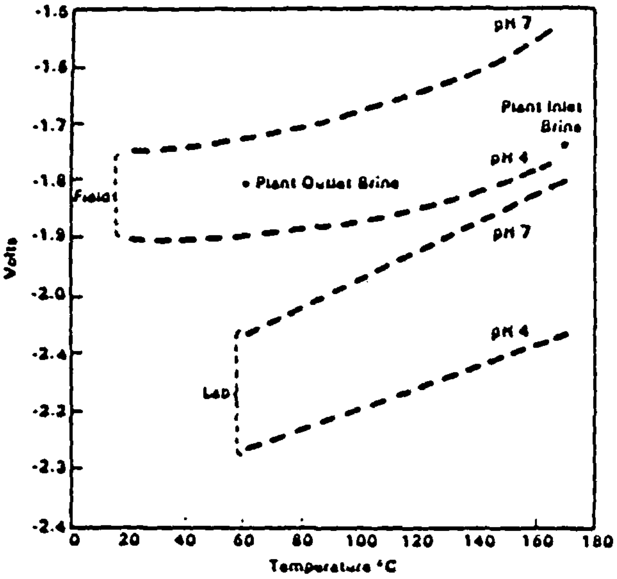
*Operated for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830 by Battelle Memorial Institute.



NOTE: Displacement of field and laboratory voltage data due to different reference electrodes.

FIGURE 1
Response of pH probe to calibration solutions and geothermal brines.

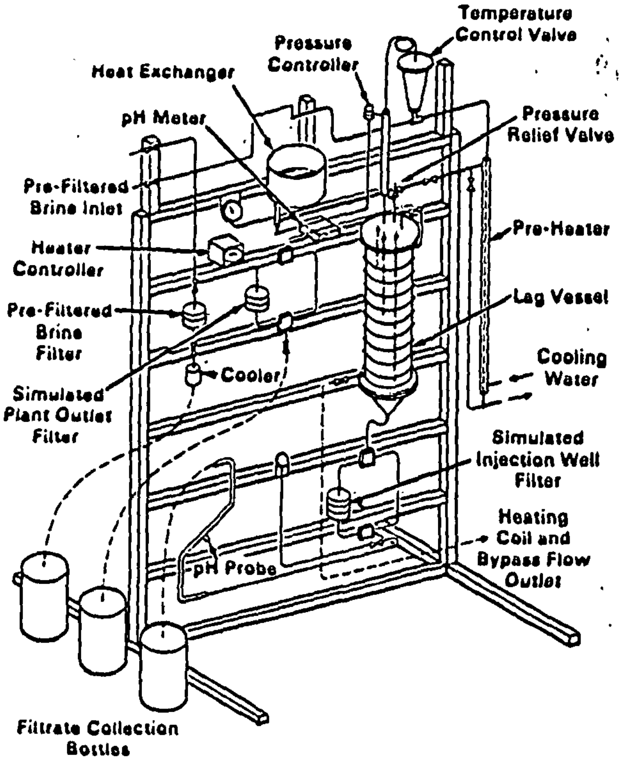


FIGURE 2
Solids filtration equipment

suspended particles represent a potential plugging problem in injection formations. Theoretically, the amount of solids formed will increase as the plant outlet temperature decreases. Actual amounts of solids which will form are difficult to predict because of the complex chemistry and limited kinetic data.

In a binary plant, one way to increase electrical output for a given brine flow is to cool the brine to a lower temperature. The danger in this is that cooling might add too much particulates to the outlet stream. PNL undertook a study to determine the effect of cooling on particle generation at the Heber Plant. Details are given in "Field Tests to Determine Scaling Tendency of Some Moderate-Temperature Geothermal Brines."[(a)]

Heber plant inlet brine was passed through the experimental test stand shown in Figure 2. The brine first passed through a 20 micron filter to remove large sand particles coming up the well. This hot prefiltered brine then passed through a 0.45 micron filter which captured particles smaller than 20 microns. The rest of the brine was cooled and then split in flow. Part was filtered immediately (designated "simulated plant outlet") and the remainder passed through a time lag vessel before being filtered again (designated "simulated well inlet"). The short lag time stream was held about 0.3-0.5 minutes before filtering; the long lag time stream was held 80 to 160 minutes.

The heat exchanger was sized to give residence times comparable to one-half of the Heber plant running at 6,000 GPM. Flow velocities were also matched in the two lines so there would be no anomalies due to particle settling. The lag vessel was sized to provide the same residence time from heat exchanger outlet to the bottom filter as the plant brine had in going from plant outlet to the injection well 2.5 miles away. This residence time is important because kinetics of silica deposition are known to be slow, especially at low supersaturations. The logic is that even if no silica formed in the heat exchangers, it might form in the reinjection line simply because more time was available for the precipitation reactions to occur.

While the filter stand was running, separate filters were collecting solids from the raw plant inlet and plant outlet streams.

The test plan called for first collecting samples with the simulated plant outlet brine cooled to 150°F. Then the brine was cooled in 10°F increments to 120°F in successive tests. Each test collected samples for about four hours.

(a) Robertus, RJ, RG Sullivan, and DW Shannon. 1986. PNL-5991. Pacific Northwest Laboratory, Richland, Washington.

Pertinent results are summarized in Figure 3. The shading in the circles shows graphically the relative particle loadings for each filter. Chemical analyses were performed on selected samples and those results are also summarized in Figure 3.

The data in Figure 3 show there is a very small increase of about 0.1 mg/ℓ in solids in the short-time lag stream which appears to be heavy metal sulfides. Further lag times of 100 times longer increased the solids loading 0.2 mg/ℓ at 140-150°F and about 0.4 mg/ℓ at 120°F. Both of these values are small and were difficult to measure accurately. Thus, very little additional solids formed during the lag time.

Chemically, the solids which did form on cooling were not silica even though the temperatures at 120°F reached the amorphous silica solubility. Typically, the amorphous silica solubility must be exceeded by 200% or more before precipitation begins. Most of the solids on the filters were heavy metal sulfides or iron carbonates.

ON-LINE PARTICULATE MONITORING

Uses

There are three main areas at a geothermal power plant where the ability to monitor particulates on-line would improve the technical and economic operation of the plant. These are:

1. The Production Well: For example, the Milford Utah Plant uses downhole injection of a calcite scale inhibitor; an on-line particulate monitor may be able to accurately determine the minimum dosage.
2. Solids Removal Process: For example, the reactor clarifier/filtration and derivative processes in the plant would be able to use an on-line monitor to perform final adjustments for flow rate, residence time, and additive dose to find the optimum compromise between particle formation/removal and plant/injection well performance.

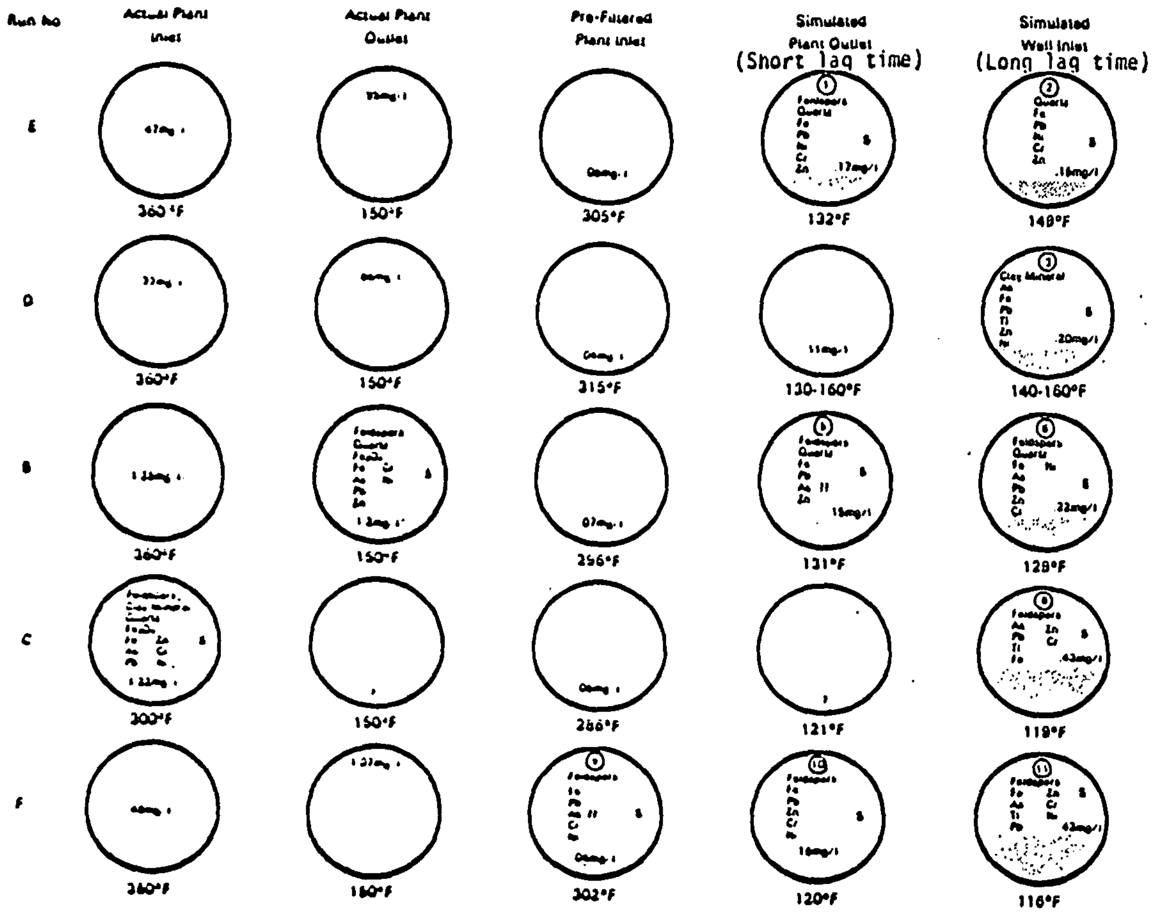


FIGURE 3
Solids filtration summary information

3. Injection Well: The lifetime of the injection well is directly related to the quantity and size of injected particulates; an on-line monitor would protect the well while providing indication of any problems upstream in the plant itself.

To achieve these goals, PNL is developing and testing two units (one laser and one ultrasonic) for operation at temperatures in the 150°F to 250°F range (injection side), the 350°F to 400°F (production side), and pressures in the 200 to 700 psi range.

Technical performance initiatives include:

- mechanical/electrical component durability
- stability during plant use
- on-site calibration.

Technology Transfer Anticipation

In order to assure availability of final instruments to the geothermal industry, both units were manufactured to our specifications by instrument companies following a difficult and lengthy procurement and prototype manufacturing phase.

Status

The basis of the ultrasonic unit is a 15 megahertz transducer mounted in contact with the flowing stream (Figure 4). The unit responds to particulates well, and its control mechanism promises a large dynamic range which would make it suitable for applications even at the solids removal process in a geothermal plant with its relatively concentrated particulate loading. Laboratory tests to date have shown good concentration response (Figure 5) and the ability to size (and count) on either side of a user-adjustable diameter. The unit has had repeated mechanical/electrical reliability problems. Currently, PNL has two new prototype high-temperature transducers (designated ULTM) which should be more durable under geothermal plant conditions.

The basis of the laser is the forward scattering from individual particulates at a specified angle from the beam. In a timed sequence, the reflected light pulse amplitude is measured and related to size and the detector is electronically relaxed to await the next pulse. The flowing pressurized stream is contained in a special high-pressure cell with sapphire windows (Figure 6). In laboratory tests the unit has shown the ability to size particulates (Figure 7). This sizing ability may be concentration dependent and degrade as the suspension becomes more concentrated because of the difficulty in relating a light pulse to a single laser/particulate interaction.

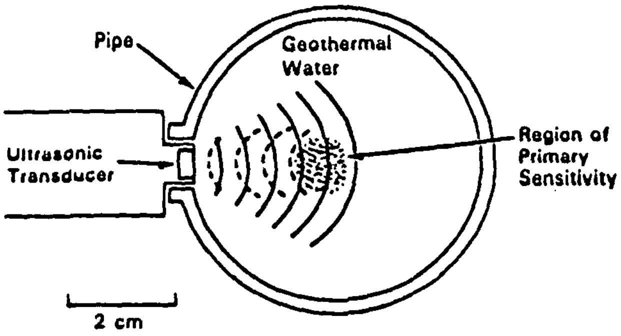


FIGURE 4
In-line ultrasonic particle monitor

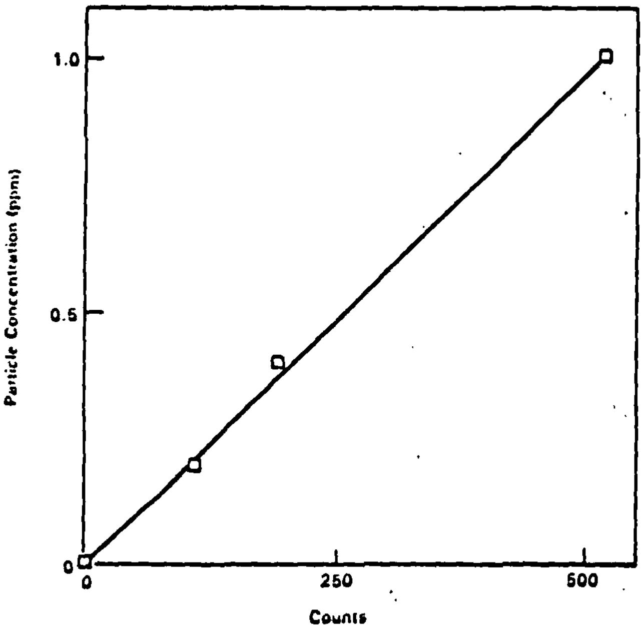


FIGURE 5
Prototype high-temperature response of ULTM transducer (50 mV Threshold; Attenuation 12; Unit C) to low concentration particulates.

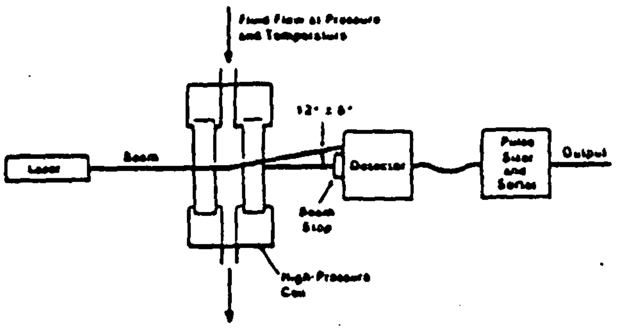


FIGURE 6
On-line laser particle counter

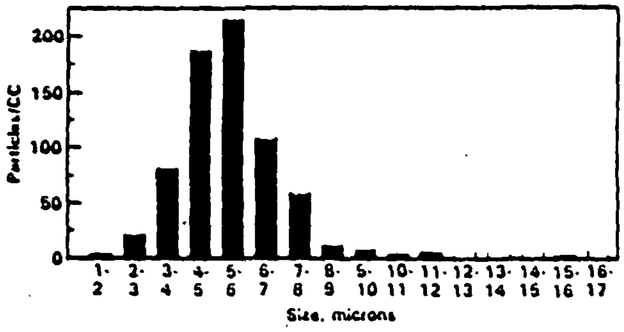


FIGURE 7
Lab test of on-line laser sizing for 4.8 micron particles.

A field test at the Heber Plant site in April 1987 is designed to:

1. Monitor the plant outlet for particulates, and

2. Establish the durability of two separate on-line particle counters under plant operating conditions.

US Geol Surv.

September 5, 1978

GEOTHERM

GEOTHERM is an operational computerized file, created by the U.S. Geological Survey, of national and international information concerning the geological and hydrological nature of geothermal resources, primarily for use in regional and national geothermal resource assessment. The file is public and services retrieval requests from private and government sources. The project chief for the GEOTHERM file is James Swanson (U.S. Geological Survey (M.S. 84), 345 Middlefield Road, Menlo Park, CA 94025, FTS 467-2906, commercial 415-323-8111, x 2906).

Objectives

The objectives of GEOTHERM are to create and maintain for the Survey's Geothermal Research Program a data base of geothermal resource information (primarily physical and chemical) using the data system, GIPSY (General Information Processing System). The initial goals were format development followed by file buildup involving data collection, keypunching, and editing. File maintenance is a continuing goal that involves standardization, updating, and deletion of data in the file. Once a core of updated records has been developed, then file retrievals can be made.

Many of these objectives have been met in part or in whole. An initial file format has been established and accepted by professionals in geothermal energy, and a system for collecting, building, and editing the data is operational. As of September 1, 1978, there were 4,400 records from the United States, Mexico, Republic of China and New Zealand. New records are added as they are received. In addition there are 38,000 water analysis records from the USGS Water Resources Division Water Quality File (WATSTORE). These data are still subject to extensive editing and verification before they can be merged with the rest of the file. Retrievals already have been made for private industry and government agencies, and interest in the file has been expressed by officials in Turkey and the Phillipines.

Purpose

The recent proliferation of geothermal resource data was the major reason for creating GEOTHERM. GEOTHERM provides a central location for a potentially large volume and variety of data, and is accessible through a sophisticated retrieval system that includes highly selective and rapid data retrieval in an assortment of outputs. The file is primarily intended for use in the characterization and assessment of geothermal resources.

The evaluation of the geothermal resources of the United States has become a matter of prime importance. In January 1979 the U.S. Geological Survey will publish its second assessment of the geothermal resources of the United States. GEOTHERM has already played an active role in this resource assessment in areas of data acquisition, editing, manipulation, and display (See "The 1978 Assessment"). GEOTHERM is also being used by the Department of Energy for a state-cooperative project to produce state maps illustrating low-temperature geothermal resources (See "Data Coordination").

Scope

The information contained in GEOTHERM is site-dependent. The initial format currently includes three topics: Geothermal Field/Area, Chemical Analysis, and Geothermal Well/Drill hole. The input forms for each topic can be obtained from the GEOTHERM project chief.

Section A: Geothermal Field/Area - This topic includes data on locality, surface description, developments, heat flow, subsurface temperatures and dimensions, porosity, stored heat calculations, general geophysics, geology, and other related information of a geothermal field or area. The coverage is broad and subject to change with time.

Section B: Chemical Analysis - This topic includes chemical analysis data from surface and well samples of a geothermal field. Space is provided for three types of analyses--water, condensate, and residual gas. Data items include sampling conditions, solutes, and isotopes.

Section C: Geothermal Well/Drill Hole - This topic includes physical data from geothermal wells and drill holes such as location, temperature, pressure, enthalpy, and well flow.

The data in the file come from many sources, primarily national but international as well, including publications, other computer files, and personal compilations and communications. The data have been compiled by many scientists, various state geological surveys and water resources departments that have cooperative agreements with the Department of Energy, and representatives from several foreign countries. The intent is to include all data that becomes available, both nationally and internationally. However, because the file is public, no proprietary data can be stored.

It should be noted that GEOTHERM is not a bibliographic or a technology file. References are cited for individual records but the bibliographic information is not the basis of the file. Similarly, the records do not contain detailed information on energy conversion or drilling technology.

Future Plans

Future plans for GEOTHERM include format expansion, broadening of subject matter, and additions to user services.

The present format can be expanded to add other topics without affecting the present format or records. One topic which will be included is a section on the detailed geophysics of geothermal areas. Other topics such as rock properties will be added as data become available.

The subject matter will also be broadened. For example, the file presently stresses high-temperature hydrothermal convective resources. However, the file is being expanded to include data from low-temperature areas throughout the US and from geopressured geothermal areas in the Gulf Coast region. The analyses for low-temperature (<90°C) water samples will be a valuable tool for assessing non-electric uses of geothermal energy.

User service will be expanded to take advantage of on-line computer capabilities. The data in GEOTHERM are standardized so that a retrieval can be made and formatted for use in outside programming packages. Future plans include "customizing" in the file with extra calculating routines which can be performed on-line or in the batch mode.

The 1978 Assessment

In 1975, the U.S. Geological Survey made a comprehensive assessment of the geothermal resources of the United States. This was a first-of-a-kind undertaking and the estimates were based upon data available in early 1975. GEOTHERM was not operational in early 1975, and information collection and manipulation for the assessment occupied the time of many scientists.

A new assessment is being prepared during 1978. The results will be published in January 1979 in the form of a USGS circular, a map, and an open-file report of data used for the assessment. GEOTHERM is fully operational now and has proven to be a valuable tool in many aspects of the assessment.

The GEOTHERM file is being used for two aspects of the assessment, the intermediate to high-temperature hydrothermal convective resources and a first-time comprehensive assessment of the low-temperature resources of the US. The file has been useful in the following ways:

1) Data acquisition and file buildup - Over two thousand records of warm spring and well data have been entered into the file for use in the assessment of low-temperature areas. In addition, 220 records from intermediate and high-temperature areas have been added to the file.

2) Data editing and maintenance - Changes or additions to records have been needed frequently and are quickly accomplished by an existing update program.

3) Map plots - Much of the data can be of maximum use only if they are plotted on maps. Over 60 maps with various scales and projections have been produced using coordinates stored in GEOTHERM. These maps show the geographic distribution of many variables.

4) Data calculations and manipulations - The raw data in GEOTHERM have been used in many operations including geothermometer calculations, gradient calculations, statistics, determinations of volume and contained heat, point graphs and regressions, and recoverable heat and work available calculations which are the core of the assessment of intermediate and high-temperature resources.

5) Data display - GEOTHERM has been important for rapid retrieval, sorting and display of data. In particular, a preliminary table of heat calculations for the intermediate and high-temperature resources has made it much easier to prepare final published tables. Also an open-file report of the intermediate and high-temperature resources will be published using a printout from GEOTHERM.

Data Coordination

The Department of Energy currently supports a program at Lawrence Berkeley Laboratory called GRID. GRID collects and disseminates both basic and site-dependent data concerning utilization of geothermal energy. GRID is considered to be a national clearing house for geothermal information. In this sense, GEOTHERM is a part of GRID in that requests for geothermal resource data are directed to GEOTHERM. In addition, Dr. Robert Fournier of the USGS in Menlo Park (Geothermal Research Program) is presently a member of the GRID steering committee.

The Department of Energy is also using GEOTHERM in a program which will produce individual state maps showing low-temperature resources. This program is based on cooperative agreements between DOE and various states. One of the tasks in these agreements calls for each state to submit a complete data set on warm springs and wells to the GEOTHERM file. Much of the data for the current USGS assessment of low-temperature areas came from these states. The data will be processed and used by DOE in the production of the maps. DOE provided FY-78 funds to the GEOTHERM project for the processing and manipulation of the data.

The international aspect of the GEOTHERM file has been overshadowed by domestic needs, and at this time there is no formal agreement which involves GEOTHERM in the collection and exchange of international data. However, data from international sources are entered into the file whenever possible, and the file is always available for requests from any other country.

Data bases are proliferating and thus there is a real possibility of duplication. To help prevent duplication, this document has been prepared to describe the objectives, purposes and contents of GEOTHERM. GEOTHERM is the only operational geothermal resource file containing the kinds of data described above, and, although the present scope of the file does not yet include all intended topics, the file will become much more comprehensive in the future. Creation of additional files concerning the geology, hydrology, geophysics or geochemistry of geothermal areas may be a duplication of the GEOTHERM file; therefore, individuals who are considering the creation of such files are urged to contact the GEOTHERM project chief, James Swanson, before doing so.

James Swanson
U.S. Geological Survey (M.S. 84)
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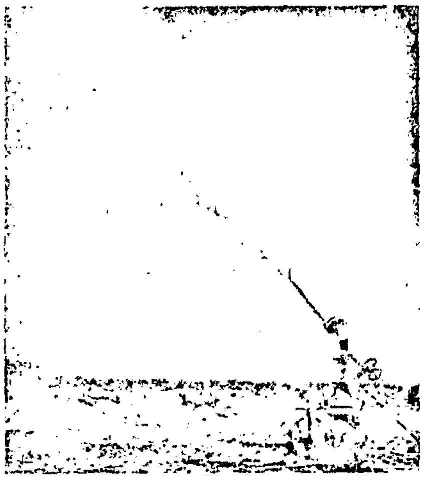
(415) 323-8111, x2906
FTS 467-2906

Geothermal energy
...the prospects get hotter



Initial flow testing at a wellhead in Imperial Valley by the Dept. of the Interior. Well is 6005 ft. deep; initial bottom temperature: 369° F.

Tapping the earth's heat as an energy source is coming on stronger than ever

By JOHN F. HENAHAN

Today everyone agrees that geothermal energy is an abundant and essentially unlimited power source. The only problem: devising systems that can turn it into electricity, and do it efficiently.

All early geothermal fields—such as those at the Geysers in California; in Laradello, Italy; and in New Zealand—are so-called dry-steam reservoirs. But those are rare: They exist only where a supply of underground water comes in contact with cracked hot rock and is turned into steam. Where this happens, it's simple to get geothermal electricity; just drill a hole and pipe the natural steam to a nearby turbine.

But there are two other potential sources of geothermal power, and these are plentiful: hot water and hot dry-rock deposits. Enormous amounts of energy are stored in such reservoirs—but it's not so easy to get it out. Some hot-water deposits—such as the vast reservoir that underlies California's Imperial Valley—are not pure water but violently corrosive brines that can clog up drill holes or eat out machinery in days. Getting energy out of hot dry rock presents considerable difficulties of its own.

All the experts agree: Before we can get really large amounts of energy from the earth, we'll have to solve a lot of tough technological problems involved with hot water and hot dry-rock fields. I've just been talking with some of the research teams at work in these areas. I found that they're coming up with a lot of ingenious solutions, and that they're excited about the prospects of geothermal energy. As they talk, you can sense the potential payoff that excites them.

Fantastic amounts

Dr. Don White, of the U.S. Geological Survey in Menlo Park, Calif., estimates that the heat in the top 10 miles of the earth's crust totals 3 x 10^{26} calories. That is about 2000 times the amount of heat that would be produced if we burned the world's entire supply of coal. Much of that heat is so spread out or so deep below the earth's surface that it defies commercial exploitation. It has been estimated, however, that if only one-tenth of the geothermal energy in the top two miles of the earth's crust could be extracted by today's techniques, and converted to electricity, it could provide 58,000 Mw annually for at least the next 50 years. Dr. Robert Rex, president of Republic Geothermal in Whittier, Calif., and one of the foremost pioneers in the field, estimates that there is enough energy sealed beneath the Imperial Valley alone to meet the electrical needs of the Southwest for at least 200 years.

A report issued by a committee headed by former Secretary of the Interior Walter Hickel estimates that it should be possible to develop as much as 132,000 Mw of geothermal generating capacity in the United States by 1985. On the other hand, the more conservative Na-

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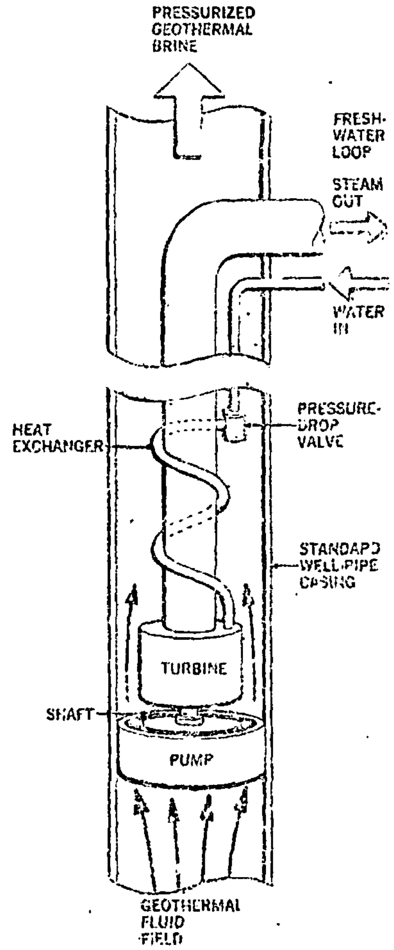

In Sperry Rand's down-hole pump, water is forced down well in narrow pipe to point where geothermal brine would flash into steam (1200 to 1700 feet down). Water passes through pressure-drop valve to heat exchanger where it turns into steam; steam drives turbine that in turn drives pump. Pump then forces geothermal brines to wellhead for use in the power plant's turbines.

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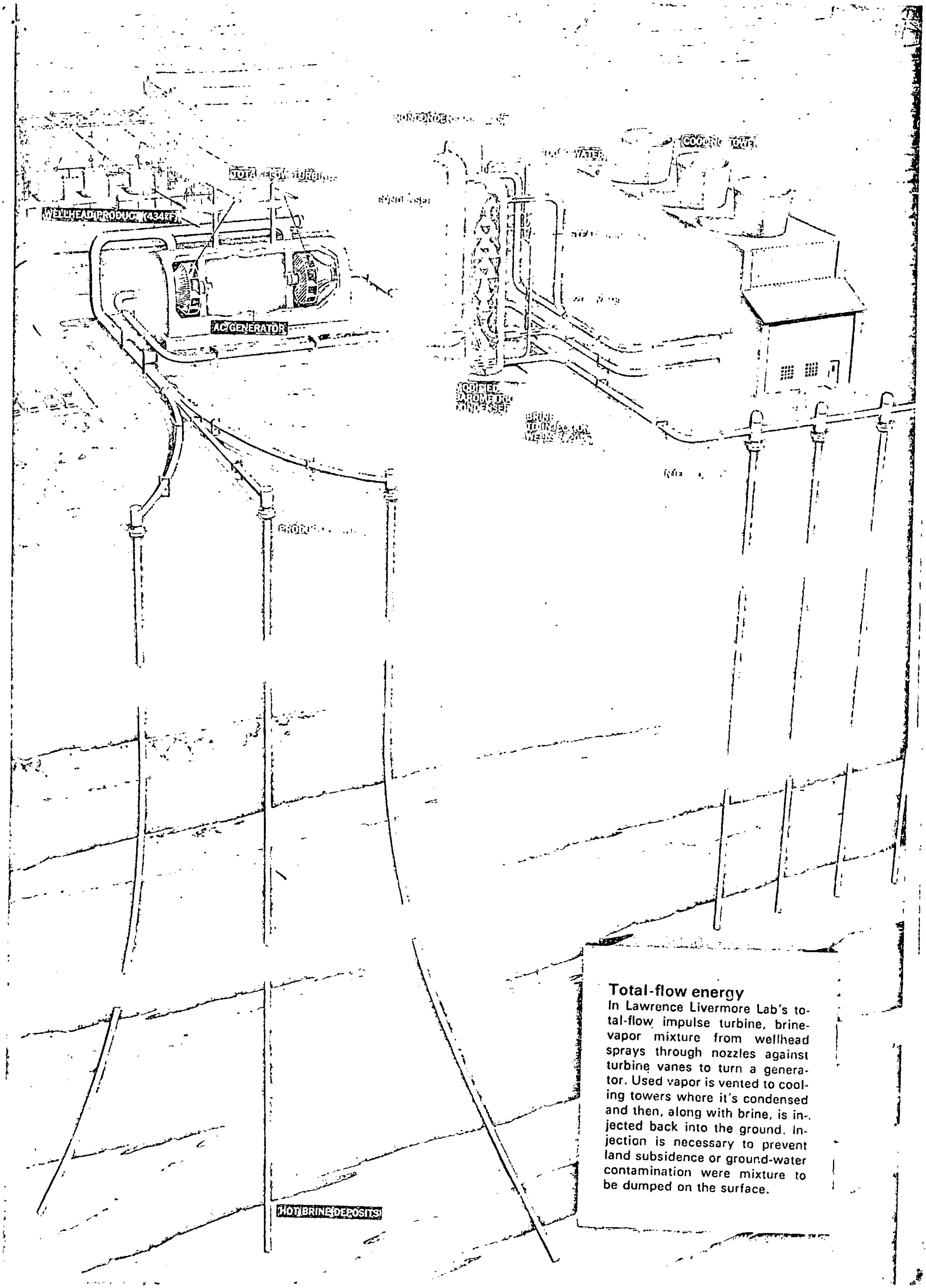


Total-flow energy
In Lawrence Livermore Lab's total-flow impulse turbine, brine-vapor mixture from wellhead sprays through nozzles against turbine vanes to turn a generator. Used vapor is vented to cooling towers where it's condensed and then, along with brine, is injected back into the ground. Injection is necessary to prevent land subsidence or ground-water contamination were mixture to be dumped on the surface.

tional Petroleum Council foresees that geothermal power capacity in the same period will reach no more than 3500 Mw. Within these extremes, geothermal energy could provide from 0.5 to 20 percent of the nation's electrical power within the next 11 years.

How they'll do it

Basically, there are three ways to use geothermal hot water to produce electricity. In Cerro Prieto, Mexico (in the southernmost extension of the Imperial Valley), the Mexican government has been operating a 75-Mw geothermal power plant that uses the flashed-steam process [PS, Aug. '72]. In this system, pressure reduction as the hot water rises in the well causes some of it to flash into steam. The steam runs a turbine that generates electricity.

Another way to take advantage of geothermal hot-water potential is through the "binary-vapor" technique now being developed by Magma Power Company in Los Angeles. In this case, the fluids are not allowed to flash into steam; instead a pump in the well keeps them under high pressure, and the hot fluids are fed into a heat exchanger where they vaporize a low-molecular-weight fluid such as isobutane or freon.

In the Magmamax process, the vapor drives a low-pressure turbine, then is condensed and recycled through the heat exchanger. Within a few months, the Southern California Edison Company plans to use the Magmamax process in a small 10-Mw power plant that will get its energy from the hot-water geothermal deposit beneath Mammoth, in northern California.

Unfortunately, neither system uses much of the heat present in the geothermal water. The flashed-steam process uses only the part that flashes into steam. The heat in the remainder is unused. The binary-vapor technique does not use the geothermal fluid directly, a necessarily less efficient system. The geothermal hot-water deposits in the Imperial Valley cannot be used directly in a power-generation system because they are really brines —with salt concentrations ranging from about two percent to as high as 25 percent in the Salton Sea area. Corrosion and caking caused by the more concentrated brines make it almost impossible to use them in a conventional power-generating system.

Nevertheless, a group of never-say-die researchers at the University of California's Lawrence Livermore Laboratory find a lot of room for maneuvering in that "almost." They believe that a new type of "total-flow impulse turbine" they are developing may be able to produce electrical power from even the most concentrated brines in the valley.

At Livermore, I talked with Dr. Gary Higgins and Roy Austin, who are developing the total-flow system —the third and possibly most efficient way to use geothermal hot-water deposits. As Gary Higgins explains it, the total-flow impulse turbine is so named because it will run on both the liquid and steam phase of the fluid mixture that comes out of the geothermal well-head. In principle, it is related to the impulse turbines that have been used in hydroelectric power plants for more than a century: Water from a dam or some other source is expanded through a spray nozzle; the force of the droplets acts against the scoop-like vanes of the turbine wheel, which then turns to operate a generator.

Between technologies

"Sometimes people look at us funny when we tell them about our idea," says Roy Austin, the chemical engineer in charge of the Livermore project. "The steam-power people tell us, 'Hell, we've worked for years to take the water out of steam and you want to put it back.' Then when we talk to the people in the hydraulic-power business, they say, 'The turbines we've worked so hard to design work on water alone, and you're talking about water and steam.' So we're sort of in the middle of two well-known technologies, trying to put them together in our own way."

Austin was only too eager to show me that the total-flow impulse turbine works when it is fed a mixture of liquid and vapor. Wheeling a table-top model over from the corner of his office, he opened a few valves and let a mixture of water and air through the spray nozzle. He smiled proudly like a man showing off his new power saw, when the ear-piercing whine of the whirling turbine cut through the office and a light bulb attached to the generator went on.

"If we can design a turbine like this to accommodate the brine-steam mixture that comes out of the well heads in the Salton Sea area, we should be able to produce at least 60 percent more electrical power than any other system now under consideration," he said.

To fill in some of the blank spots between the table-top model in front of us and the power-plant-sized turbine of the future, Austin and his colleagues are now testing several experimental designs in a facility recently completed at Livermore.

Field test

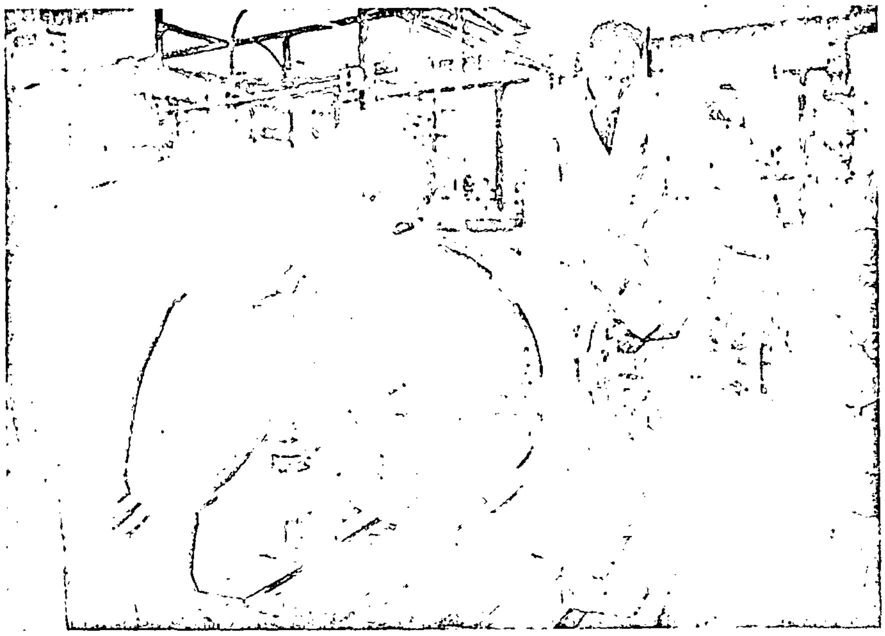
"Here, it's the mechanical performance of the turbine we're interested in," he said. "We want to see whether or not it will run well on a mixture of water and steam in approximately the same proportions found at the geothermal well-head. If we can make a turbine work with a mixture of water and steam, it should work just as well with a mixture of brine and steam," he said. "But the only way we can check out how the brines affect the turbines is to go down to the Imperial Valley. You just can't duplicate the well-head conditions of the brine in a laboratory setup." In fact, on the day I visited Livermore, Austin and his colleagues were shipping a small test chamber to the Imperial Valley, where it would be hooked up to a geothermal well.

Austin foresees two problems: scaling inside the nozzle, and corrosion of the turbine wheel. Some nozzles now being tested are composites of mild steel and tantalum carbide. The turbine wheels, buffeted as they are by the full force of the hot brines, may be made of titanium metal coated with corrosion-resistant titanium nitride. The piping to be used throughout the system may be made of polymers, such as epoxy resins and polyesters.

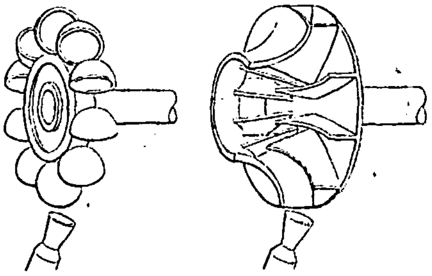
By 1978, if all goes well, a small one-megawatt power plant using a total-flow impulse turbine should be feeding electricity into the grid of a power company in southern California, Gary Higgins told me. By 1981, it should be possible to scale up to a more impressive 200-Mw size.

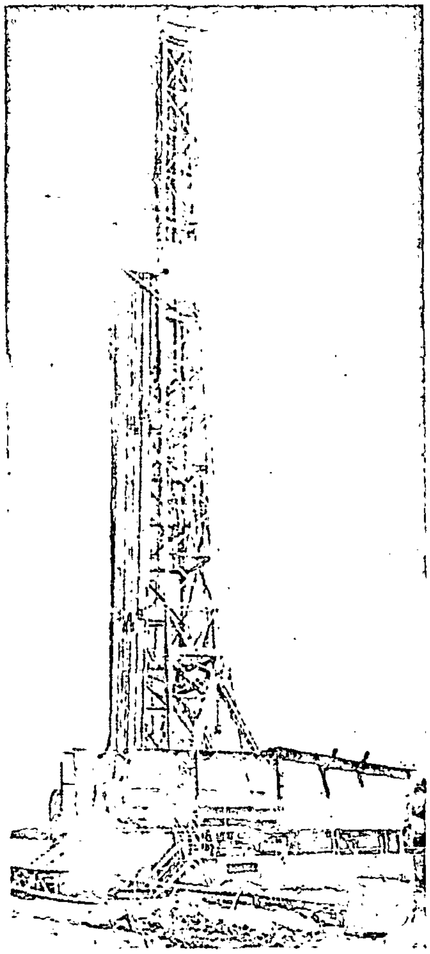
Higgins is confident that a geothermal power plant could be built and operated for about the same or even less money than traditional power plants.

"It all depends on how difficult it is to solve the materials problem," he told me. "But even if the turbine material is as expensive as titanium, we should be able to produce electricity for about seven to 13 mills per kilowatt hour. Power plants now fueled with coal or oil come in at around 12 mills/kwh, while nuclear plants will probably



Lawrence Livermore engineers check total-flow test chamber (left). When connected to well in Imperial Valley, four nozzles will spray brine-steam mixture against four test plates, testing four nozzle designs and four materials. Below are designs for turbine wheel. Radial inflow (right) vents spent brine through wheel's center. Tangential flow (left) has nozzle tangential to buckets, which are shaped to respond simultaneously to liquid droplets and vapor.





Los Alamos Lab's latest test well is in the Jemez Mountains, about 35 miles from Los Alamos, N. M. (left). LASL's scheme is to drill down into hot dry rock, create a network of cracks and fissures by pumping water down into well, then withdraw steam from a second well after water has heated up. Above, project engineer Don Brown (left) and LASL crew prepare to lower probe to check temperature at the bottom of the shaft.

cost about 12 to 15 mills/kwh by 1980, just about the time when geothermal energy should be coming into its own."

Lost in transit

Geothermal developers who plan to use the hot-brine deposits of the Imperial Valley are facing another major problem: Much of the theoretical power output of the well gets lost between the time the hot liquid flashes into steam at some point down the well and the time it reaches the wellhead and the power-production system.

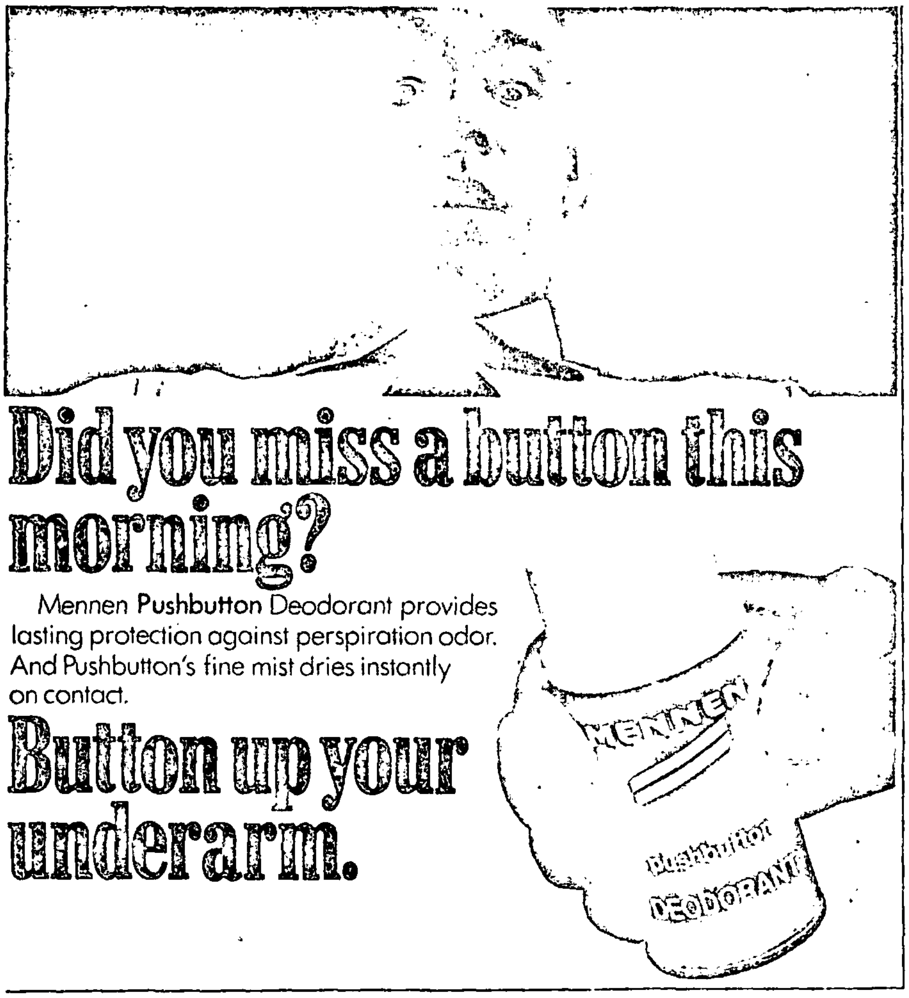
To boost the power output of hot-water wells, H. B. Matthews and his colleagues at the Sperry Rand Research Laboratories in Wellesley, Mass., are designing an ingenious down-hole pump that could keep the geothermal brines from boiling until they reached the power turbines at the top of the well. Using such a pump, the Sperry Rand group estimates that the power output of a typical Imperial Valley well could be boosted from 15 to 30 percent over what is now possible.

Aside from the substantial increase in power that goes with it, the pump could also minimize the serious scaling of the well casing that normally occurs when the brine flash-distills in the well. (If the brine is not allowed to flash, it doesn't cause scaling.) So says Dr. Warren McBee, Director of the Sperry Rand Systems Requirements and Applications Laboratory.

McBee expects that the down-hole pump now being built by the group should be ready to be put down a well—probably in the Imperial Valley—about six to nine months from now. There is no reason why the pump could not be used in tandem with the total-flow impulse turbine now being developed by Roy Austin, or with any other power production scheme now being considered for use in the Valley, he continued.

So far, the Sperry Rand group doesn't seem overly concerned about corrosion or scaling. They expect that the bulk of the pump components will be made of a stainless-steel alloy, with the pump's impeller blades, exposed as they are to the hot brines, made of titanium. The vanes and wheels of the small 400-hp turbine that powers the pump will probably be fabricated of tungsten carbide according to present plans.

[*Continued on page 142*]



Geothermal energy

[*Continued from page 99*]

While the Imperial Valley's hot brines are undoubtedly a geothermal bonanza, there is an even greater supply of untapped heat stored in concentrations of hot dry-rock formations—usually granite—relatively close to the earth's surface. It has been estimated that 95,000 square miles of a 13-state area in the American West are underlaid at a depth of about 3½ miles with hot dry rock averaging temperatures of about 550° F (290° C). During the last five years, Morton Smith, Don Brown, and Bob Potter, all of the University of California's Los Alamos Laboratory (LASL), have had a strong yen to do something with all that heat. They devised what sounded like an outrageous idea at the time: to pump water down into the hot-rock area and create useable steam in the same way that nature does.

As we described two years ago [PS, Aug. '72], the LASL researchers planned to use a new rock-melting technique they had just developed to drill a well deep enough to reach dry-rock areas where the temperature is about 450° F. Since then, they decided that conventional oil-well drilling techniques would be just as economical and equally efficient.

Once the well is dug, water is pumped down the shaft to create a hydraulic fracture in the rock, a pancake-shaped network of interconnected cracks and fissures. The next step is to pump more water into the fracture zone, wait for it to heat up, then withdraw the steam from a second well drilled into the upper edge of the fracture zone.

On the brink of success

In April 1973, at least part of the plan became reality. On the edge of a volcano near Los Alamos, the LASL team created a circle-shaped fracture about 140 feet in diameter at a depth of 2500 feet. The rock temperature was "a very satisfying 110.4° C," according to Morton Smith. Everything went as predicted. Since then, with that mild success under their belts, he and his colleagues have been digging other wells, shooting for deeper depths, larger fracture zones, higher temperatures, and granite formations tight enough to hold the hot water.

At the latest well site, 35 miles from Los Alamos, I met Don Brown, number-two man on the LASL hot dry-rock project. He was everywhere at once as he and his crew readied a thermocouple to be lowered down the well to check the temperature at the bottom.

Although they should have hit only dry rock, unexpectedly they encountered some water running through the rock formation. Temperatures were only about 100° C, much cooler than they anticipated at a depth of 3700 feet. Nevertheless, there was still another 800 feet to go, and Smith and Brown were optimistic that they'd break through to dry rock again before they finished. It wouldn't be an overnight affair; well-digging through granite is slow, tedious, sometimes frustrating, and always expensive. Picking up a worn-out bit, Don Brown shouted to me above the din of well-drilling sounds:

"Ten feet an hour . . . ten feet of granite at $1000 a foot. This bit is studded with carborundum inserts. It costs $1800 and we have to replace it every 300 feet."

Once the new LASL well is completed, the routine will be to rerun last April's experiment. "Then we'll know whether the results we got last time were representative of the geology of the area or whether we were just lucky," Morton Smith said. "After experimenting with the new hole for a few months, we'll begin drilling two more wells, one 7500 feet deep, the other 6000 feet. By fall, we'll try to connect the holes by creating a large hydraulic fracture. Then we'll know if the system really works."

If the LASL hot dry-rock technique works in New Mexico, Smith sees no reason why it could not also be applied to the Conway granites beneath New Hampshire or even the rock underlying New York's Manhattan Island. However, those formations will probably not be hot enough to produce steam for electrical power, he says. Instead, they could be used to produce water hot enough to be used in space heating or air-conditioning systems. Reykjavik, Iceland, which sits on a geothermal hot-water deposit, uses 275° F water for heat and hot water.

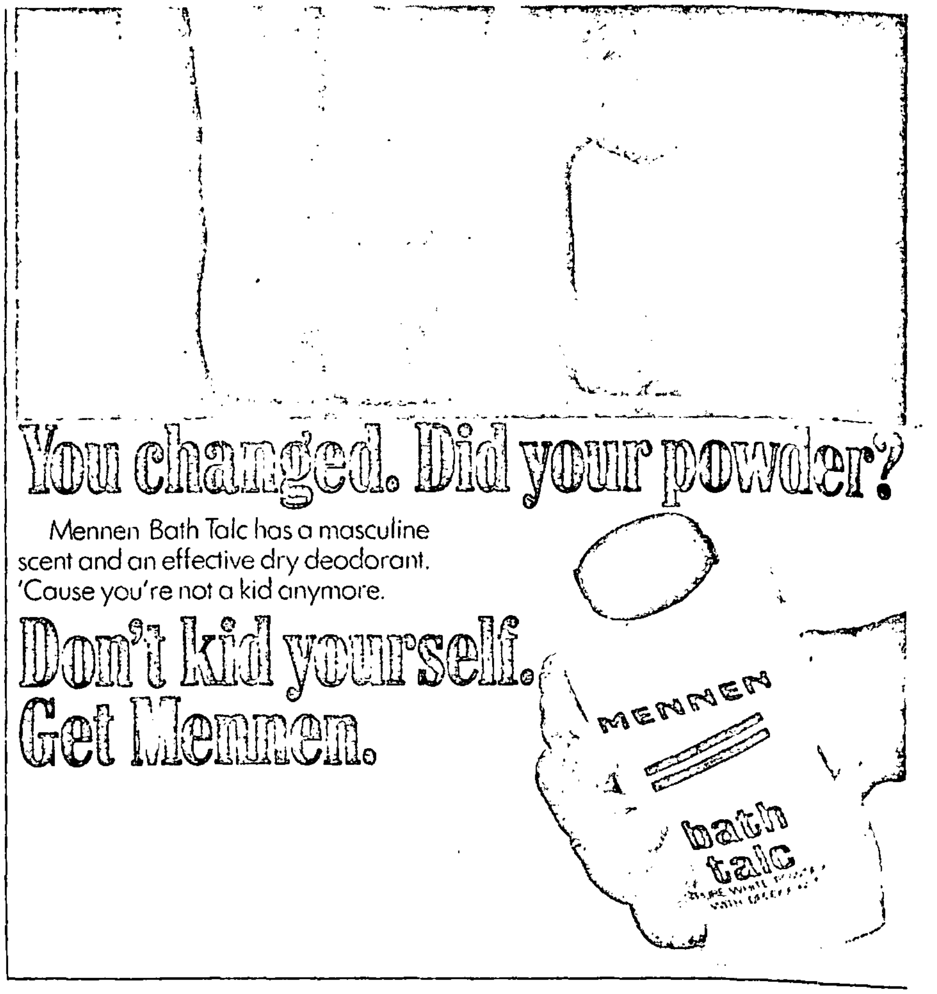
Prospects and plans

Meanwhile, the search for new sources of geothermal energy or new ways of using the old sources goes on:

- In Marysville, Mont., a team headed by researchers from Battelle Memorial Institute in Richland, Wash., is sinking a well into what could be a multibillion-dollar geothermal hot spot. The thermal reservoir, covering a 10-sq.-mi.-area, was apparently created by the intrusion of hot lava from the earth's mantle into its crust tens of thousands of years ago. Temperatures at the bottom of the well are 7000° to 8500° F. This first well is primarily a scouting probe designed to find out just how large and hot the deposit is. Exactly how the subterranean energy supply will be converted into electrical energy depends on whether it turns out to be an impermeable hot dry-rock area as expected, or a hot-water deposit. Drillers should determine this soon. Any prospects for commercial development are at least two years off, says project manager Bill McSpadden. The three-year project is sponsored by a $2.5 million grant from the National Science Foundation.

- The Bureau of Reclamation plans to use the Imperial Valley's geothermal brines as a source of fresh water to replenish the Colorado River's dwindling and increasingly salty lower reaches. A 30,000-gallon-per-day pilot desalination plant is now operating near Holtville, Calif. It operates like the conventional desalting plants, except that it isn't necessary to heat the brine, which rushes from the well head at 300° F.
- Researchers at the University of California, Riverside, have mapped the geothermal deposits of the Imperial Valley by measuring tiny electrical currents in the ground—a method that's faster and cheaper than drilling test wells.
- The Atomic Energy Commission is investing $8 million to construct an experimental 10-Mw power plant over a geothermal hot-water reservoir near Battle Mountain, Nev.
- The Geysers dry-steam field north of San Francisco continues to prove its worth. A new power plant, to be finished in 1977, should increase the capacity of the installation from its present 396 Mw to 502 Mw.
- The federal government has finally begun to lease hundreds of thousands of acres of federal land to private geothermal developers.

There is no doubt that a geothermal bonanza lies somewhere beneath our feet, and the trend of geothermal research and development is definitely on the upswing. Once new energy sources are discovered, they will certainly be put to good use. PS



Try a transit level

[*Continued from page 119*]

rod on the second stake, sight on it and set the angle scale at 0°.

- Carefully swing the transit 90° and have your helper locate the rod so it's centered on the vertical cross hair. Measure on a line between the first stake and the rod to locate the third corner stake. Repeat from the second stake to locate the fourth.
- Check by starting at the fourth stake and working back. On a rectangular layout, diagonal measurements should be equal.

Obviously, as you're going to dig right where the stakes are, you'll need something permanent to retain your layout. Professional builders usually set up batter boards at least five or six feet outside the building perimeter. Here's how to do it:

- Drive three 2-by-4 stakes as if you were going to fence in each corner well back from the plot line.
- Pick a handy height, about 2', and drive a nail part way into the side of one stake.
- Have your helper place a stick on the nail, mark the stick where the cross hair cuts it, and move to the next stake.
- Sight the mark on the stick, and when your helper has located it so it's dead in the cross hair, have him mark the stake using the bottom of the rod as a guide. Repeat for each stake, then drive nails part way in at the marks.
- Hold boards so their top edges are firm against the nails and nail them to the stakes.
- Using your existing corner stakes, sight along the line of each wall and mark or notch each board.

Establishing levels

You now have a permanent means of establishing your footing corners down in the trench. You also have height references, so forms may be set and concrete poured level.

With a little practice, you can align verticals, triangulate [illegible], or map your property. For directions are given in a booklet, "How to Use Transits and Levels for Faster, More Accurate Building," from Berger Instruments, [illegible] Williams St., Boston, Mass. [illegible].

For most jobs the [illegible], probably the most common rental model, will do just fine. PS

June 1, 1972

STATE OF WASHINGTON
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Olympia, Washington 98504

GEOTHERMAL ENERGY—QUESTIONS AND ANSWERS

WHAT IS GEOTHERMAL ENERGY?

Geothermal energy is the heat of the earth's interior. This heat deep within the earth is generated by radioactive decay and is conducted through the rocks of the earth's crust to the surface, where the heat slowly escapes. At the places where molten rock is cooling near the earth's surface, the escape of heat may be much greater than normal. Man is attempting to harness this energy and utilize it as a source of power.

WHAT FORMS DOES GEOTHERMAL ENERGY TAKE AND HOW IS IT MANIFESTED AT THE EARTH'S SURFACE?

Over most of the earth's surface the temperature in the earth's crust increases slowly with depth—at an average rate of about 1 degree Fahrenheit per 100 feet. Under these conditions the escape of heat from the surface can be detected only by sensitive instruments, and there are no visible signs of geothermal energy.

In a few areas, such as hot springs or the oceanic ridge systems, where igneous rocks (rocks formed by solidification from a molten or partly molten magma) are cooling and fairly near the earth's surface, the temperature increases rapidly with depth. Within the earth, circulating ground water may absorb the escaping heat and reach temperatures that exceed the boiling point. This can result in surface manifestations such as geysers, hot springs and pools, or vents where hot gases escape into the atmosphere. Here, the surface of the earth is often warm or even hot to the touch.

WHAT GEOLOGIC CONDITIONS ARE NECESSARY FOR THE EXISTENCE OF A GEOTHERMAL FIELD?

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1. A source of heat, usually a cooling igneous rock.
2. A reservoir rock with high porosity and permeability (ability to hold and transmit large quantities of fluid).
3. A cap rock that is impermeable to keep the hot geothermal fluids from escaping.
4. A source for recharge of the reservoir. Recharge is usually accomplished by percolation of ground water into the geothermal reservoir.

HOW IS GEOTHERMAL ENERGY TAPPED?

In areas where the escape of heat toward the surface is much greater than normal and hot ground water is present at depth, the energy can be tapped by using drills and drilling methods similar to those used in the oil industry for handling fluids at high pressures and temperatures. The deepest geothermal wells drilled so far are 9,000 to 10,000 feet deep.

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Geothermal energy is used for recreation (resorts), space heating, domestic hot water, and industrial process heating. Where it is hot enough to produce steam, it may be used to drive turbines for the generation of electricity.

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Geothermal energy is being used for electric power generation at The Geysers geothermal field in California; at Cerro Prieto, near the Gulf of California in Mexico; in New Zealand; Italy; Japan; and the Soviet Union. Geothermal energy is used for heating in Iceland; Klamath Falls, Oregon; and Boise, Idaho. Resorts in many parts of the world use hot springs for bathing and recreation.

WHAT AREAS OF THE WORLD MIGHT HAVE GEOTHERMAL POTENTIAL?

Since cooling igneous rocks are required as a heat source, most discoveries of geothermal fields will probably be made in areas where volcanic activity has recently occurred. Most of these active or recently active areas are located around the rim of the Pacific Ocean and in a belt passing through the Mediterranean-Himalayan region.

IS GEOTHERMAL POWER ECONOMICAL IN RELATION TO OTHER ENERGY FORMS?

The geothermal electric-generating plants constructed so far have been able to produce power at costs equal to or less than power costs for competing coal-fired, nuclear, or hydroelectric generating plants.

WILL OUR PRESENT OR PLANNED COAL-FIRED, NUCLEAR, OR HYDROELECTRIC GENERATING FACILITIES BE ADEQUATE FOR THE FUTURE?

Recent studies show that the Pacific Northwest is entering a period when supplies of electricity may not be able to meet peak demands. Thus, we may be subjected to "brownouts" such as those that have occurred on the east coast. New generating plants must be built to correct this situation and provide for anticipated increases in demand for energy. Since our hydroelectric sites have been nearly used up, it will be necessary to build coal-fired or nuclear plants. But there is considerable concern regarding the environmental impact of nuclear plants, and the Pacific Northwest does not have economically extractable coal supplies to support additional coal-fired generating plants. Any new method of supplying energy, including geothermal, should be investigated in order to evaluate its potential capacity and environmental impact.

HOW SIGNIFICANT IS THE NORTHWEST'S GEOTHERMAL ENERGY POTENTIAL IN COMPARISON WITH OTHER POWER SOURCES?

There has not been enough study to predict the amount of power that might eventually be produced from geothermal sources in the Pacific Northwest. However, most authorities agree that geothermal power will not be more than a supplementary source of power—able to supply only a few percent of the power needs of the Pacific Northwest.

WHAT ARE THE TYPES OF GEOTHERMAL FIELDS AND THE ENVIRONMENTAL CONSIDERATIONS OF EACH?

There are two types of geothermal fields. A dry steam field, such as The Geysers in California, produces steam, without liquid water, from its wells. The steam can be used to drive turbines as it comes from the ground. The steam contains about 0.5 percent of gases other than steam. These gases include carbon dioxide, methane, hydrogen sulfide, hydrogen, nitrogen, argon, and ammonia. After the steam has passed through the turbines, these gases escape into the atmosphere. The Geysers is in a sparsely populated area and the escape of these gases has been tolerated—there has been no noticeable effect on the local flora and fauna. "Spent" steam evaporates into the air as water vapor, and any condensate is pumped back into the geothermal reservoir.

The other type of geothermal field—the hot water field—produces a mixture of steam and hot water from its wells. The steam may be used to operate turbines, but the hot water presents disposal problems because of its content of heat and dissolved solids, and its large volume. Plants now in operation in Mexico and New Zealand simply allow this waste water to flow into nearby rivers or accumulate in holding ponds.

One alternative might be to desalt the waste water and use it for irrigation or drinking, and the mineral salts recovered may be sold. However, this alternative has not yet proven economical.

The production of electricity from dry steam fields is possible by using present technology and with only minor environmental disruption. Hot water geothermal fields present serious environmental problems that must be solved before such fields can be developed in this country.

IS SPECIAL EQUIPMENT REQUIRED IN GEOTHERMAL POWER PLANTS?

The design of geothermal turbines and piping is different from other power plants because the steam is at lower pressure and temperature. Since the steam is mildly to severly corrosive because of the presence of gases other than steam, special corrosion-resistant metals and materials must be used in the manufacture of geothermal equipment. These differences from conventional power plants can, in most cases, be easily handled using present levels of technology.

CAN A GEOTHERMAL POWER PLANT BE BUILT WHEREVER IT IS NEEDED?

No, geothermal fields occur at relatively few places, and these places are generally not in the highly populated areas where most of the electrical power is needed. Generating facilities must be constructed near the geothermal field because steam cannot be transported more than 1 or 2 miles without losing much of its energy.

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WHAT IS THE "PLOWSHARE" GEOTHERMAL PROGRAM?

The "Plowshare" geothermal program is designed to use underground nuclear explosions to create heat and fracture naturally hot rock. Water then may be circulated through this rock and the resulting steam used to drive turbines and create electric power. The concept has not been fully tested, and its economic and environmental feasibility is still not proven.

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Surface geologic mapping is an important tool that may be used to find areas with suitable geologic structure. Chemical analysis of hot spring waters and measurements of temperature gradients in drilled holes can supply much information about how hot and how large a geothermal field may be.

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See p. 2

Circulate

NEWS RELEASE June 5, 1979

San Francisco, California ...

Pacific Gas and Electric Company ("PGandE") will begin commercial operations of its Geothermal Unit 15 at The Geysers geothermal field in northern California on June 15, 1979.

Unit 15 is a 70.5 MVA/60 MW turbine-generator set manufactured by General Electric Company and is capable of serving 60-61,000 people 24 hours a day, 30 days a month, 365 days a year for at least 30 years, less maintenance downtime.

Unit 15 is the world's first geothermal power plant to be equipped with an H_2S scrubber. Commercial tests of the scrubber have just been completed and have demonstrated its capability of removing 98.7% of the small amount of hydrogen sulphide contained in the steam as it comes from the wellhead.

Unit 15 brings the capacity of The Geysers geothermal field up to 663 net megawatts. Over 2,000 megawatts are expected to be on line in the field by 1985.

FOR FURTHER INFORMATION CONTACT:

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GEOTHERMAL ENERGY RESOURCES AND TECHNOLOGY

June 1979

By: Donald F. X. Finn
Managing Director
Geothermal Energy Institute press release
P. O. Box 1287
Natchez, MS, U.S.A. 39120

Tel.: 601-442-1601

Geothermal energy resources are presently supplying 663 net MW of installed electrical generating capacity in the United States at The Geysers geothermal field in northern California.

By 1985 this capacity will be increased to over 2000 MW and by 1990 ten to twelve additional geothermal fields in California, Nevada, Utah, New Mexico, Idaho, Oregon, and Hawaii should be supplying geothermal energy resources for about an additional 2000 MW.

Direct or non-electrical use of geothermal energy resources in the United States for space heating and cooling, agricultural and aquacultural purposes amount to about 100 MWt and will increase rapidly in the next decade with the introduction of geothermal heat pumps and absorption machines.

The introduction of binary power plants, downhole pumping and well-head generating units, advanced drilling technology (including MWD), advanced logging and instrumentation, and the development of new exploration techniques are expected to rapidly accelerate the use of geothermal energy resources in the United States.

The Geothermal Resource Group of the National Research Council recently (March 1979) estimated that 144,600 MW of installed geothermal energy capacity can be achieved in 30 years, i.e. by 2010. Geothermal Resources and Tehcnology in the United States, p. 30 (National Academy of Sciences, 1979).

Worldwide, the utilization of geothermal energy resources is also increasing rapidly.

Country	Geothermal Power Plants Megawatt (MW) Capacity	
	Operating	Planned
United States	663	4200 (1990)
Italy	420	30
Japan	222	6060 (1990)
New Zealand	200	140 (1985)
Mexico	150	800 (1985)
Nicaraqua	70 (1980)	135 (1981-5)
El Salvador	70	35 (1981)
Philippines	55	385 (1980)
Soviet Union	50.6	
Iceland	3	60
People's Republic of China	2.6 +	
India	1	
Republic of China	.5	.3 (1979)
Indonesia	.25	

20,000 MW of geopressured-geothermal capacity is capable of being brought online by 1990. The development of these resources may prove to be of great importance as it is expected to demonstrate the availability of large amounts of methane dissolved in geofluids at depth.

A major conference on geothermal resource developments will be held in September 1979 in Reno, Nevada.

Donald F. X. Finn

REVISED UP-DATE ON THE GEYSERS - May 1979

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May 21, 1979

TABLE I

DETAILS OF GEOTHERMAL GENERATION[1]

Year of Commercial Operation	Unit No. Designation	Ownership	Capacity	Voltage of Transmission	Cumulative Geothermal Generation
			(MW)	(kV)	(MW)
On or Before Dec. 31, 1977	1,2	PG&E	24	60	
	3,4,7,8	PG&E	160	115	
	5,6,9,10,11	PG&E	318	230	502
1978	12	PG&E	106	230	
	15	PG&E	55	115	663
1979	14	PG&E	110	230	
	13	PG&E	135	230	908
1980	-	-	-	-	908
1981	17	PG&E	110	230	
	16	PG&E	110	230	
	18	NCPA-1S[2]	55	230	
	19	NCPA-2S[2]	55	230	1,238
1983	20	PG&E-18	110	230	
	21	PG&E-19	110	230	
	22	CDWR-Site 1	55	230	
	23	CDWR-Site 2	55	230	
	24	NCPA-1N[2]	33	230	
	25	NCPA-2N[2]	33	230	1,634
1984	26	PG&E-20	110	230	
	27	PG&E-21	110	230	1,854
1985	28	PG&E-22[3]	110	230	1,964
1986	29	PG&E-23[3]	110	230	2,074
1987	30	PG&E-24[3]	110	230	
	31	PG&E-25[3]	110	230	
	32	CDWR-Site 3	55	230	
	33	CDWR-Site 3	55	230	
	34	NCPA-3S[2]	55	230	
	35	NCPA-4S[2]	55	230	
	36	NCPA-3N[2]	100	230	2,614[4]

[1] PG&E Geothermal generation details, except for Unit No. 31 (PG&E-25), are obtained from Western Systems Coordinating Council Reply to United States Department of Energy order 383-5, Docket R-362 "Reliability and Adequacy of Electric Service" dated April 1, 1978. Unit No. 31 (PG&E-25) is to be in service by December 1987 as per telephone discussion of March 27, 1978, of the Consultant with Mr. H.R. Perry, Chief Planning Engineer of PG&E. CDWR and NCPA Geothermal generation details are based on the Consultant's understanding of CDWR and NCPA plans for such type of generation.

[2] Designation given by the Consultant-First figure signifies unit number.

N Signifies North Site
S Signifies South Site

[3] Unit numbers are designated as per the Consultant's understanding with Mr. H.R. Perry, Chief Planning Engineer of PG&E.

[4] PG&E (H.R. Perry) letter July 6, 1978 (Appendix B) totals 110 MW less installed by 1987 on 230 kV system.

Date: 10-10-1978

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PG&E Geysers Development. As of 1 June 1979 total scheduled and planned additions through 31 December 1984 came to 1432 net MW

Unit	Year	Gross MW	Net MW	Cumulative GeoThermal Net MW	Producer	Date of commercial operation	Capital investment (dollars)	Cumulative capital investment (dollars)
1	1960		11	11	UMT	9/25/60	$ 4,010,000	$ 4,010,000
2	1963		13	24	UMT	3/19/63		
3	1967		27	51	UMT	4/28/67	7,610,000	11,620,000
4	1968		27	78	UMT	3/2/68		
5	1971	55	53	131	UMT	12/15/71	12,756,235	24,376,235
6	1971	55	53	184	UMT	12/15/71		
7	1972	55	53	237	UMT	8/18/72	13,520,000	35,896,522
8	1972	55	53	290	UMT	11/23/72		
9	1973	55	53	343	UMT	10/25/73	13,520,000*	49,416,522*
10	1973	55	53	396	UMT	11/31/73		
11	1975	110	106	502	UMT	3/1/75	19,666,292*	69,082,764*
12	1976	110	106	608	UMT	3/1/79	27,580,000*	96,662,764*
13+	1980*	135	129	792	A	2/ /80	28,934,000*	125,596,764*
14+	1980*	120	110	802	UMT	/80	27,966,000*	153,562,764*
15	1979	63	55	663	TGI/PEC	6/15/79	25,530,000*	179,092,764*
16**	1982*	120	110	912	A	/81	42,700,000*	221,792,764*
17**	1982*	120	110	1022	UMT	/81	41,592,000*	263,384,764*
18**	1982*	120	110	1132	UMT	/83	48,882,000*	312,266,764*
19++	1983*	120	110	1242	A	/83	48,800,000*	361,066,784*
20++	1984*	120	110	1352	UMT	/83	52,284,000*	413,350,764*
21++	1984*	120	110	1452	UMT	/84	52,221,000*	465,571,764*
	1990*			2200++		/90		

Note: UMT is Union Oil Company, Magna Power Company, and Thermal Power Company; TGI is Thermogenics, Inc., a subsidiary of Hughes Aircraft Company; PEC is Pacific Energy Corporation; A is Aminoil USA.

*Estimated
+Under Construction
**Permits Pending
++Planned

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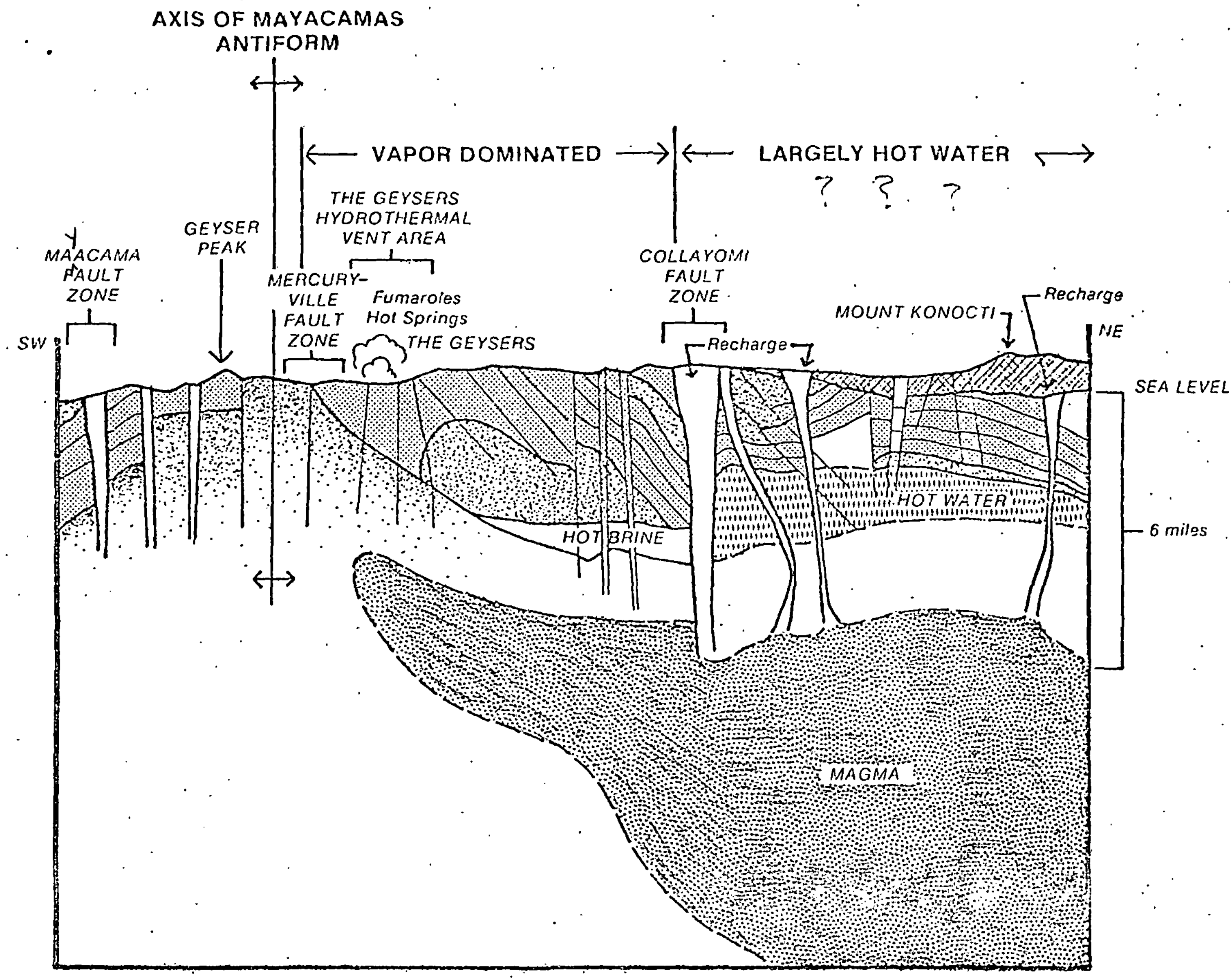

Figure I: CROSS SECTION THROUGH THE GEYSERS—CLEAR LAKE REGION

▒	Impermeable cap rocks (Serpetinite, greenstone, melange, metagraywacke)
⁘	Fracture networks in graywacke reservoir rocks
▩	Clear Lake Volcanics and associated vents providing recharge to geothermal system
▓	Partially crystallized magma body inferred to be at depth with center below 10 kilometers
☐	Water vapor in steam reservoir above boiling water table
▥	Hot water

Structural model for the Geysers geothermal system. Cross-section through The Geysers-Clear Lake region, from the Maacama fault zone on the southwest, to Mount Knocti on the northeast, depicting structural elements of The Geysers-Clear Lake geothermal system.

Source: "Field-trip Guidebook Castle Steam Field, Great Valley Sequence," April 29, 1978, 53rd Annual Meeting, Pacific Sections AAPG, SEPM, SEG. Modified by the California Energy Commission, February, 1979.

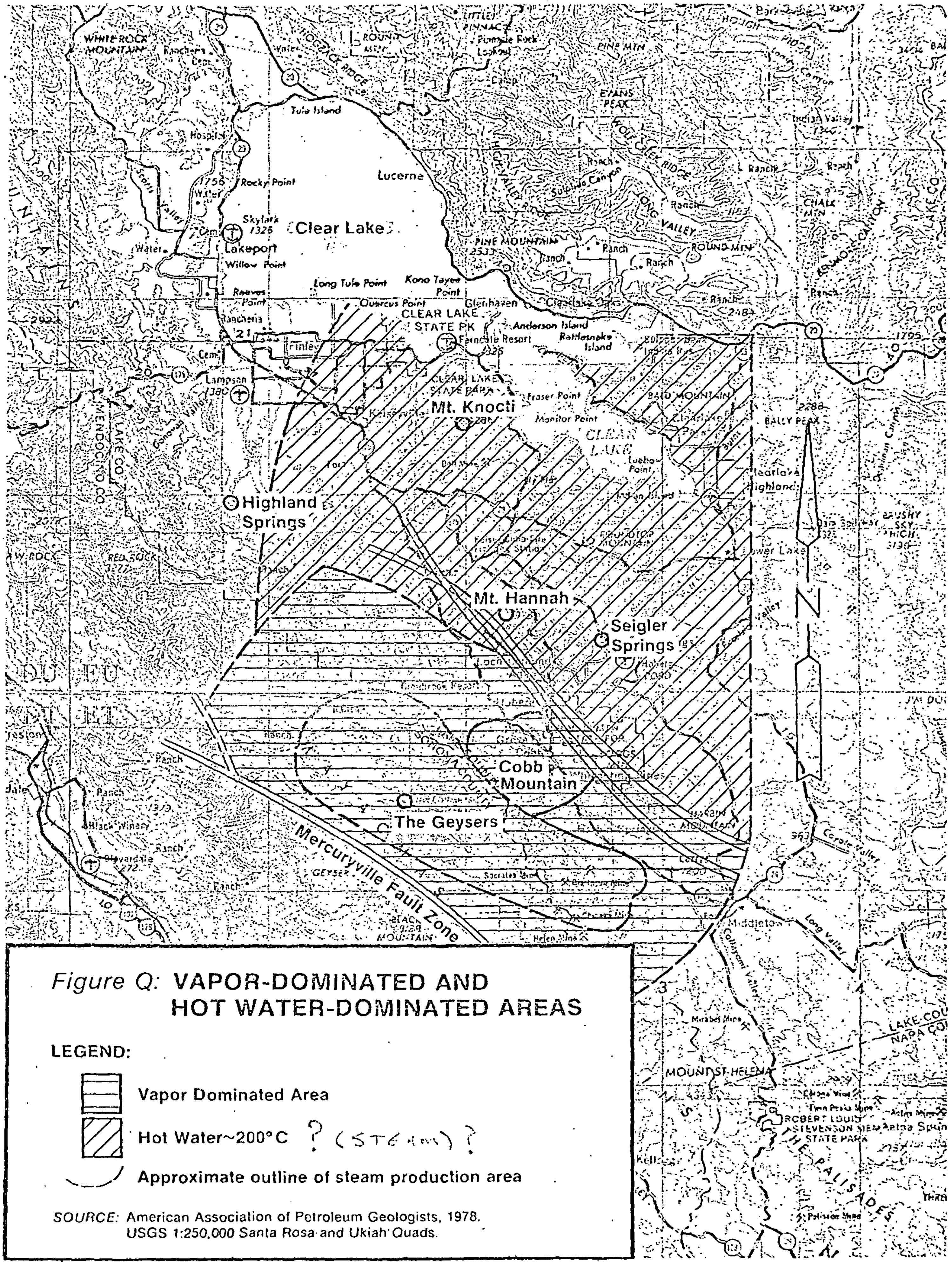

Figure Q: VAPOR-DOMINATED AND HOT WATER-DOMINATED AREAS

SOURCE: American Association of Petroleum Geologists, 1978.
USGS 1:250,000 Santa Rosa and Ukiah Quads.

CHINESE-ENGLISH DICTIONARY AVAILABLE

A modern Chinese-English Dictionary (Han Ying Ci Dian) is available. Published by the People's Republic of China it presents translations of Chinese characters, pinyin spellings, and brief explanations in English. ?

Since these Dictionaries must be specially ordered may we request you place your order with us if you wish a copy. Please send us your full name, address, zip code, and telephone number together with a check or money order for $30 and we will place a group order, obtain the Dictionaries from the People's Republic of China's agent, and mail one to you.

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GEOTHERMAL ENERGY INSTITUTE
P. O. Box 1287
Natchez, MS 39120

We are preparing a survey of geothermal operations and prospects in the People's Republic of China, Indonesia, and Japan. We will be meeting with a PRC geothermal delegation in June and will be traveling to Indonesia, China, and Japan in July and August.

If you would be interested in sponsoring our trip and receiving a copy of the report we will prepare, please contact me by June 8, 1979.

Donald F. X. Finn

Donald F. X. Finn
Managing Director

601-442-1601

THE GEOTHERMAL POTENTIAL OF THE REPUBLIC OF CHINA

By: Donald F. X. Finn
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Tel.: 601-442-1601

Geothermal exploration activities began on Taiwan in 1966. Three principal geothermal areas have been delineated: Tatun; Tuchang-Chingshui; and Lushan. Eight potential geothermal areas have been located. In 1977 a 1.5 MW non-condensing turbogenerator set was installed at Chingshui. One well supplying steam at a pressure of 8 kg/cm^{2}g and a temperature of 170°C is used to generate 500 KW of electricity.

A 400 KW geothermal power plant was installed at Sanhsing Village, Yilan in April 1979. A 300 KW plant is being installed one kilometer away and will begin operations in 1980. The facilities are called 'The Chingshui Geothermal Power Plant.'

The geothermal power potential at Tatun has been estimated at 100-560 MW. Shallow acidic geofluids have heretofore been an obstacle to the development of a 293°C reservoir. Recent geochemical surveys suggest that a non-acidic geofluid reservoir exists at depth (below 1 m) and investigations are continuing to determine if it in fact exists.

Exploration is underway at Lushan where geofluids at 168°C have been encountered at 227 m.

Eight hot spring areas have been preliminarily evaluated at Wulai; Szechu; Moupien; Juishui; Leetau; Chipen; Kuantzeling; and Tungpu where temperatures range from 42°C to 99°C.

The ROC Mining Research & Service Organization has constructed a pilot project to demonstrate the direct use of geothermal steam for agricultural purposes. A 40 m^3 lumber drying kiln, a 99 m^3 horticulture greenhouse, and an 165 m^2 laboratory for testing soil sterilization, cereal drying, and shrimp and poultry cultures was completed in 1975. A vegetable greenhouse and speciality wood drying kiln has also been constructed.

As of 1978 the total installed generating capacity on Taiwan was 7,683 MW of which 52% was oil-fired, 18% was hydro, 17% was nuclear, and 13% was coal. Over 98% of Taiwan's oil is imported. Onshore natural gas production is about 1.96 billion cublic meters annually.

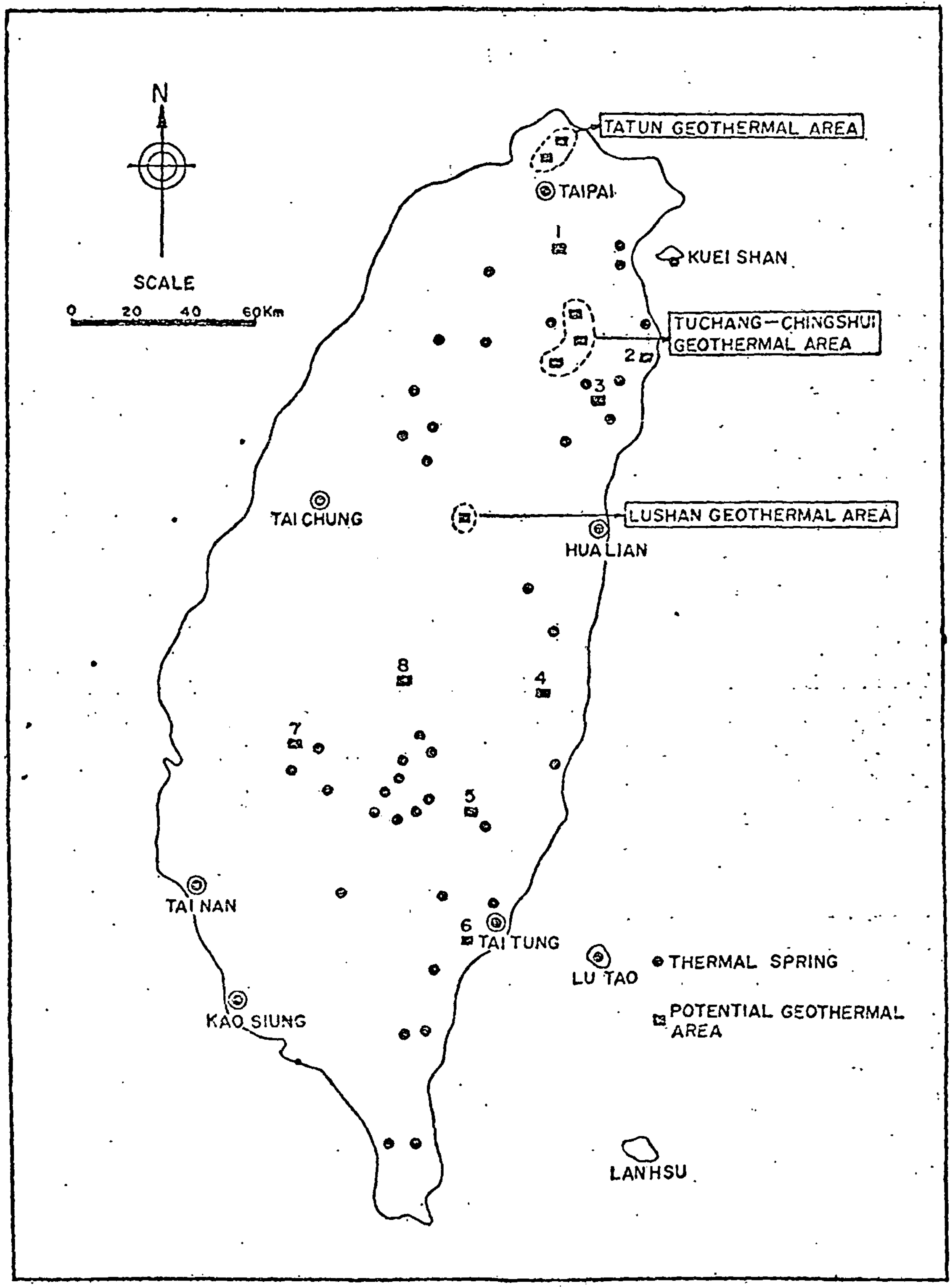

Fig. 1. Geothermal Areas in Taiwan

REVISED UP-DATE ON THE GEYSERS - May 1979

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May 21, 1979

8/3/82

GEOTHERMAL ENERGY RESOURCE ASSESSMENT OF PARTS OF ALASKA

by

Eugene M. Wescott and Donald L. Turner

Final Report to:

The Division of Geothermal Energy of the U.S. Department of Energy
Under Cooperative Agreement DE-FC07-79-ET-27034

Principal Investigators:

Eugene M. Wescott
Donald L. Turner
Juergen Kienle

August 1982

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SUMMARY

Under the sponsorship of the U.S. Department of Energy, the Geophysical Institute in cooperation with the Alaska Division of Geological and Geophysical Surveys has investigated the geothermal energy potential of several areas in Alaska. This report primarily summarizes the effort of the Geophysical Institute although other personnel and agencies participated in some of the work.

Detailed site-specific geologic, geophysical and geochemical surveys were carried out in the vicinity of Pilgrim Springs, Alaska in 1979 and 1980. Preliminary test drilling by the State of Alaska confirmed the existence of a near surface reservoir 50 m thick and about 1 km^2 in area with artesian flow at a temperature of 90°C and up to 400 gallons per minute from six inch diameter wells. A state funded exploratory drilling program is now in progress.

In 1980 a reconnaissance survey of the central Seward Peninsula revealed evidence of extensive tensional tectonic features suggestive of an incipient rift system. Although no new geothermal resource areas were discovered, the proposed rift model should be useful for future more detailed geothermal studies.

In the interior of Alaska, hot springs are typically associated with fracture systems near the margins of granitic plutons. Two areas have been studied in detail: Chena Hot Springs about 96 km east of Fairbanks and Manley Hot Springs 145 km west of Fairbanks. Both areas show helium and mercury anomalies. Privately funded drilling is scheduled at Manley Hot Springs for the summer of 1982.

In 1981 an extensive helium soil gas sampling program and a gravity survey were carried out in the lower Susitna Basin where several wildcat

wells were found to have anomalously high temperatures at accessible depths. The results indicate the presence of discontinuous geothermal reservoirs of about 40 square miles in area in the Willow-Big Lake area, perhaps at depths accessible to water well drilling rigs.

Geophysical and geochemical surveys were also carried out in 1981 on Unalaska and Akutan Islands in the Aleutian Islands jointly with the Alaska Division of Geological and Geophysical Surveys. At Summer Bay on Unalaska Island a suite of geophysical and soil sampling techniques have outlined a near surface reservoir of warm water. At Akutan these techniques discovered a much hotter and more extensive reservoir. Scientific reports on this work will be published under the auspices of the Alaska D.G.G.S. later this year.

The scientific reports and papers produced under this program and other Alaskan geothermal studies are listed in Appendices A and B.

Geothermal Investigation of Pilgrim Springs, Alaska

INTRODUCTION

Pilgrim Springs, Alaska was the subject of an intensive geophysical and geological survey during June-August, 1979. The springs are located on the Seward Peninsula, about 75 km north of Nome (Figure 1). Earlier studies, including a reconnaissance geological and geophysical survey by Forbes, et al. (1975), and geochemical studies of Pilgrim Springs water by the U.S. Geological Survey (Waring, 1917; Miller, et al., 1975) had indicated that Pilgrim Springs might be an important geothermal target.

Geophysical Institute personnel were responsible for project management, bedrock mapping, geophysical surveying, analysis and integration of field data, and preparation of the final report. Alaska Division of Geological and Geophysical Surveys (A.D.G.G.S.) personnel were responsible for surficial mapping, geological supervision and logging of test drill holes, geochemical analyses, and preparation of the sections of a report covering these areas (Turner and Forbes, 1980).

Base camp was established at Pilgrim Springs, Alaska on June 16, 1979. The field program was initiated with the thermal gradient measurements which were accomplished with driven probes on a 100 meter grid. Helicopter supported mapping produced a 1:63,360 scale geologic map of the surrounding area. A surficial geologic map of the area was prepared at a scale of 1:63,630 by the A.D.G.G.S. (Klein, 1982). Mapping, temperature measurement and electrical conductivity work was completed by July 15, 1979. Seismic, resistivity, and gravity studies were completed on July 29, 1979, and the camp was closed on July 31, 1979.

A preliminary report to the Alaska Division of Energy and Power Development (A.D.E.P.D.) with analysis of field data and drilling

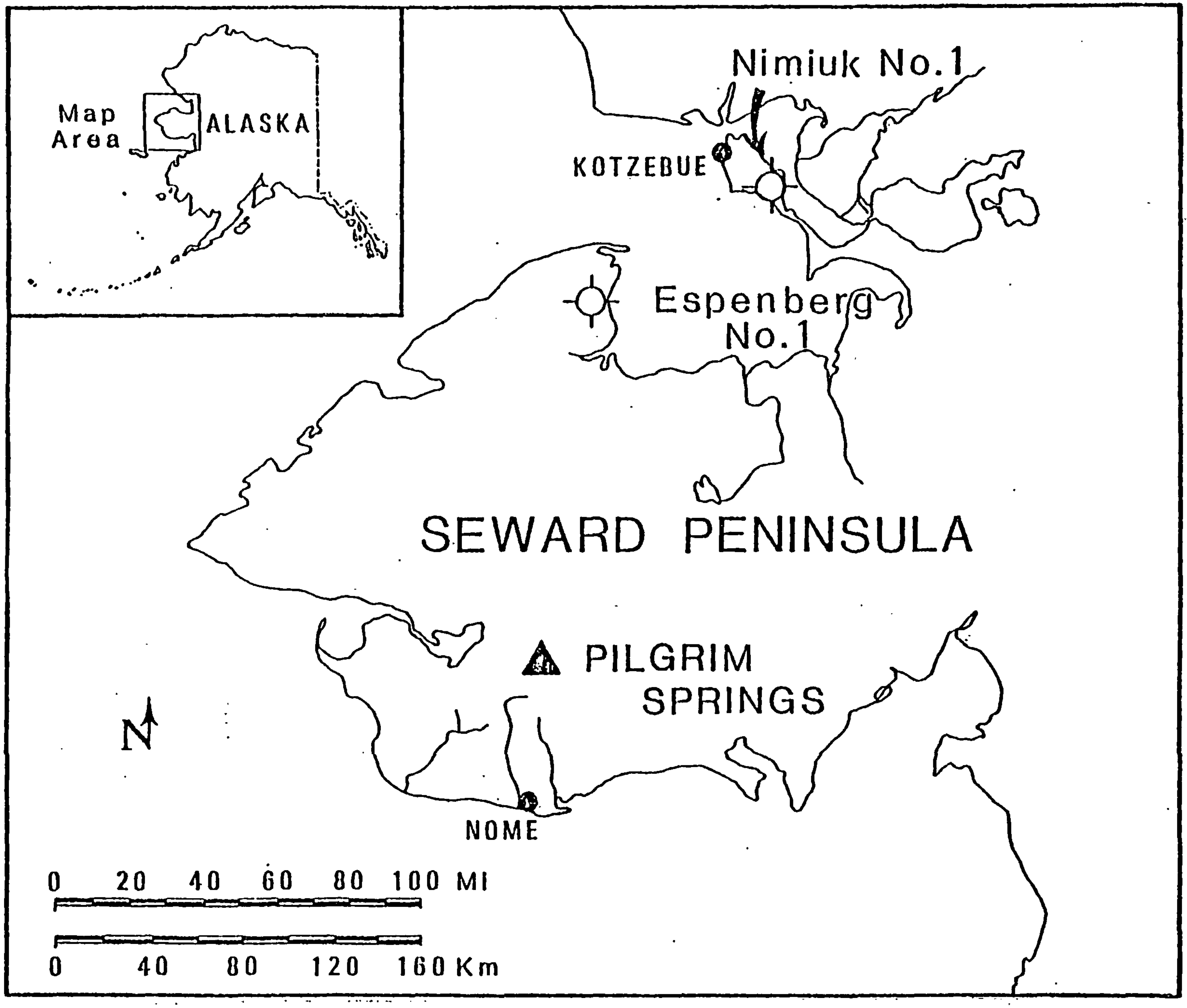

Figure 1. Location of Pilgrim Springs.

recommendations was completed in late August, 1979 (Forbes, et al., 1979). Based on the recommendations of the report, the A.D.E.P.D. contracted for two 15-ft test drill holes which were drilled in November, 1979, with geologic supervision and logging by the A.D.G.G.S.

Our final project report (Turner and Forbes, 1980) contains a more extensive analysis of the results of the geological and geophysical surveys than was presented in the preliminary report. It also provides a preliminary discussion of the recent initial exploratory drilling results and recommendations for phase-two geophysical surveys, hydrologic studies, exploratory drilling and geochemical studies, as summarized in the following section.

The Geophysical Institute part of the Pilgrim Springs study was supported by funding from the U.S. Department of Energy, Division of Geothermal Energy ($97,000); State of Alaska Division of Energy and Power Development ($56,000); Comprehensive Employment Training Act ($20,000); and National Science Foundation, Division of Polar Programs, Polar Earth Sciences Section, NSF Grant DPP77-20462 ($15,000).

SUMMARY

The Pilgrim Springs geothermal area, located about 75 km north of Nome, was the subject of an intensive, reconnaissance-level geophysical and geological study during a 90-day period in the summer of 1979. The thermal springs are located in a northeast-oriented, oval area of thawed ground approximately 1.5 km^2 in size, bordered on the north by the Pilgrim River. A second, much smaller, thermal anomaly was discoverd about 3 km northeast of the main thawed area. Continuous permafrost in the surrounding region is on the order of 100 m thick.

Present surface thermal spring discharge is ≈ 4.2×10^{-3} m^3 s^{-1} (67 gallons/minute) of alkali-chloride-type water at a temperature of 81°C. The reason for its high salinity is not yet understood because of conflicting evidence for seawater vs. other possible water sources. Preliminary Na-K-Ca geothermometry suggests deep reservoir temperatures approaching 150°C, but interpretation of these results is difficult because of their dependence on an unknown water mixing history. Based on these estimates, and present surface and drill hole water temperatures, Pilgrim Springs would be classified as an intermediate-temperature, liquid-dominated geothermal system.

The springs are located in the Pilgrim River Valley, a fault-bounded tectonic depression, or graben, flanked on the north and south by mountains composed of highly-deformed, upper amphibolite facies metamorphic rocks of probable Precambrian age, cut by discordant granitic plutons of probable Mesozoic age. Seismic, gravity and resistivity surveys indicate that the crystalline basement of the valley floor is at least 200 m beneath Pilgrim Springs, much deeper than was previously believed. The gravity data also suggest that Pilgrim Springs is near the intersection of two inferred fault zones forming the corner of a deep, downdropped basement block.

The seismicity of the area indicates currently active normal faulting. Mapped north-south trending faults in the Kigluaik Mountains south of Pilgrim Springs may extend through the downdropped crystalline basement under the Pilgrim River Valley. One or more of these faults could possibly provide a deep conduit for the geothermal system. Surficial geologic mapping indicates considerable subsidence of the Pilgrim River Valley during Quaternary time. A north-south trending Quaternary fault extends across the valley and appears to coincide with the western boundary of the main thawed area. Resistivity studies confirm the presence of this fault but do not suggest that it is presently serving as a hot water conduit in the vicinity of our resistivity profile.

Geologic evidence suggests that the low-lying region extending from the Imuruk Basin through the Kusitrin Valley to the Imuruk lava fields may represent an incipient rift through the Seward Peninsula. We therefore propose that the manifestations of anomalous heat flow (young volcanism and alkali-chloride hot springs) in this region may be associated with tensional tectonics and active rifting.

Resistivity surveys have located a shallow, 50 m-thick, pancake-shaped reservoir of hot, saline water about 1 km^2 in area under Pilgrim Springs (Figure 2a-b). Shallow ground electromagnetic surveys (used here for the first time in a geothermal area), ground temperature surveys and modelling of convection cells have been used in conjunction with deep resistivity surveys to determine drilling targets within the area of this reservoir. Thermal, hydrologic and geologic models of the total geothermal system suggest that hotter reservoirs could be present at greater depths. Computer modelling of resistivity data does not rule out this possibility.

Two 50 m exploratory test holes, separated by 100 meters, were drilled in November, 1979, in the area of the primary drilling target recommended in our preliminary report. Artesian aquifers were encountered in a 20-30 m depth interval. Flow rates were estimated at 200 and 300-400 gallons per minute, respectively, at a temperature of 90°C.

Preliminary hydrologic studies involving a Pilgrim River temperature survey and ground water flow estimates calculated from temperature profiles have resulted in a proposed water balance model and power estimates for

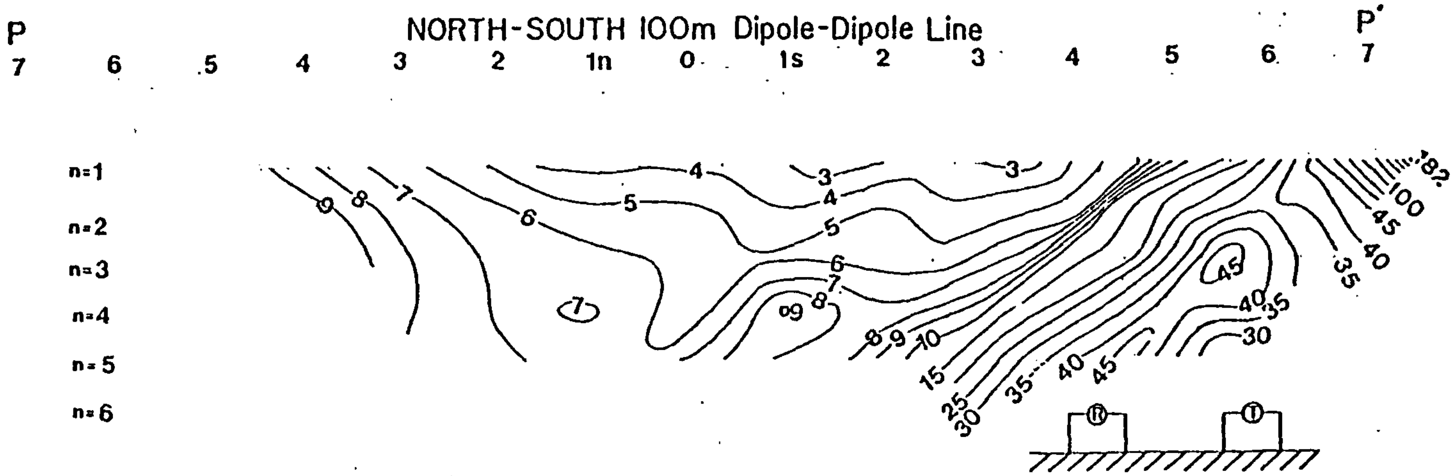

Figure 2a. Field data, N-S 100 m dipole-dipole pseudosection. Station numbers in hundreds of meters (e.g., 1S = 100 m south of origin).

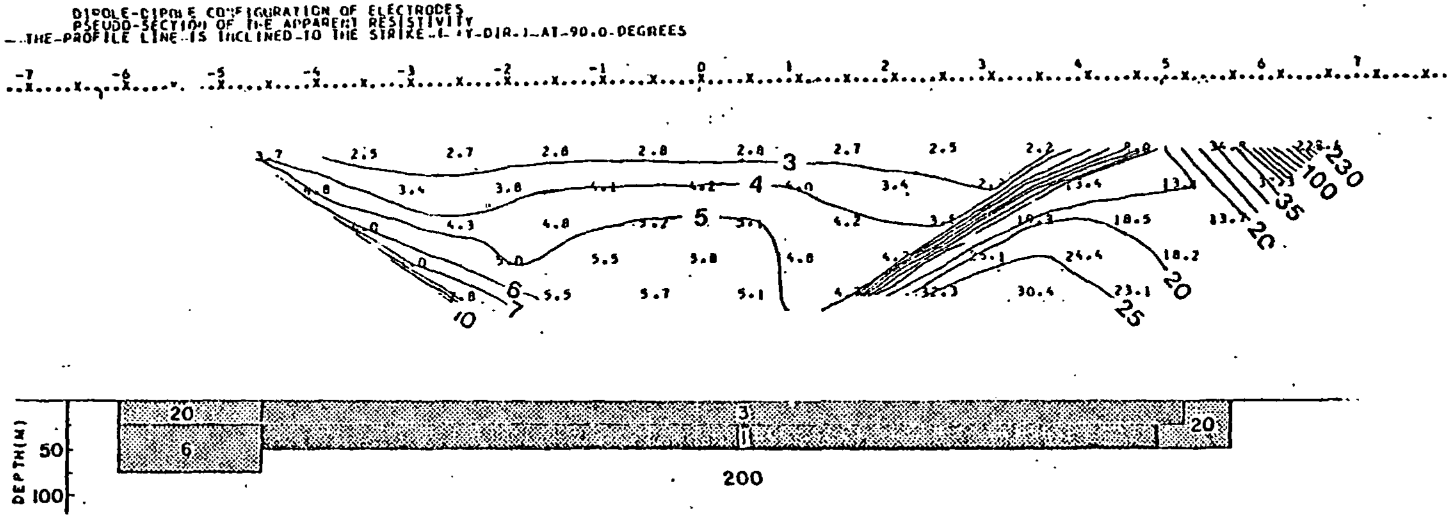

Figure 2b. Two dimensional computer model of the basic shallow reservoir structure underlain by rocks of greater resistivity. All values in Ω-m.

the geothermal system. This analysis suggests that the power presently being dissipated from the upper 50 m of the system is a minimum of 350 megawatts (MW), with more than 300 MW of this amount in subsurface groundwater discharge beneath the Pilgrim River (Osterkamp et al., 1980; Gosink et al., 1980). The accessible resource base for the upper 50 m of the system referenced to 0°C is estimated at 500 MW. The beneficial power available for direct (nonelectric) use is estimated at 30 MW. Referencing these estimates to 15°C would reduce them to 2/3-3/4 of the above values. Quantitative estimates of the electrical power potential will depend on engineering and reservoir parameters which are presently unknown. It is clear, however, that the electrical power potential will probably be a small fraction of the 30 MW beneficial power estimate.

We emphasize that many hydrologic measurements are preliminary, based on reconnaissance-level studies, and that our preliminary power estimates should be viewed with caution until they can be tested by more extensive field measurements and analysis.

CONCLUSIONS

Our reconnaissance-level studies suggest that the Pilgrim Springs area is underlain by an intermediate-temperature, liquid-dominated geothermal system (Muffler, 1979) of substantial magnitude. Initial exploratory drilling has confirmed the presence of the shallow, ≈ 1-1.5 km^2 hot water reservoir delineated by our geophysical surveys. Large artesian flow rates of 200 and 300-400 gallons/minute of 90°C water indicate that at least one good aquifer is present at shallow depths within this reservoir. Resistivity surveys suggest that the shallow reservoir is approximately 50 m thick. Deeper hot water reservoirs may also be contained in the thick sedimentary section identified by the seismic and gravity surveys, but they have not as yet been located by our initial resistivity surveys.

Our analysis indicates that the power presently being dissipated from the upper 50 m of this geothermal system is a minimum of 350 megawatts (MW), with more than 300 MW of this amount in subsurface groundwater discharge beneath the Pilgrim River. The accessible resource base (Muffler, 1979) for the upper 50 m of the system referenced to 0°C is estimated at 500 MW. The beneficial power (Muffler, 1979) available for direct (nonelectric) use is estimated at 30 MW.

These power estimates are referenced to 0°C, the approximate mean annual ground temperature in the unthawed region surrounding Pilgrim Springs, and a value close to the mean annual air temperature (-3.5°C at Nome). Referencing these estimates to 15°C would reduce them to 2/3-3/4 of the above values.

The available evidence indicates that the geothermal system at Pilgrim Springs is not likely to have steam temperatures at depth which are adequate for economic production of electricity using conventional steam turbine generation technology. Pilgrim Springs does appear to have excellent potential for the production of hot water for direct heat applications and, perhaps, an as yet undetermined quantity of relatively low-temperature steam. Such a system is capable of generating moderate amounts of electricity for local community use, particularly if Rankin-cycle turbines are used. These turbines utilize an organic working fluid, such as isobutane, which flashes to vapor at a temperature well below the boiling point of water. The organic fluid is heated by passing through a heat exchanger coupled to the geothermal system.

Estimation of the electrical power potential of Pilgrim Springs must depend on engineering parameters associated with this special technology, as well as ultimate reservoir temperatures and production parameters which are presently unknown. It is therefore premature to attempt a quantitative estimate of electrical power potential at this time, except to state that it will probably be a small fraction of the 30 MW beneficial power (non-electric) estimate.

Further discussion of engineering applications is beyond the scope of this report. Engineering, developmental, and economic studies should be initiated as soon as the next phase of geophysics, hydrology, and exploratory drilling, and geochemistry are completed and the extent and magnitude of the hydrological and thermal regimes in the geothermal resource have been delineated.

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Geothermal Reconnaissance of the Central Seward Peninsula

INTRODUCTION

This was the third of a series of reports on the geothermal energy resources of the Seward Peninsula. Our two previous reports focused on Pilgrim Springs (Figure 1) and gave the results of geological, geophysical, geochemical and hydrologic studies, accessible power estimates and recommendations for follow-on studies and exploratory drilling targets (Forbes et al., 1979; Turner and Forbes, 1980).

During our 1979 investigations at Pilgrim Springs we developed the hypothesis that these hot springs were associated with tensional tectonics and active rifting. We also proposed that the low-lying region extending from the Imuruk Basin through the Kuzitrin Valley to the Imuruk lava field (Figure 3) represents an incipient rift through the Seward Peninsula (Turner and Forbes, 1980)

In July 1980, we conducted a helicopter-supported geological and geophysical reconnaissance survey of the central Seward Peninsula, designed to test the rift hypothesis and to provide information on the regional geothermal energy potential of the area. The results of this work, together with our previous studies have provided evidence for a tectonic model of active rifting extending 250 km across the central Seward Peninsula and offshore into the Bering Sea. This rift model should be useful as a working hypothesis and an exploration model for future, more detailed geothermal studies on the Seward Peninsula.

In order to increase scientific yield as well as cost effectiveness, we operated a combined field camp with our NASA-supported project designed to test the effectiveness of remote-sensing (synthetic aperture radar and thermal infrared) techniques in the exploration and assessment of geothermal

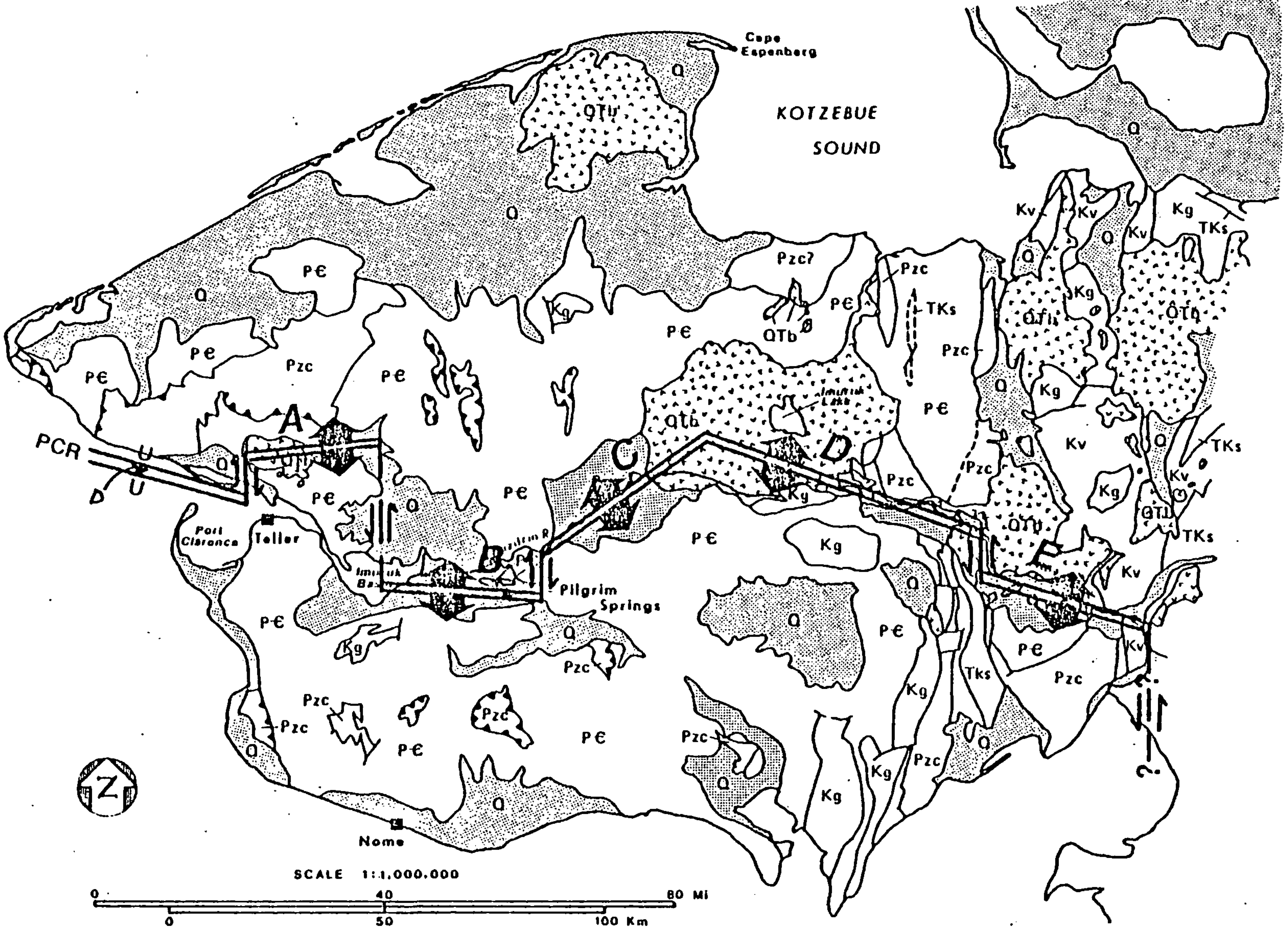

Figure 3. Diagram of proposed rift model for the central Seward Peninsula. The graben structure offshore (PCR) is the Port Clarence Rift (Hopkins et al., 1974). Geology generalized from Hudson (1977) and Hopkins et al. (1974).

energy resources. The Pilgrim Springs area was utilized as a known geothermal target for this study. The results of the remote sensing study are included in this report and integrated with our geological and geophysical work.

SUMMARY

The central Seward Peninsula was the subject of a geological, geophysical and geochemical reconnaissance survey during a 30-day period in the summer of 1980. The survey was designed to investigate the geothermal energy resource potential of this region of Alaska. Based upon our previous work (Turner and Forbes, 1980) and the 1980 survey, we have proposed a continental rift system model to explain many of the Late Tertiary-to-Quaternary topographic, structural, volcanic and geothermal features of the region. Geologic evidence for the model includes normal faults, extensive fields of young alkalic basalts, alignment of volcanic vents, graben valleys and other features consistent with a rift system active from late Miocene time to the present. Rift systems in many parts of the world are known for their abnormal heat flow and significant geothermal potential.

Five traverses crossing segments of the proposed rift system were run to look for evidence of structure and geothermal resources not evident from surface manifestations. Gravity, helium and mercury soil concentrations were measured along the traverses. Both helium and mercury soil concentrations have been shown elsewhere to be useful indicators of geothermal resources. We found that mercury soil content varied widely along the traverses and cannot be used to identify areas of interest in the environment of the central Seward Peninsula. Helium in soil gas, however,

offers great promise as a geothermal exploration tool. Our surveys found numerous He anomalies that tend to support the rift model. With the exception of two sampling sites, all helium anomalies were found near proposed rift segments. Several areas of significant helium soil gas concentration warrant closer study in any further detailed exploration for geothermal resources.

Gravity profiles across the proposed rift segments generally show features consistent with a rift system. One traverse, the Noxapaga, has been interpreted by a two-dimensional model, and can be explained by low density sediments filling a valley 1.25 km deep and 32 km wide. Geologic evidence indicates that this valley is a structural feature (graben). Gravity profiling across the Pilgrim River Valley also appears to agree with a graben structure, as supported by geologic evidence.

A long-spaced seismic refraction line was run in the Pilgrim River Valley at Pilgrim Springs to determine the depth to crystalline bedrock. Despite some intrumental problems a depth of 425 m was obtained. Previous depth estimates were much shallower (> 200 m; Turner and Forbes, 1980). The revised depth estimate suggests that deeper geothermal reservoirs may be present and that the reservoir potential of the Pilgrim Springs geothermal resource area may be even greater than was previously estimated (Turner and Forbes, 1980).

We also carried out deep resistivity and VLF studies in the Pilgrim River Valley to further our understanding of the nature of the geothermal resources at and outside of the hot springs area. Three-dimensional modelling of galvanic resistivity generally agrees with a shallow reservoir as determined by drilling but does not rule out deeper significant reservoirs in the 425 m of valley fill. VLF and galvanic resistivity measurements confirm the existence of low resistivity (presumably hot saline water) under a zone along the Pilgrim River and under a small thawed area 4 km northeast of Pilgrim Springs. We found that the VLF EM-16R technique agreed well with galvanic resistivity measurements and could be very useful as a regional exploration tool.

A National Aeronautics and Space Administration study of remote sensing techniques in the Central Seward Peninsula was also carried out in 1980, centered on Pilgrim Springs. Radar measurements proved to be useful in locating linear features under the vegetation which are useful in structural mapping and geothermal resource exploration. Thermal infrared imagery disclosed three warm ground zones in the Pilgrim Springs vicinity under less than ideal conditions. However, the interpretation of infrared imagery appears to be too difficult and expensive to be useful in regional studies of significantly larger areas.

We did not discover any new geothermal resource areas in our 1980 work. However, we have established that the central Seward Peninsula may contain a continental rift system with some areas of abnormal helium soil gas concentrations and likely abnormal heat flow, suggesting that the geothermal energy potential of the area is high, and that Pilgrim Springs may only be the "tip of the iceberg".

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Geothermal Investigations of Chena Hot Springs, Alaska

INTRODUCTION

Chena Hot Springs are located about 96 km east of Fairbanks, Alaska on a good, all-weather road (see Figure 4). The springs were known from the gold rush days and are currently owned by the "Chena Hot Springs Group", a limited partnership. Extensive resort development is now well underway. Guidance for future drilling to expand production from the geothermal reservoir is desired.

The Springs flow from alluvial fill in the Valley of Monument Creek. The valley fill is underlain by quartz monzonite of the Chena Pluton, which was emplaced about 58 m.y. ago.

The Chena Hot Springs area was the subject of a Masters thesis project in 1973-74 by Norma Biggar under the direction of Dr. R. B. Forbes. This project marked the beginning of geothermal assessment and resource definition studies by the Geophysical Institute of the University of Alaska. The first half of the report edited by Wescott and Turner, (1981) is an abridged and updated version of Biggar's thesis.

A ground temperature survey at 0.5 m depth defined a narrow, southeast-trending anomaly pattern with a maximum temperature of 48°C (Figure 5). The elongated orientation of this anomaly parallels a dominant set of shear zones and faults in the granitic pluton. Analysis of 1979 U-2 aerial photography indicates the presence of a bedrock fault adjacent to the temperature anomaly surrounding the springs and probably contiguous with it, suggesting that the thermal waters are rising along the fault system into the valley fill.

In August and September, 1979 geophysical crews from the Geophysical Institute conducted preliminary surveys at the Springs area to extend the earlier work and to explore to greater depths. In summer 1980 the

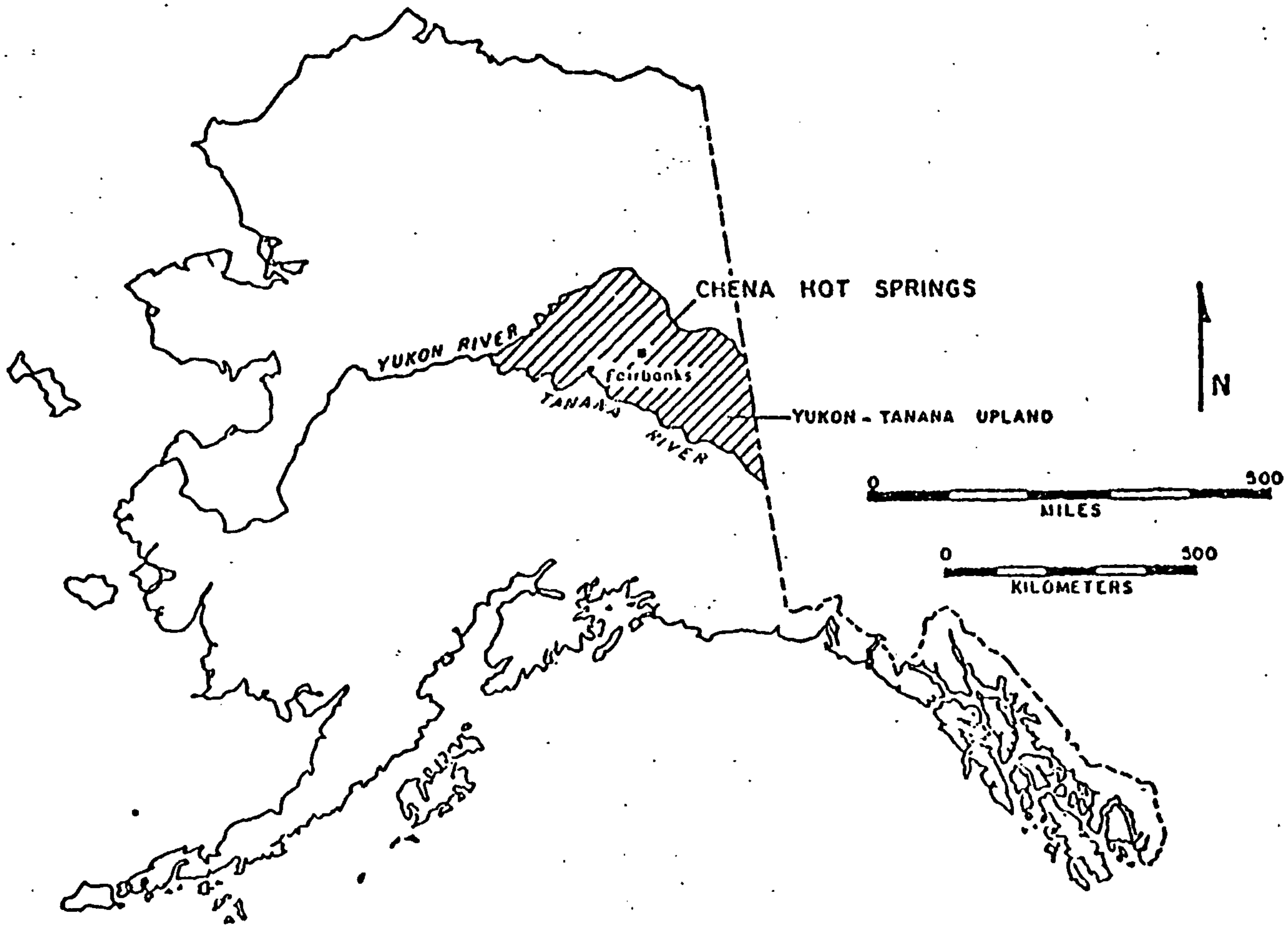

Figure 4. Map of Alaska, showing the Yukon-Tanana Upland and the location of the study area.

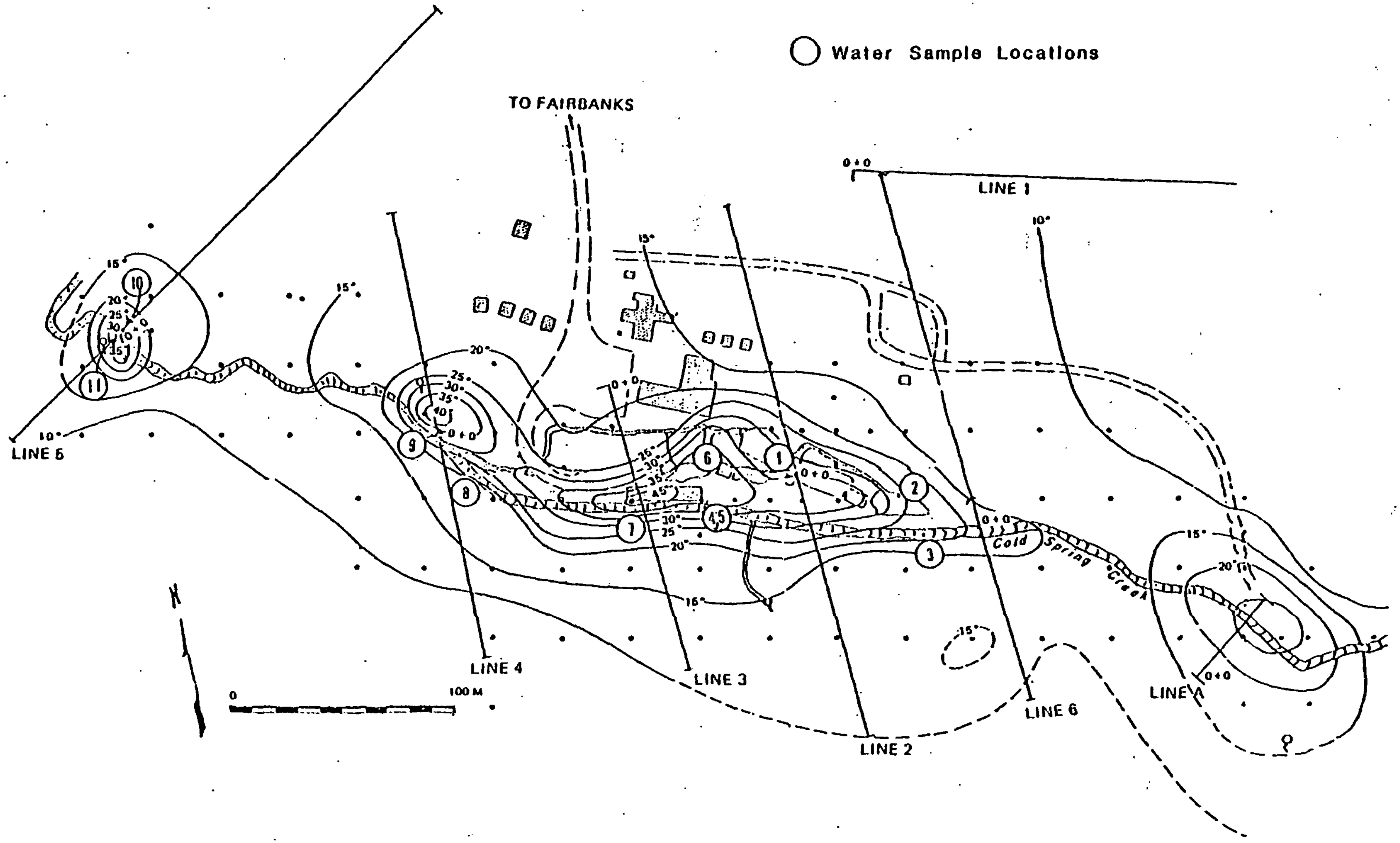

Figure 5. Shallow (0.5 m) isotherms, conductivity survey lines and water conductivity sample locations at Chena Hot Springs.

work was continued with geological mapping, helium and mercury soil sampling and further electromagnetic profiling.

SUMMARY

In August and September 1979 geophysical surveys were carried out. An electromagnetic survey was used to investigate the near-surface (~ 10 m) conductivity (Figure 5). In general, the zones of good conductivity were broader than the 0.5 m-depth temperature anomalies but confirmed the narrow, SE-trending thermal source.

Deeper galvanic resistivity measurements using the Schlumberger depth profiling method revealed that the quartz monzonite basement rocks under the alluvial fill are fractured and water-saturated to considerable depths. A resistivity contrast of 20:1 was found between the cold water and hot water-filled rocks.

A seismic refraction survey also indicates that the granitic "bedrock" reported in water well logs is fractured and water-saturated. Massive granitic rock was inferred to be present at a depth of about 40 m.

A pipe was driven to emplace a plastic tube for temperature and groundwater flow measurements. An impenetrable layer was encountered at 7.7 m, which is assumed to be the top of the granitic rubble zone. A downhole temperature maximum of 58.8°C was measured at 5.5 meters.

In summer 1980 helium and mercury soil sampling was carried out in the vicinity of the mapped thermal anomaly to establish the usefulness of these techniques in the area. Samples were also obtained in a much larger area of the Chena Pluton and towards Fairbanks. More shallow electromagnetic surveys were carried out in the vicinity of the thermal anomalies. Further geological mapping has defined the Chena Pluton contacts, petrological relationships and faults which seem to control the geothermal resource. No evidence for geothermal reservoirs other than below the known hot springs was found. Significant helium and mercury anomalies along the fault are recommended as drilling targets for expanded utilization of the resource.

CONCLUSIONS

Chena Hot Springs seems to be a classic example of hot springs formed by deep ground water percolating through a fracture system near the margin of a granitic pluton. Near-surface EM-31 conductivity surveys, helium and mercury soil sampling, and near-surface temperature measurements are all consistent with Biggar's hypothesis that the source of Chena Hot Springs is a southeast-trending fault in the quartz-monzonite of the Chena Pluton. The surface expression of this fault has been found on U-2 photographs and by ground geologic mapping in 1980.

Seismic and galvanic resistivity surveys penetrated into the bedrock underlying the sediments of Monument Creek Valley. Both methods indicate that the bedrock is fractured and water-filled to depths of about 40 m or more. Neither method found solid bedrock underneath the springs area, but the narrow, elongate nature of the thermal anomaly makes it difficult to explore with methods we employed.

Helium surveys in the vicinity of the hot springs proved to be very useful in delineating the regions of possible conduits for hot water. Helium brought near the surface by water rising up the fault will tend to be released and rise straight to the surface as pressure and temperature decrease. The significant helium anomalies are confined to a very narrow zone, presumably the trace of the fault. A very large helium anomaly at the northwestern end of the thermal anomaly is an attractive target for drilling into the conduit. Significant helium anomalies near the southeastern end of the thermal anomaly may also indicate that additional hot water could be reached by shallow drilling. Mercury soil values tend to correlate with near surface temperatures in the hot springs vicinity, but show large statistical fluctuations at sites in the greater Chena Pluton area probably not related to geothermal causes.

Our limited helium and mercury surveys in the Chena Pluton vicinity did not disclose any other geothermal prospects, but much more extensive surveys would be required to rule out other resources in the Fairbanks-Chena area. The U.S.G.S. Water Resources Division which measures stream flow in the Chena River reports that several stretches of the river between Fairbanks and Chena Hot Springs typically remain unfrozen during the winter (personal communication, 1980). Investigation of these areas to determine if warm springs are present is recommended for future work.

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Geothermal Investigations at Manley Hot Springs, Alaska

INTRODUCTION

Manley Hot Springs lies within the Yukon-Tanana upland physiographic province of the Interior of Alaska, near the junction of the Tanana A-2 and Kantishna River D-2 quadrangles, latitude 65° 00' N, longitude 150° 38' W (Fig. 6). By air, Manley is 145 km west of Fairbanks and 71 km east of the village of Tanana. State Highway 2, known as the Elliott Highway, connects Manley Hot Springs with Eureka, Livengood and Fairbanks along a 260 km gravel-surfaced road. From Manley Hot Springs, a road continues 21 km northeast to Tofty, an old placer mining district. Manley Hot Springs is also connected by a 5 km road to a barge landing on the Tanana River. The village of Manley Hot Springs is situated on the northern margin of the Tanana Valley along Hot Springs Slough, a 13 km long, shallow waterway which drains into the Tanana River. Elevations in the Manley Hot Springs area range from less than 260 feet for the Tanana Valley floor, to 2650 feet for the summit of Hot Springs Dome located to the northwest. The dome is the highest part of a narrow, 43 km-long, northeast-trending ridge known as Bean Ridge, which separates the Tanana Valley from a parallel valley occupied by Patterson and Baker Creeks.

The Manley Hot Springs area lies within the zone of discontinuous permafrost. Normal vegetation consists of thick brush on the upper slopes, and white spruce, black spruce, birch, aspen, poplar and scattered brush on the lower slopes. Trees are up to 0.6 m in diameter. The poorly drained portions of the lowlands consist of black spruce and muskeg-type vegetation. The climate is typical of the Yukon River valley; long, cold winters and short, warm summers with a possible range of

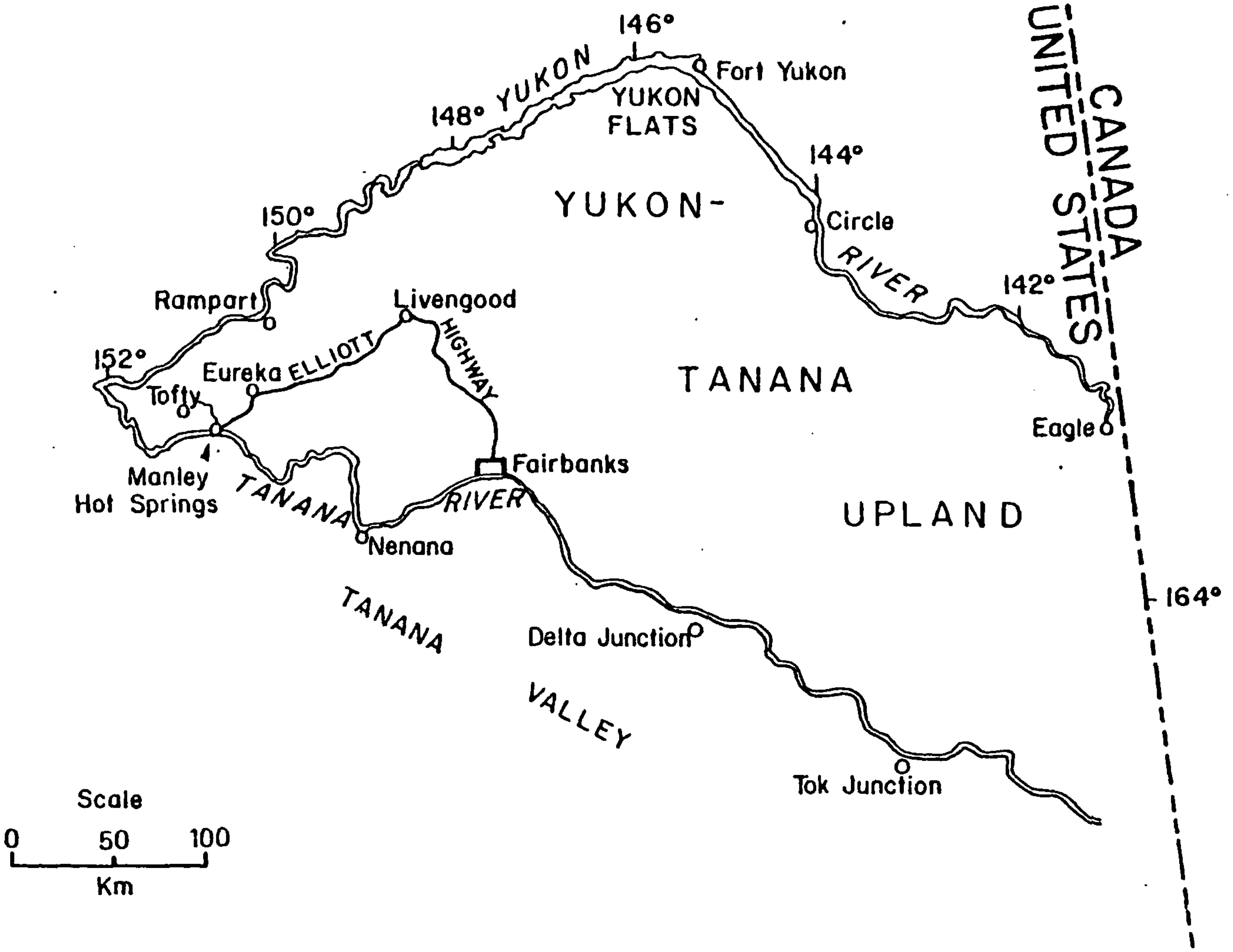

Figure 6. The Yukon-Tanana Upland physiographic province showing the location of Manley Hot Springs.

temperatures from 70° F below zero to 98° F above zero. The annual precipitation is 25 to 30 cm, most of which falls as rain through the summer months. The town has an airstrip, post office, store, lodge and elementary school. Power is supplied by diesel generator with a 40 kw capacity.

The main hot springs are 0.75 km north of the central part of town, and several occurrences of warm seeps are found within a 0.8 km radius of the main springs. In general, the warm springs and seeps occur near the base of east-facing slopes of Bean Ridge near the edge of the Tanana Valley. However, they are localized only along a 1.4 km long portion of these slopes between Ohio Creek and the highway road to Tofty. Charles and Gladys Dart own the hot springs and the surrounding 236 acres. They utilize the thermal water for space heating of their home and the operation of a 30 by 45 m greenhouse and a small public bath house. The hot springs also serve as the community's principle water source for drinking, washing, and other uses. The greenhouse is located next to the main springs and is used primarily for raising tomatoes. The tomatoes are sold locally and have also been shipped into Fairbanks where there is always a ready market. Other greenhouse vegetables which are sold locally include cucumbers, eggplants and melons. A few wells have been drilled adjacent to the Dart's land, and one of these has warm (29° C) water. However no wells have been drilled close to the hot springs. Water is piped and used as it flows from the spring mouths. Since the thermal water is mixing to some extent with ground water and/or water from Karshner Creek, drilling could result in hotter water with higher rates of flow. One of the main purposes of this study was to help delineate targets for drilling of a geothermal well to be drilled in the summer of 1982.

SUMMARY AND CONCLUSIONS

The Manley Hot Springs Dome stock is characteristically massive and well-jointed. Drilling done by the Bureau of Mines near the summit of Hot Springs Dome discovered almost complete oxidation of rock to a depth of 136 meters which was the deepest hole drilled. This suggests that the fracture permeability of the granite allows for migration of ground water to substantial depth from the dome summit, and quite possibly, the slopes of the dome. Hopkins and Taber (1962) show the margin of the Hot Springs Dome Stock as dipping moderately to gently underneath the "Boulder Ridge Formation" in the Manley Hot Springs area. The intersection of the granite-metasediment contact with the surface is approximately 0.6-0.8 km upslope of the hot springs. Hornfelsed sediments which include recrystallized, thin-bedded quartzite and "knotted" slates overlie granitic rocks in the Manley Hot Springs area. Contact metamorphism may have increased fracturing within these rocks, or water may be migrating along bedding planes in thin-bedded quartzite.

All of the springs and seeps appear to be issuing from surficial deposits of either loess or alluvium which overlies loess. The loess is composed of massive, homogeneous silt and may be fairly impermeable unless fractures are present. Cliff exposures of loess 10-30 meters in thickness are observed in the Manley Hot Springs area, however it is not believed that loess deposits attain thicknesses much greater than this. Gravel alluvium is found along the floor of Karshner valley. The valley conspicuously widens near the main hot springs, and two low knolls flank either side of the valley. The knolls are composed of highly permeable sand and gravel alluvium, and several hot springs flow near the base of one of the knolls. Other springs and seeps appear to issue from loess or at the base of loess cliffs. In general, the springs and the shallow, thermally disturbed ground are distributed over a 1.2 km long, northeast trending belt as shown in Figure 7. Variations in elevation of the springs suggest that they may be structurally and not topographically controlled.

Based on the above evidence, the following model is proposed for the low temperature geothermal system present at Manley Hot Springs: Ground water along the southeast slopes of Bean Ridge enters joints and fractures in granitic rocks of the Manley Hot Springs Dome stock. The water migrates deeply enough in the granite to be heated by a normal geothermal gradient of 30-50°C/km. Given a reservoir temperature of 137°C, derived from the cation geothermometers, this would imply migration to depth of about 2.5-4.5 km. As water is heated, it circulates towards the surface, eventually rising along bedding planes or fractures in hornfelsed "Boulder Ridge Formation" metasedimentary rocks. The overlying loess apparently acts as a caprock, allowing the hot water to migrate along the loess-metasediment interface. Areas of fracturing in the loess allow for final escape of thermal water to the surface, expressed as hot springs and seeps. Another method of escape of thermal water apparently involves sub-surface migration downslope to the main valley. This may be the case for some of the springs and one temperature anomaly.

The conspicuous widening of Karshner Valley near the main springs, as well as the differences in elevations of the spring sites suggests structural control for the springs. No faults were detected, but exposures are poor.

Future analysis of the water chemistry will aid in interpretation of sub-surface water-rock reactions, as well as the extent of mixing of thermal water with ground water. A seismic survey would aid in delineating the depth to basement in Karshner Valley, as well as possible faulting.

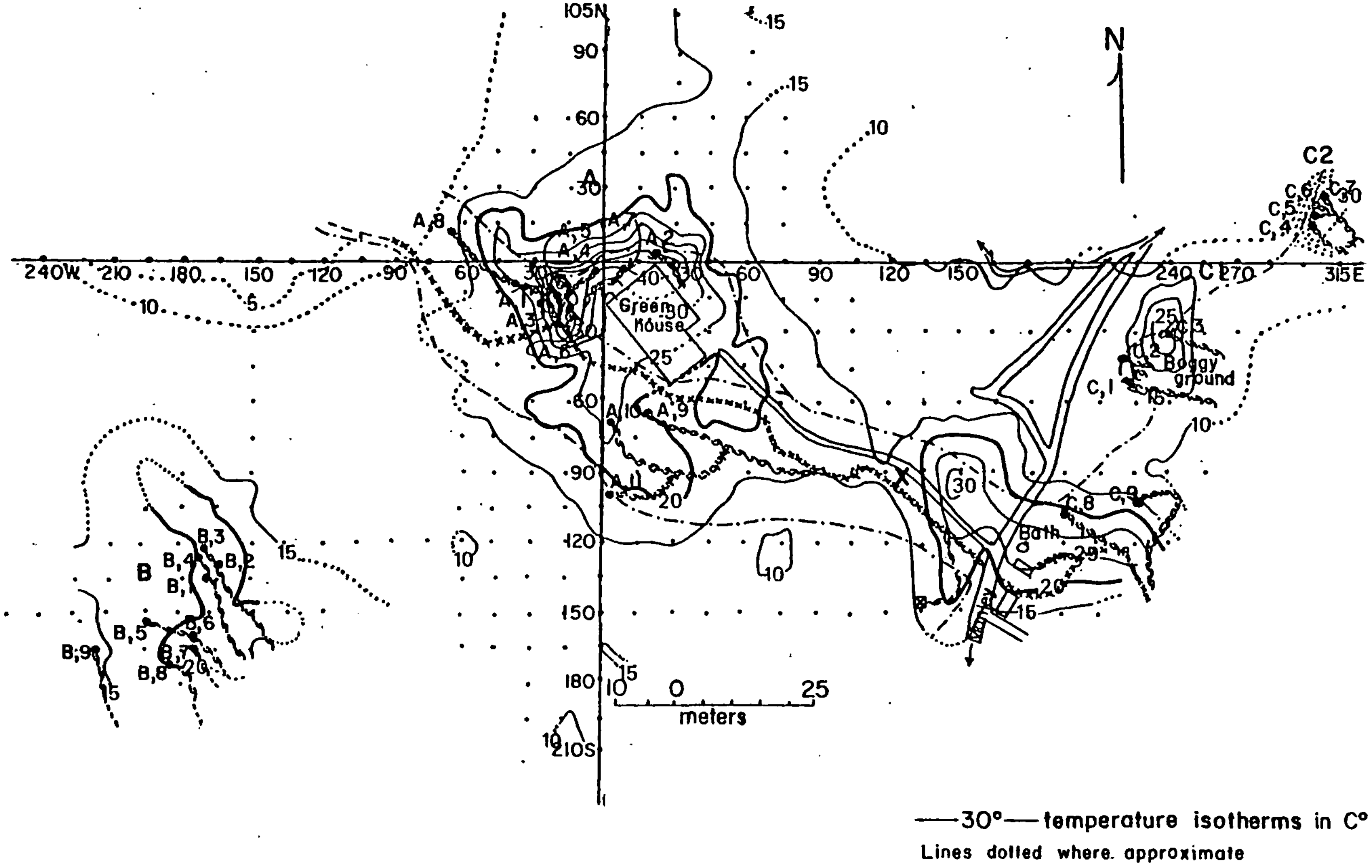

Figure 7. Shallow (0.5 m) isotherms and thermal spring locations at Manley Hot Springs.

More extensive helium surveys could be useful in defining areas of hot water migration and detection of the fault or fracture system which may control the Manley Hot Springs geothermal area.

Based on findings from the helium, temperature, mercury, and resistivity surveys, three localities at Manley Hot Springs were chosen as likely sites for a geothermal well (Figure 8). The first and most promising site is the area just north to northwest of the greenhouse, referred to as site 1. The area is an obvious choice, since the hottest springs are located here. Helium soil gas values are anomalously high, as are shallow ground temperature and shallow resistivity values. Site 2 is the second most likely site based on anomalous helium values. It is located on the floor of Karshner Valley near the intersection of drainages of several springs. Site 3, the third most likely drilling site, is located near a temperature anomaly just west of the main road on the north side of Karshner Creek Valley. It is characterized by anomalous temperature and resistivity values and anomalous mercury values occur several meters upslope. Helium soil gas values, however, are not anomalously high.

The thermal water of Manley Hot Springs has probably been mixed with cooler ground water and/or water of Karshner Creek. Drilling to an adequate depth could result in substantially hotter water, allowing for geothermal energy utilization on a much larger scale than at present.

The low-temperature geothermal resource present at Manley Hot Springs is a highly viable energy source, especially in light of its location near a small population center in the interior of Alaska. The work of Karshner and Manley in the early part of the century attests to the fact that Manley Hot Springs as well as other hot springs of the Interior, can be utilized on a much larger scale than they are presently. Agricultural

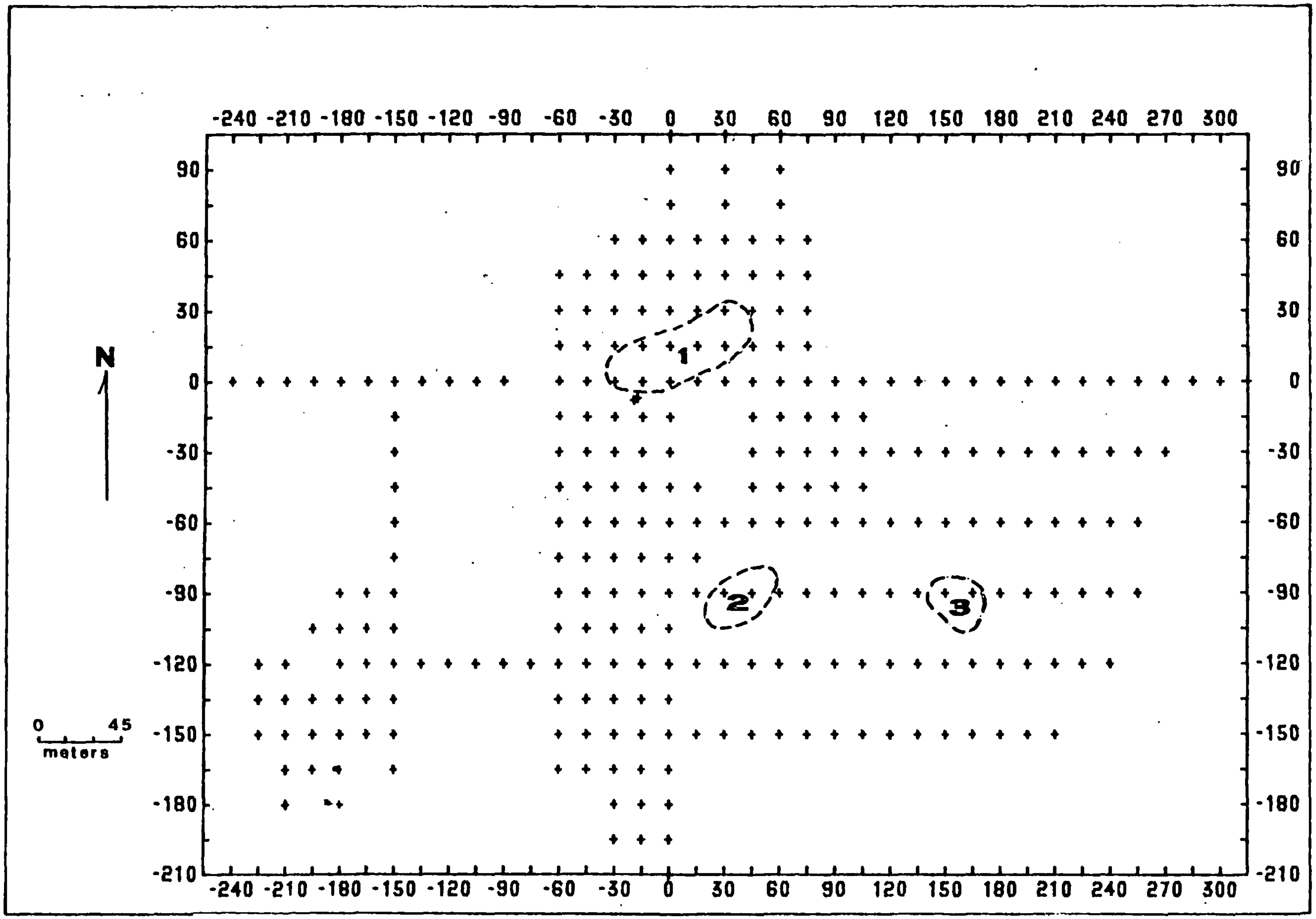

Figure 8. Proposed geothermal well sites.

production, spaceheating and even the generation of small amounts of electricity by geothermal means could be highly beneficial to surrounding communities.

A Preliminary Investigation of the Geothermal Energy Resources of the Lower Susitna Basin

INTRODUCTION

Four dry wildcat wells drilled in the lower Susitna basin have encountered anomalously high temperatures, suggesting that low temperature geothermal resources might be present which could be used for space heating and agriculture. There are no known surface manifestations of a geothermal resource in the area but a water well driller has recently encountered a warm saline reservoir at 40 ft depth. North of the Castle Mtn. Fault the basin contains about 2,000 ft. of coal-bearing Tertiary sediments overlain by glacial drift and underlain by a granitic basement. South of the fault the basin has been down dropped and contains a much thicker sedimentary section.

SUMMARY AND PRELIMINARY CONCLUSIONS

A helium soil gas and water survey was conducted with an approximately one mile grid spacing in order to explore for hot water reservoirs at depth. The helium data corroborate the temperature anomalies in the three hot wells studied and suggest that discontinuous hot water reservoirs totalling at least 40 square miles may be present in the Willow-Big Lake area (Figure 9). The helium anomalies extend to within six miles of Wasilla, where our preliminary survey ended. It is possible that this anomaly trend may extend as far east as Wasilla, or even possibly farther to the east.

There is a strong suggestion of elongate trends in the helium anomaly patterns of Figure 9, suggesting that these patterns could be controlled by Tertiary faults which are covered by the glacial drift that mantles the region.

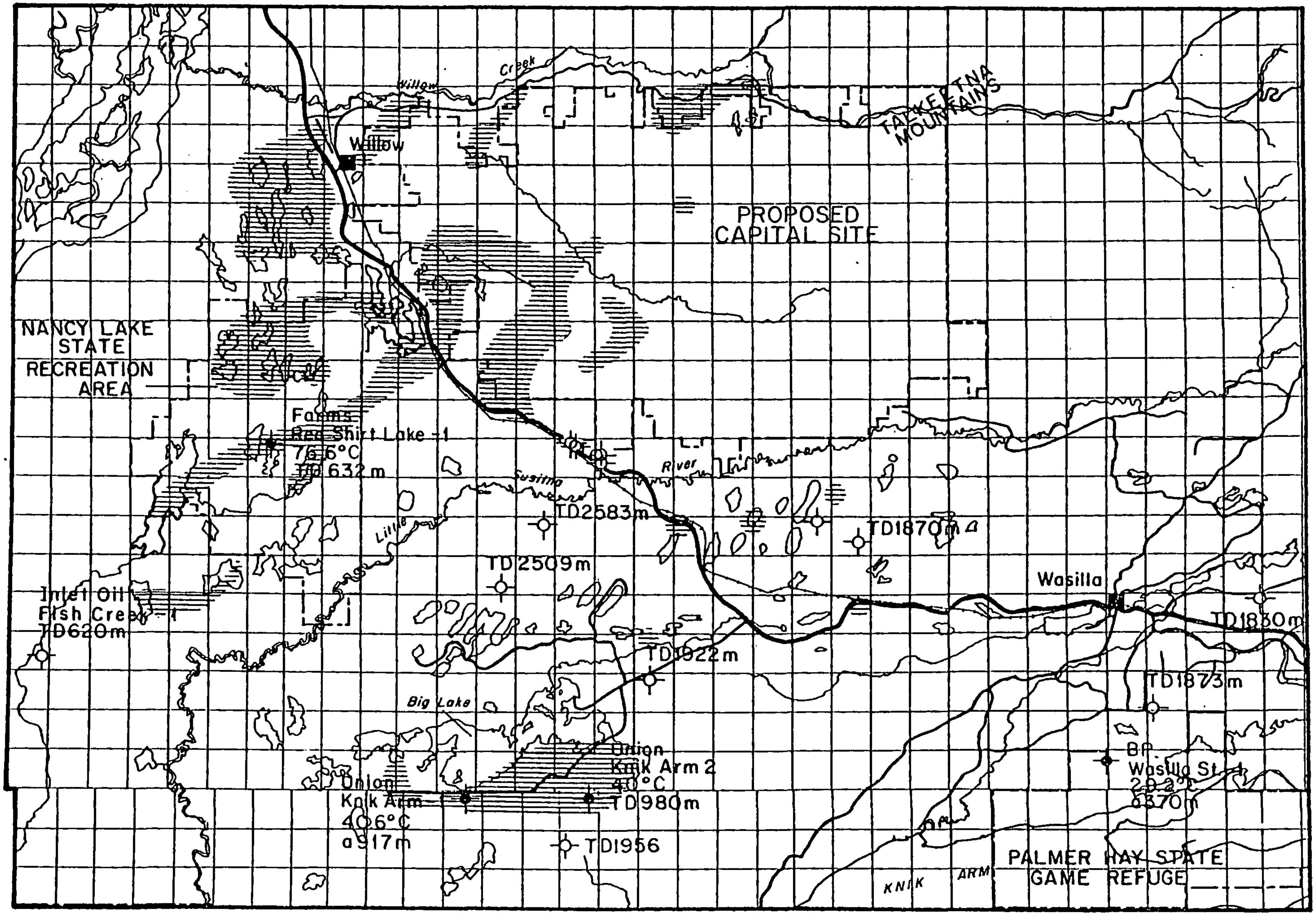

Figure 9. Map of the lower Susitna basin showing estimated areas of high helium concentrations (shaded areas).

A gravity survey of the area indicates that two basement ridges are present (Figure 10). The Tertiary sedimentary section containing good aquifers is inferred to be thinner over these ridges than in adjacent areas and is believed to be accessible by normal water well drilling techniques. Helium anomalies are present over both basement ridges (Figure 10). Geothermal aquifers are therefore likely to be encountered at shallower depths over these ridges than in adjacent areas studied.

We have postulated two models - radiogenic heating of aquifers by U and Th-rich basement pegmatites and fault-controlled hydrothermal convection to account for the geothermal system in the area studied. The very large extent and apparent elongate orientation of most helium anomaly patterns appear to favor the fault model (Figure 9).

Our initial study appears to indicate that a substantial geothermal resource may be present in the Willow-Big Lake area. However, very large gaps exist in the preliminary data base we have used to delineate this resource, and the nature of the geothermal system supplying the reservoirs is not understood. Reservoir depths and thicknesses are presently unknown. We have also been unable to determine the lateral extent of the suspected reservoir system, and, in particular, whether or not it extends to the rapidly growing population center of Wasilla.

We strongly recommend the follow-on work discussed below which will focus on providing a much better definition of the nature of the geothermal system and the lateral and vertical distribution of geothermal reservoirs, as well as detailed recommendations for exploratory drilling. Indirect evidence from our helium survey is very encouraging, but the actual confirmation of the suspected geothermal resource will require exploratory drilling and well testing. Drilling should be relatively inexpensive

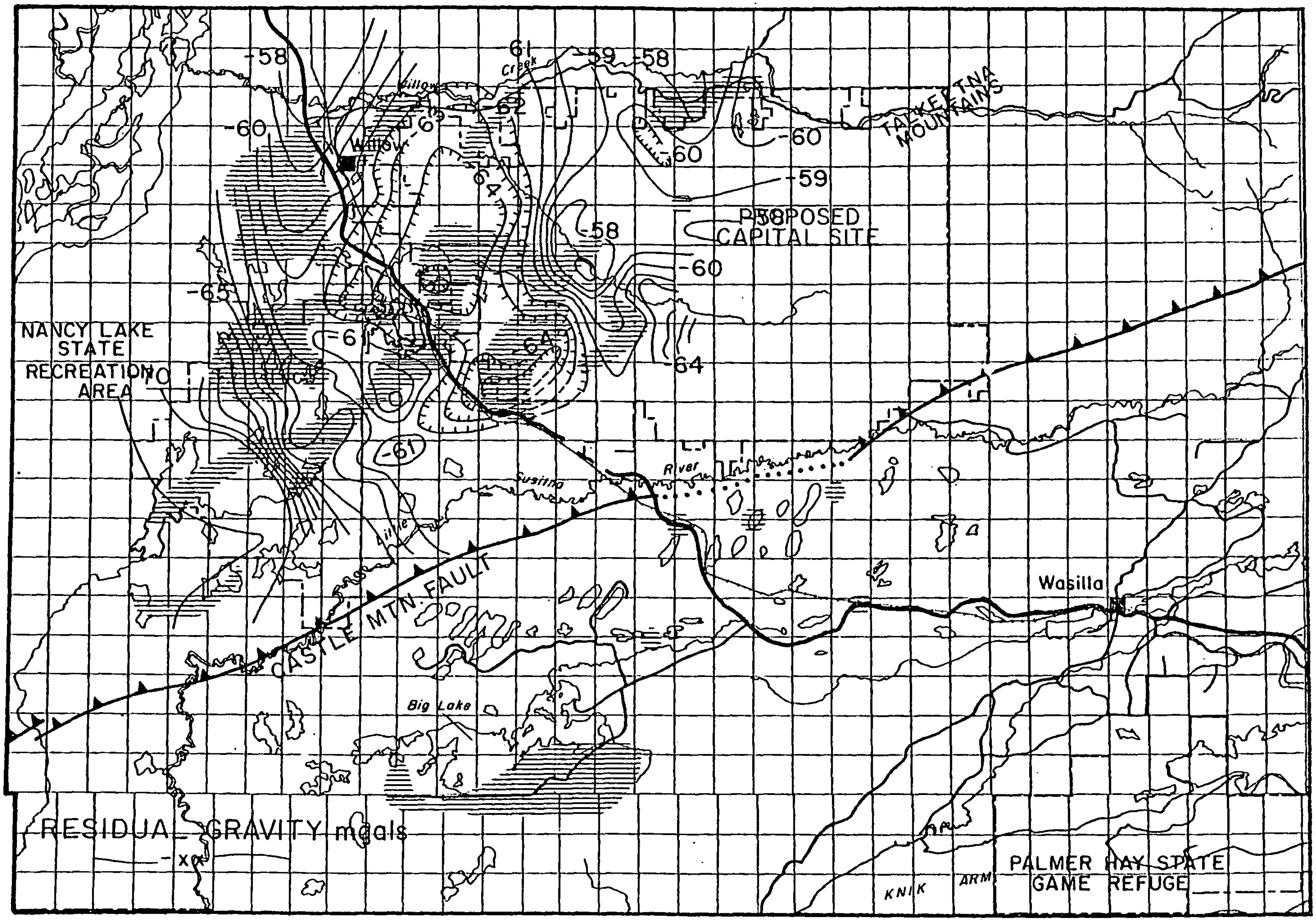

Figure 10. Residual gravity anomaly map of the lower Susitna basin. Estimated areas of anomalously high helium concentrations from Figure 9 are shaded.

due to the shallow depths to suspected reservoirs inferred from the gravity survey.

RECOMMENDED FOLLOW-ON WORK

The specific phases of a proposed follow-on work plan are as follows:

1. Completion of the 1/sq. mi. grid of the helium soil gas survey. Gaps in the existing data base should be filled in to allow a better definition of the distribution of areas believed to be underlain by hot water. A helicopter-supported survey should focus on the central and eastern areas shown in Figures 9 and 10, and include the area around Wasilla. A finer (0.5 mile) grid spacing should also be used in critical areas if available helicopter time permits.
2. A wider-spaced helium reconnaissance survey extended to the Palmer area to investigate the remote possibility that geothermal anomalies might extend that far to the east. This survey should utilize a 5 mile spacing along existing road systems and will not require helicopter support. The additional cost will be low and we believe that the large population and potential energy market of the Palmer area justifies checking the possibility out.
3. A helicopter-supported gravity survey designed to fill in gaps in the existing gravity data base and to extend its detailed coverage to the south and east. This survey will provide better regional control for estimates of depth to granitic basement for the purpose of siting geothermal exploration wells.

4. A seismic refraction survey along the basement ridges inferred from the present gravity survey. This survey should provide accurate estimates of basement depths in these critical areas.

6. Deep resistivity surveying in selected areas of large helium anomalies. Resistivity results should be correlated with available well logs in the area to help determine the depths and thicknesses of geothermal reservoirs.

6. Continued research on helium soil gas surveying and on various electrical resistivity surveying techniques as geothermal exploration tools, both in site-specific and regional applications under Alaskan conditions and geologic settings. We have accumulated a considerable amount of information on this subject from our geothermal studies of Pilgrim, Chena and Manley Hot Springs, and from our regional work on the Seward Peninsula.

EXPLORATORY DRILLING AND RESERVOIR TESTING

We hope to generate interest in a cooperative program of exploratory drilling and reservoir testing based on the results of this report and the recommended follow-on study. We think it is possible that the State Park System might find it desirable to plan for use of hot water for park facilities in the Nancy Lake State Recreation Area (Figure 9).

A future program of drilling might involve the State or local government, the Division of Parks, with geologic and geophysical well logging by the Geophysical Institute and Alaska Division of Geological and Geophysical Surveys; and with flow testing to estimate reservoir characteristics and energy potential by the University of Alaska Petroleum Engineering Department.

Preliminary Drilling Recommendations

We recommend the following exploratory drilling, based on the results of the present study. First, Red Shirt Lake #1 should be redrilled to 2000 ft depth. A detailed temperature log should be run, together with appropriate flow tests to evaluate the reservoir parameters of zones producing hot water. Geochemical studies to determine water quality and geothermometry should also be made. Water quality data will be critical to the design of appropriate heat exchangers (e.g. scaling and corrosion problems) and to the question of whether or not the water should be reinjected after use vs. surface disposal.

Several shallow wells should be drilled to granitic basement southwest of Willow, in the area of the superposed basement ridge and helium anomaly pattern shown in Figure 10. Depth to basement is inferred to be approximately 200-500 ft. in this area from analysis of the gravity data. Specific siting of these wells within the designated area should be determined by local considerations (logistics, land status, etc.) and by the results of a detailed helium soil gas survey to be done prior to final site selection. Temperature, self potential, resistivity and lithologic logs should be run in these wells. Flow testing and water chemistry should also be done as discussed above.

Note: The following sections on Unalaska and Akutan Islands have not yet been made available to the public. They will be incorporated in future reports to be published by the Alaska Division of Geological and Geophysical Surveys. Because this work has not been reported previously, the results are given in more detail than the previous sections which summarize previously published work.

Geophysical Surveys of Summer Bay Warm Springs, Unalaska Island, Alaska

INTRODUCTION

In the summer of 1980 two wells were drilled near the Summer Bay warm springs at the southern shore of Summer Lake on Unalaska Island (Reeder, 1981). In well #1 50°C artesian water was encountered at 42 ft depth, and in well #2, 43.5°C artesian water was produced at 44 ft depth. In the summer of 1981 we carried out a suite of geophysical and geochemical surveys in the area of Summer Lake and the warm springs to determine the nature and extent of the geothermal reservoir, and to make recommendations for possible future drilling.

The geophysical survey included a seismic refraction line, EM-31 near-surface apparent electromagnetic conductivity measurements, Schlumberger vertical electric soundings, dipole-dipole galvanic resistivity measurements beneath Summer Lake, and a gravity profile. Helium concentrations in water from the warm springs, in soil gas and soil were sampled in a grid system south of Summer Lake to locate sources of upwelling hot water. Mercury soil concentrations were also sampled. The helium and mercury survey results are also summarized in this report.

A coherent model of the near surface warm water reservoir can be derived from the geophysical measurements.

SUMMARY

The integrated geophysical survey carried out in the Summer Bay warm springs area has revealed a shallow (20-40 m base) geothermal reservoir confined to the northeast end of the valley at the southern end of Summer Lake. EM-31 conductivity measurements indicate the presence of saline water within 6 m of the surface (Figure 11). Deeper galvanic resistivity

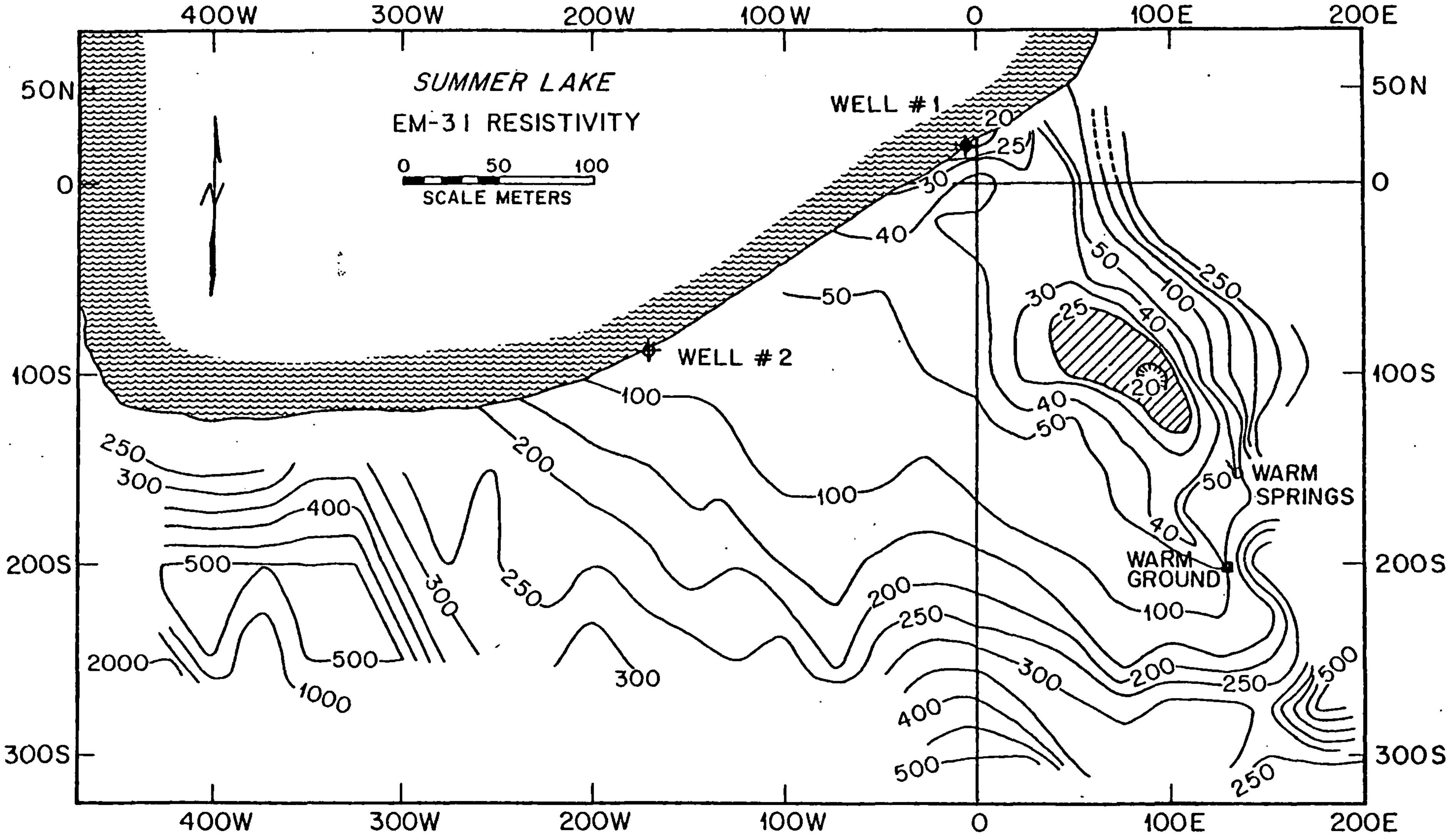

Figure 11. Contour map of EM-31 apparent resistivity in Ω-m with transmitter and receiver coils horizontal, at the southern end of Summer Lake, Unalaska Island. The locations of the warm springs, an area of warm ground, and two test wells which produced artesian flow are shown.

vertical-electric soundings verify that a low resistivity zone exists. This zone is confined to the northeast end of the valley and has a base between 20-40 m in depth. Seismic refraction and gravity profiles along the N-S baseline have shown that the basement slopes to the north and have produced evidence of a fault with about 15 m throw, near the south end of Summer Lake. Reeder (1981) has mapped an east-northeast trending fault extending through this locality. The fault may serve as a conduit for warm water and may form a boundary of the near surface reservoir. Deep dipole-dipole resistivity measurements spanning Summer Lake suggest deeper geothermal reservoirs may be present under the northern end of the lake.

Drilling Recommendations

The results of the geophysical surveys have shown the existence of a near-surface reservoir of limited extent. From the resistivity and seismic data it may be 30 m deep and 750 m^2 in area. The two test wells produced water of 50°C maximum temperature and maximum flow rate of 50 gallons per minute at a depth of 42 ft. It is possible that somewhat hotter water might be obtained nearer the center of the resistivity anomaly. Any future drilling should verify the fault offset, and probable deeper reservoir base southeast of drill hole #1.

The temperature and size of the reservoir suggest that it cannot be used for electric power generation, or for direct heat applications in Unalaska or Dutch Harbor. The resource might, however, be utilized to develop a spa resort area with a pool, cabins etc. in the Summer Lake area.

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Helium and Mercury Surveys of Parts of Unalaska Island

INTRODUCTION

The concentrations of helium and mercury in soil, and of helium in water have been shown to be useful indicators of geothermal resources [Roberts, et al., (1975); Bergquist, (1980); Matlick and Buseck, (1975)]. In Alaska, helium and mercury surveys in the Chena Hot Springs area (Wescott and Turner, 1981a), at Pilgrim Springs (Wescott and Turner, 1981b), at Summer Bay Warm Springs, Unalaska Island (Wescott, et al., 1982) and at Manley Hot Springs (East, 1982) have shown excellent correlations with areas of upwelling of geothermal waters. More recently an extensive helium survey in the lower Susitna basin has revealed extensive areas of helium anomalies probably associated with geothermal resources (Turner and Wescott, 1982).

The radioactive decay of uranium and thorium is the source of helium in the earth. The solubility of helium in water increases with temperature above 30°C, so geothermal waters are efficient scavengers of helium produced at depths in the rocks (Mazor, 1972). As the geothermal waters rise towards the surface, helium is released due to cooling and de-pressurization. Aleutian volcanic rocks contain much less uranium and thorium than the more acidic igneous and metamorphic rocks of the Chena Hot Springs and Pilgrim Springs areas and thus we would expect Aleutian helium anomalies to be less pronounced. The average atmospheric concentration of helium is 5.24 ppm. Allowing for uncertainties in the collection and analysis procedure, we have assumed that any soil concentration of helium greater than 5.40 ppm is a significant anomaly. The results of the helium survey are shown in in Figure 12.

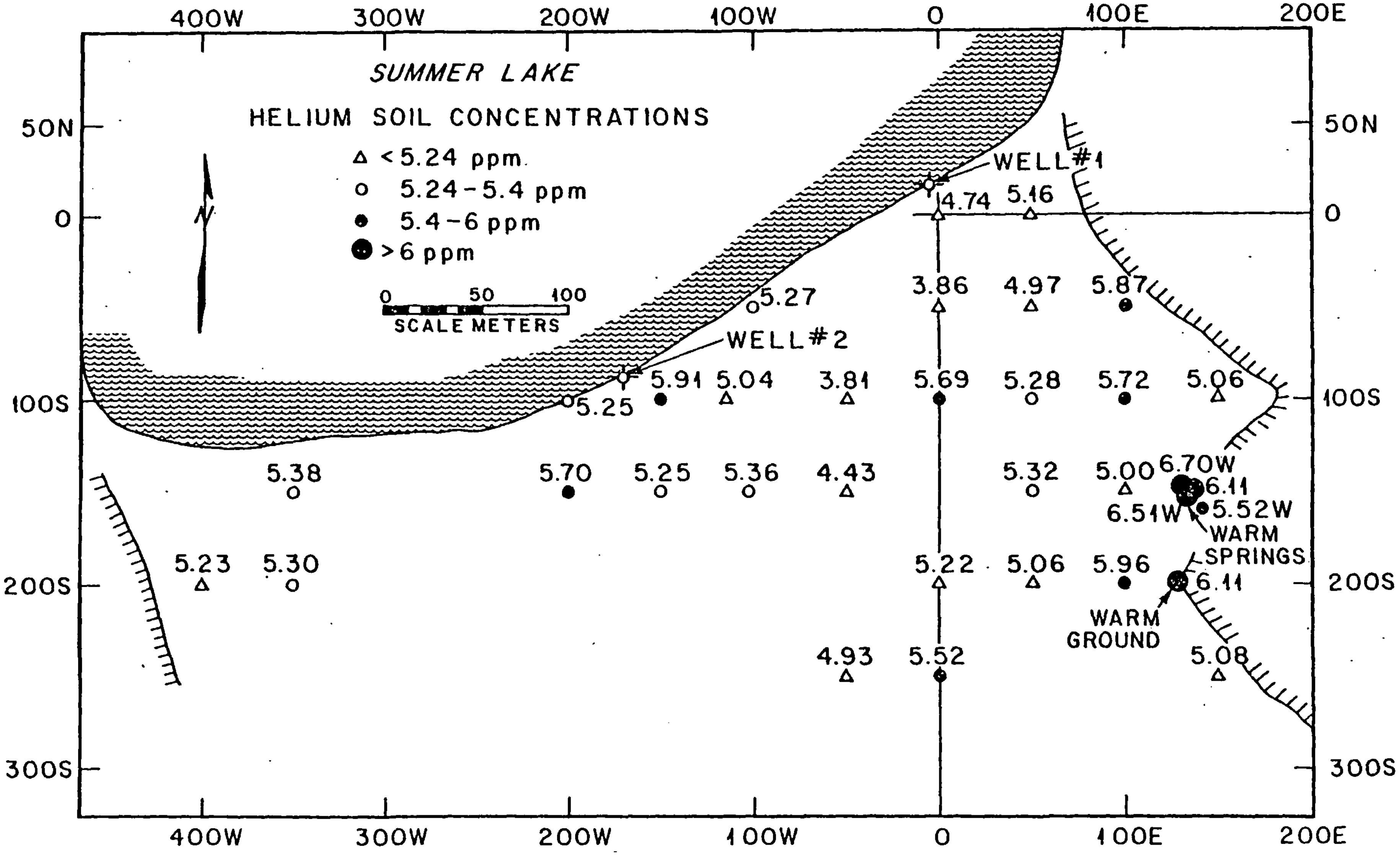

Figure 12. Map of the warm springs area at the southern end of Summer Lake, Unalaska Island, showing helium soil concentrations in ppm. Anomalously high values are shown by solid circles. Anomalously low values which are probably due to gas dilution are shown by open triangles. Three water samples are suffixed W.

CONCLUSIONS

Although the helium and mercury sampling surveys were limited, the results of these surveys have been very encouraging. Because the helium production rate in Aleutian basic volcanic rocks is lower than in continental granitic rocks, the helium anomalies were smaller than those found at Pilgrim Springs, Chena Hot Springs and Manley Hot Springs.

Fewer mercury samples were collected and analyzed than helium samples, so the mercury anomaly patterns are not as clear, although the Summer Bay anomalous mercury values are in the same general area as the helium anomalies. In spite of low helium production rates and the limited He and Hg sampling distribution in the areas studied, we find that the helium and mercury anomalies have effectively defined areas of geothermal interest. We recommend that detailed helium and mercury surveys be included in future exploration programs on Unalaska.

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A GEOPHYSICAL SURVEY OF HOT SPRINGS BAY VALLEY, AKUTAN ISLAND, ALASKA

INTRODUCTION

A series of hot springs occur along a 1.5 km distance at the NW edge of Hot Springs Bay Valley, Akutan Island, Alaska. The island has an active volcano - Akutan. Motyka et al. (1982) have reported that the geothermometry gives an estimated reservoir temperature range of 160°-190°C. The heat loss by the springs is estimated at 1.6 MW (Motyka et al., 1981). In the summer of 1981 geologic mapping and geophysical surveys were carried out in the valley to locate and evaluate geothermal energy resources. Geophysical techniques included near surface conductivity profiling, seismic refraction profiling, Schlumberger vertical electrical soundings, and dipole-dipole resistivity profiling.

GEOLOGY

The Hot Springs Bay Valley has steep side walls composed of an upper section of lava flows and minor mudflows of 1.4 m.y. age lying unconformably on a thick section of well indurated volcanic mudflows cut by abundant fine-grained dikes.

The valleys on the island appear to have been scoured to U shapes by glaciers. Hot Springs Bay Valley has a flat floor formed by volcanic debris flows. The uppermost unit is a lahar which is nonporous and impermeable where exposed.

GEOPHYSICAL SURVEYS

Electrical resistivities of the waters from two of the springs with temperatures of 84 and 59°C are 2.39 and 8.03 Ω-m respectively. The resistivities of the valley sediments are generally much higher, so the near surface resistivity should be well correlated with temperature anomalies where hot water is closest to the surface. We used a Geonics EM-31 electromagnetic conductivity meter to measure the near surface (6 m depth) resistivity over a 1.26 square km area. The contoured data are shown in Figure 13. The low resistivity zones form a narrow sinuous pattern along the NW side of the valley. No other low resistivity zones were located. The pattern suggests that an ancient buried stream channel forms a permeable zone through the lahar. The near surface resistivity is about 100 Ω-m over the rest of the valley except for two sand dune areas where it is 500 Ω-m.

Four Schlumberger vertical electrical soundings were made: one 900 m inland parallel to the valley and 200 m from the NW side, a second parallel to it on a terraced debris flow, a third between hot springs C and D and a fourth near hot springs A (Figure 13). The data were interpreted by an automatic curve fitting program (Zhody, 1974). Figure 14 shows the vertical electric sounding (VES) curve and interpretation run about 150 m from the NW edge of the valley on a lahar terrace. All appear to indicate a geothermal reservoir of 2.2 to 12 Ω-m resistivity, 23 to 42.5 m thickness and a depth of 13 m near the NW edge of the valley to 52 m towards the center.

Three 100 m dipole-dipole pseudo sections were run along and perpendicular to the valley. The results are plotted in Figure 15 to show where they intersect. They all suggest a cap rock, presumably an impermeable lahar, of thickness 40-70 m underlain by a reservoir thicker towards the center of the valley and towards the NE. The SE-NW dipole-dipole no. 1 section was modeled using a two-dimensional program. The result suggests a basement rock of 1500 Ω-m perhaps 150 m deep towards the valley center. Archie's law suggests a porosity of 45-82% for the reservoir and 4-7% for the basement rocks (Archie, 1942).

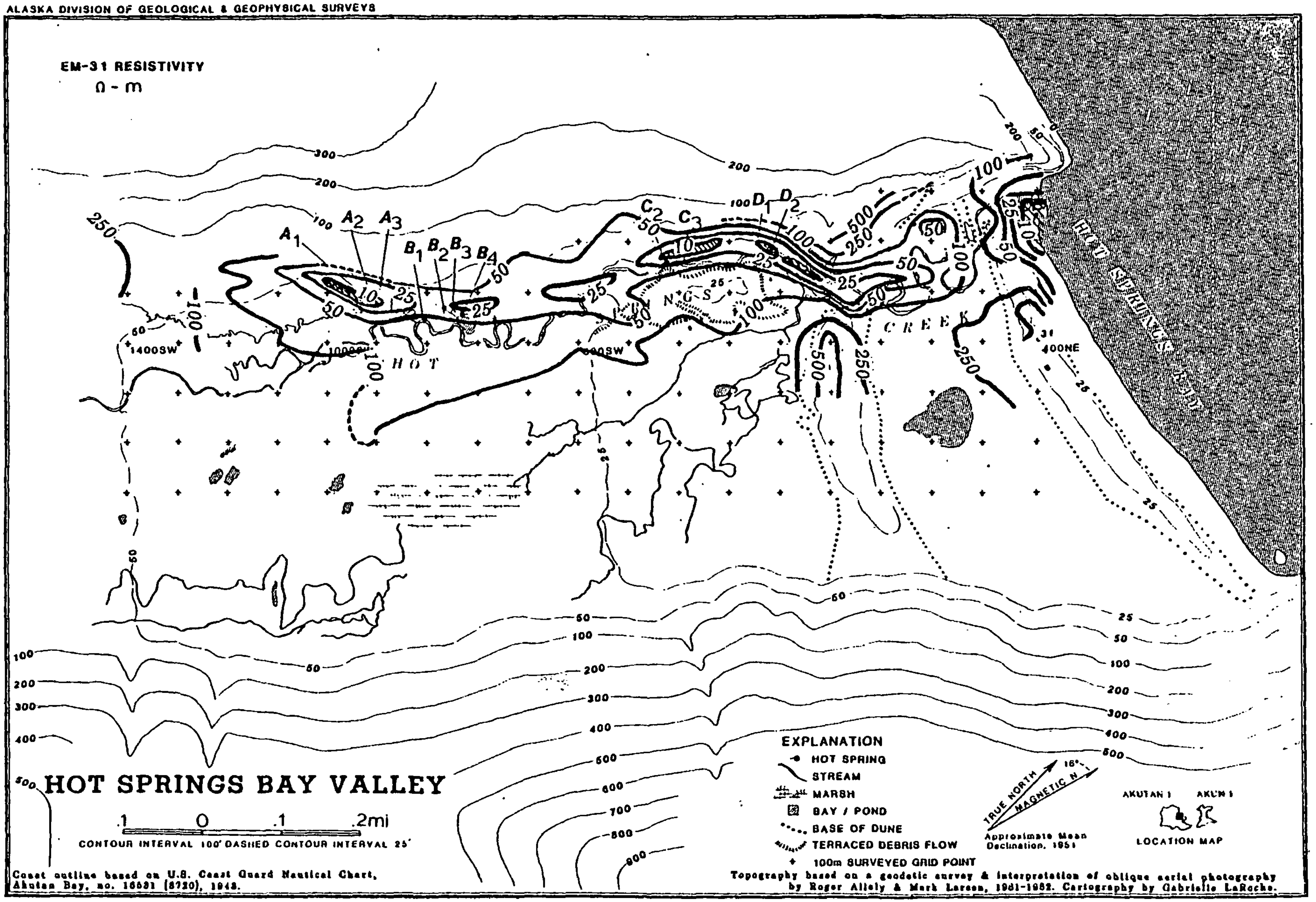
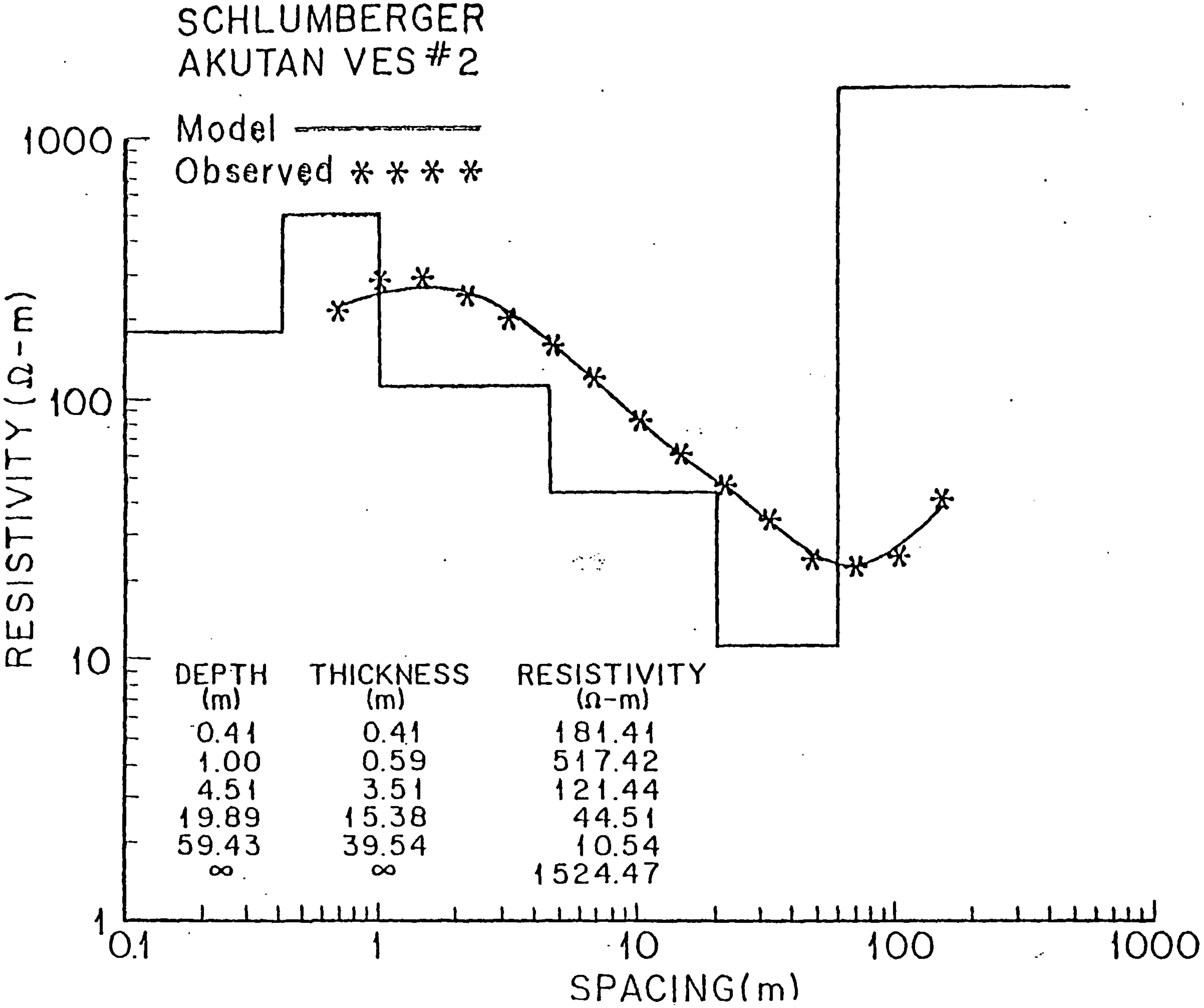


Figure 13. Map of Hot Springs Bay Valley, Akutan Island, Alaska, with superposed near-surface (6 m) electrical resistivity contours from a Geonics EM-31 survey. The resistivity values appear to be inversely related to anomalously high ground temperatures.



DEPTH (m)	THICKNESS (m)	RESISTIVITY (Ω-m)
0.41	0.41	181.41
1.00	0.59	517.42
4.51	3.51	121.44
19.89	15.38	44.51
59.43	39.54	10.54
∞	∞	1524.47

Figure 14. Plot of vertical electric sounding #2 on a lahar terrace 100 SE of the C springs (see Figure 1). True resistivity vs. depth of the model is also plotted. The lowest resistivity layer is interpreted as a geothermal reservoir of porosity 45-82%.

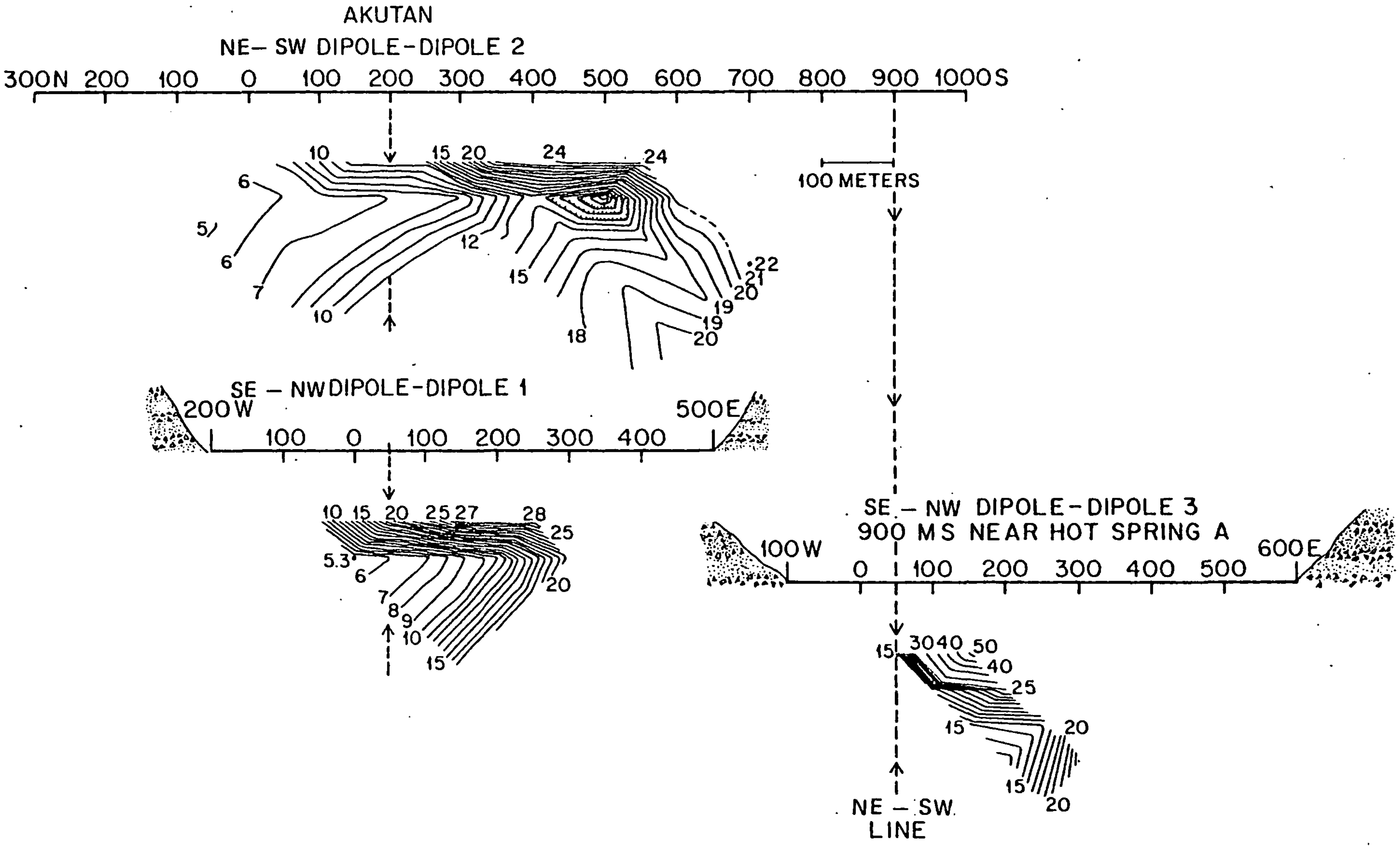


Figure 15. 100 m dipole-dipole resistivity pseudo-sections plotted to show where the NW-SE sections intersect the NE-SW section contours in Ω-m. The sections generally show a medium resistivity cap layer 40-70 m thick overlying a geothermal reservoir layer 40-75 m thick underlain by high resistivity bedrock.

Seismic profiling results agree with the resistivity data. There are three basic units: the top or lahar unit has a velocity ranging between 1630-1960 m/sec and a thickness of 30-75 m; the geothermal reservoir unit has a velocity of 3240-3505 m/s, a thickness of 40-75 m and a base which slopes steeply towards the center of the valley and down the valley towards the ocean. The basement rocks have a velocity of 4900 m/s, and probably correspond to the indurated volcanic mudflows that form the valley walls, although they could also be lava flows, intrusives, or hydrothermally cemented sediments. Figure 16 shows the seismic profile parallel to the valley. The reservoir apparently coincides with the medium velocity layer.

CONCLUSION

Geophysical surveys have located a probable geothermal reservoir at least 1.5 x 0.5 km^2 in area with a thickness ranging between 40-75 m. Figure 17 shows a composite profile parallel to the valley about 200 m from the NW side. The reservoir probably extends further to the NE as evidenced by hot spring E (Figure 13) at the ocean shoreline. It may be thicker toward the NE end of the valley which was not fully explored. Deep resistivity and seismic profiling agree on the general shape of the reservoir which probably rests on a glaciated volcanic bedrock surface. The resource outlined is sufficient to supply hot water and power to the town of Akutan and to an expanded fish processing industry 5 km distant.

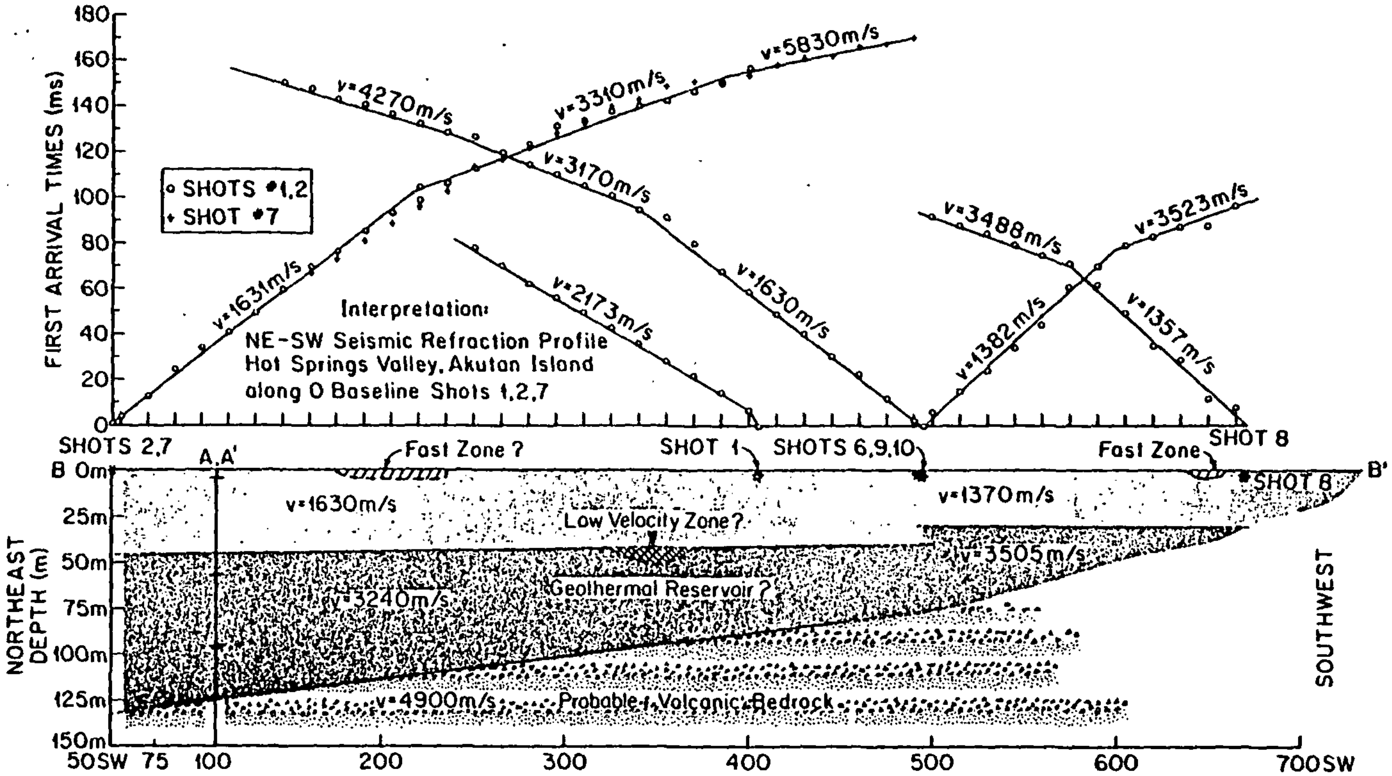


Figure 16. First arrival seismic travel time curves for profile parallel to valley. Bottom interpreted cross section. The interface where dashed indicates zones of no seismic information.

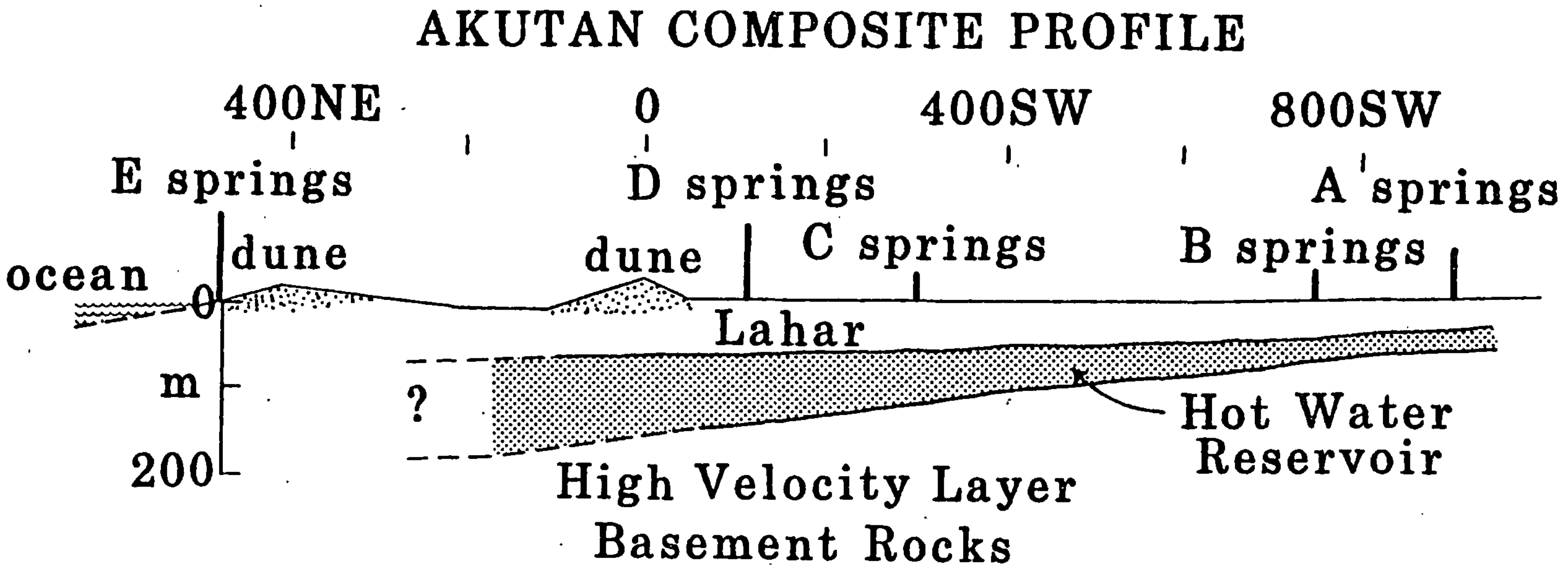


Figure 17. Composite cross section of lower Akutan Hot Springs Bay Valley taken parallel to axis of valley.

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Helium and Mercury Soil Surveys of Hot Springs Bay Valley, Akutan Island, Alaska

Introduction

The concentrations of helium and mercury in soil, and of helium in water have been shown to be useful indicators of geothermal resources [Roberts, et al., (1975); Bergquist, (1980); Matlick and Buseck, (1975)]. In Alaska, helium and mercury surveys in the Chena Hot Springs area (Wescott and Turner, 1981a), at Pilgrim Springs (Wescott and Turner, 1981b), at Summer Bay Warm Springs, Unalaska Island (Wescott, et al., 1982) and at Manley Hot Springs, (East, 1982) have shown excellent correlations with areas of upwelling of geothermal waters. More recently an extensive helium survey in the lower Susitna basin has revealed extensive areas of helium anomalies probably associated with geothermal resources (Turner and Wescott, 1982).

The radioactive decay of uranium and thorium is the source of helium in the earth. The solubility of helium in water increases with temperature above 30°C, so geothermal waters are efficient scavengers of helium produced at depths in the rocks Mazor (1972). As the geothermal waters rise towards the surface, helium is released due to cooling and de-pressurization. The Aleutian volcanic rocks contain much less uranium and thorium than the more acidic igneous and metamorphic rocks of the Chena Hot Springs and Pilgrim Springs areas and thus we would expect Aleutian helium anomalies to be less pronounced. The average atmospheric concentration of helium is 5.24 ppm. Allowing for uncertainties in the collection and analysis procedure, we have assumed that any soil concentration of helium greater than 5.40 ppm is a significant anomaly.

Helium Survey

He samples were collected in the area of the Hot Springs Bay Valley by one of three methods: 1. Driving a hollow collection tube about 75 cm into the ground and drawing off a gas sample in a syringe. The gas was then introduced into a small evacuated steel "CO_2" cartridge and sealed. 2. Augering a soil core sampler about 75 cm into the ground, placing the bottom soil core in a steel can and sealing it. 3. Water samples were collected in a sample bottle with a known volume of air. The bottle was shaken for 30 seconds to allow the helium in the water to equilibrate with the air, then a gas sample was drawn off by syringe and inserted into an evacuated steel cartridge as in the soil gas sampling technique.

The helium analysis was done at Western Systems Inc., Morrison, Colorado, by mass spectrometry with a precision of 10 ppb. There are 43 soil or soil gas sample localities and 4 hot springs water samples. The hot springs water samples are about 22% above the atmospheric background: 6.56, 6.41, 6.57 and 6.05 ppm. In comparison, water samples from Manley Hot Springs at 30 ppm are 573% above background, consistent with the higher He production rate in the acidic plutonic and metamorphic rocks of that area (East, 1982). Of the 43 soil sample locations, 27 show anomalously high helium values. The two largest He values of 6.12 ppm are at 150 NW, 300 NE and 150 NW, 200 SW; somewhat removed from the sinuous pattern of anomalously conductive ground found with the EM-31. In general the helium anomalies extend farther out into the valley than the near surface conductivity anomaly.

The pattern of helium anomalies is probably distorted by the production of other gases in the organic-rich marsh. There are 3 samples which are below the atmospheric concentration of 5.24 ppm, one as low as 4.84 ppm. Friedman (personal communication, 1981) has found similar anomalously low helium values in other surveys, and has ascribed this phenomenon to dilution of the helium content of the soil gas by other gases such as methane and CO_2. Thus, since we know some sample sites show anomalously low values below the atmospheric value of 5.24, others which are above 5.24 may have also been lowered by this effect. Since we did not sample for other gases, we cannot correct for this effect.

Mercury Survey

Mercury content in soils has also been reported as a possible indicator of geothermal resources (Matlick and Buseck, 1975). They confirmed a strong association of Hg with geothermal activity in three of four areas tested (Long Valley, California; Summer Lake and Klamath Falls, Oregon). Mercury deposits often occur in regions containing evidence of hydrothermal activity, such as hot springs (White, 1967).

Mercury is highly volatile. Its high vapor pressure makes it extremely mobile, and the elevated temperatures near a geothermal reservoir tend to increase this mobility. The Hg migrates upwards and outwards away from the geothermal reservoir, creating an aureole of enriched Hg in the soil above a geothermal reservoir. Such aureoles are typically much larger in area than a corresponding helium anomaly.

We collected 15 soil samples about 10 cm below the organic layer. The samples were air dried in the shade and sized to -80 mesh using a stainless steel sieve. The -80 portions were stored in airtight glass vials for analysis.

The Hg content of the sample was determined by use of a Jerome Instrument Corp., model 301 Gold Film Mercury detector with sensitivity of better than 0.1 ng of Hg. A standard volume of -80 mesh soil (0.25 cc) was placed in a quartz bulb and heated for one minute to volatize the Hg adsorbed on the mineral grains, which was collected on a gold foil. Heating of the gold foil in the analysis procedure releases the Hg for analyses as a gas in the standard manner. Calibration is accomplished by inserting a known concentration of Hg vapor with a hypodermic syringe.

The background concentration of Hg in soils varies widely from area to area, and must be determined from a large number of samples. It is generally on the order of 10 parts per billion. We calculated a mean value of 139 ppb for the 15 samples collected at Hot Springs Bay Valley and used that as an anomaly level.

Figure 18 shows a map with the mercury values plotted on our grid system. One of the largest values of 395 ppb is at 0 NW, 100 S several hundred meters away from the near surface temperature anomalies. As we did not sample the complete grid system, we cannot make a definitive statement regarding the mercury pattern. It does seem that mercury sampling might be useful for future surveys in this area because there is a wide range of Hg values probably related to the geothermal reservoir at depth.

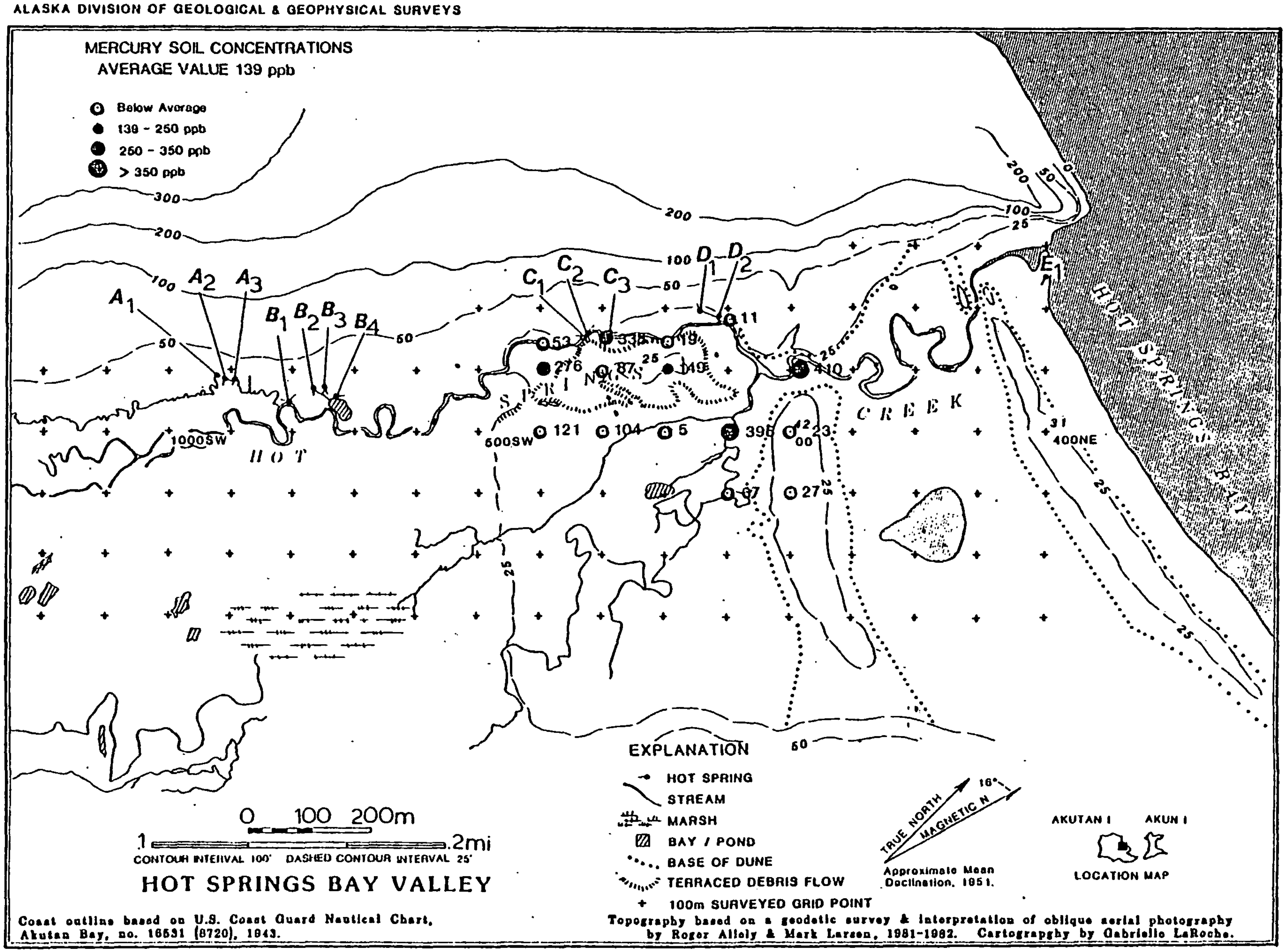

Figure 18. Mercury soil values at Hot Springs Bay Valley.

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Appendix A

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GEOTHERMAL ENERGY

A VIABLE ALTERNATIVE ENERGY SOURCE

**UNIVERSITY OF UTAH
RESEARCH INSTITUTE
EARTH SCIENCE LAB.**

JANUARY 1981

TODAY'S ENERGY PICTURE IN THE U.S.

- THE U.S. PRODUCES ONLY 3/4 OF THE ENERGY IT CONSUMES
- APPROXIMATELY 1/2 OF OUR OIL COMES FROM FOREIGN SOURCES
- ENERGY USE FORECASTS FOR THE YEAR 2000 AND BEYOND INDICATE THAT ALL FEASIBLE ALTERNATIVE ENERGY SOURCES PLUS CONSERVATION MEASURES WILL BE NEEDED.

GEOTHERMAL ENERGY

CAN REPLACE

PETROLEUM

FOR

ELECTRICAL POWER GENERATION

AND

DIRECT APPLICATIONS

RESOURCE TYPES

CONGRESS IS SUPPORTING RESEARCH AND DEVELOPMENT ON THREE TYPES OF GEOTHERMAL ENERGY RESOURCES:

1. HYDROTHERMAL
2. GEOPRESSURED
3. HOT DRY ROCK

THE STATUS OF THE COMMERCIAL DEVELOPMENT OF EACH OF THESE SYSTEMS IS SHOWN BELOW :

		ESTIMATED COMMERCIALIZATION DATE *
HYDROTHERMAL ENERGY	—	LIMITED COMMERCIAL USE NOW
GEOPRESSURED RESOURCES	—	1990
HOT DRY ROCK RESOURCES	—	2000

* ESTIMATES FROM THE FOURTH ANNUAL REPORT OF INTERAGENCY GEOTHERMAL COORDINATING COUNCIL - JUNE, 1980

CONGRESS IS SUPPORTING RESEARCH AND DEVELOPMENT ON THREE TYPES OF GEOTHERMAL ENERGY RESOURCES :

1) HYDROTHERMAL
2) HOT DRY ROCK
3) GEOPRESSURED

FEDERAL ASSISTANCE

IS NEEDED TO :

- ACCELERATE HYDROTHERMAL COMMERCIALIZATION
- BUILD FLEDGLING INDUSTRY
- CONTINUE DEVELOPMENT

GEOTHERMAL POTENTIAL IN THE U.S.

	AVAILABLE ENERGY [1]	ESTIMATED COMMERCIALIZATION DATE [5]
HYDROTHERMAL ENERGY	2400 Q [2]	LIMITED COMMERCIAL USE NOW
HOT DRY ROCK RESOURCES	1,400,000 [3]	BEGIN MID-1990'S
GEOPRESSURED RESOURCES	430 - 4400 Q [4]	BEGIN MID-1980'S

1. ESTIMATES BY U.S. GEOLOGICAL SURVEY, CIRC. 790

2. $1 Q = 10^{15}$ BTU . THE U.S. CONSUMES 80 Q/YR FOR ALL USES

3. NO RELIABLE RESOURCE ASSESSMENT AVAILABLE

4. VARIATION DEPENDS ON HOW MUCH LAND SUBSIDENCE TO ALLOW

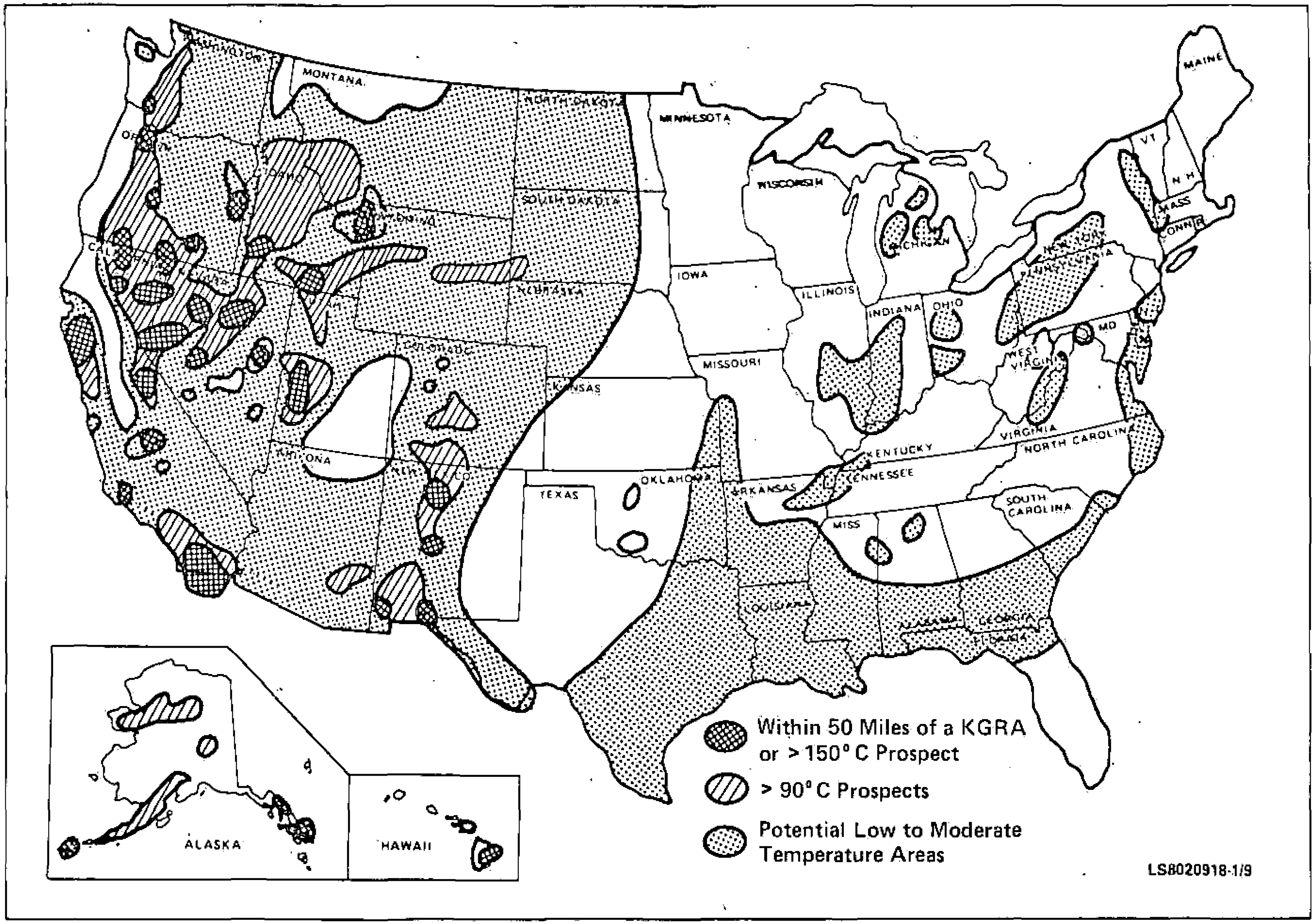
5. GEOTHERMAL ENERGY - PROGRAM SURVEY DOCUMENT, DOE, JAN 1980

GEOTHERMAL DEVELOPMENT POTENTIAL

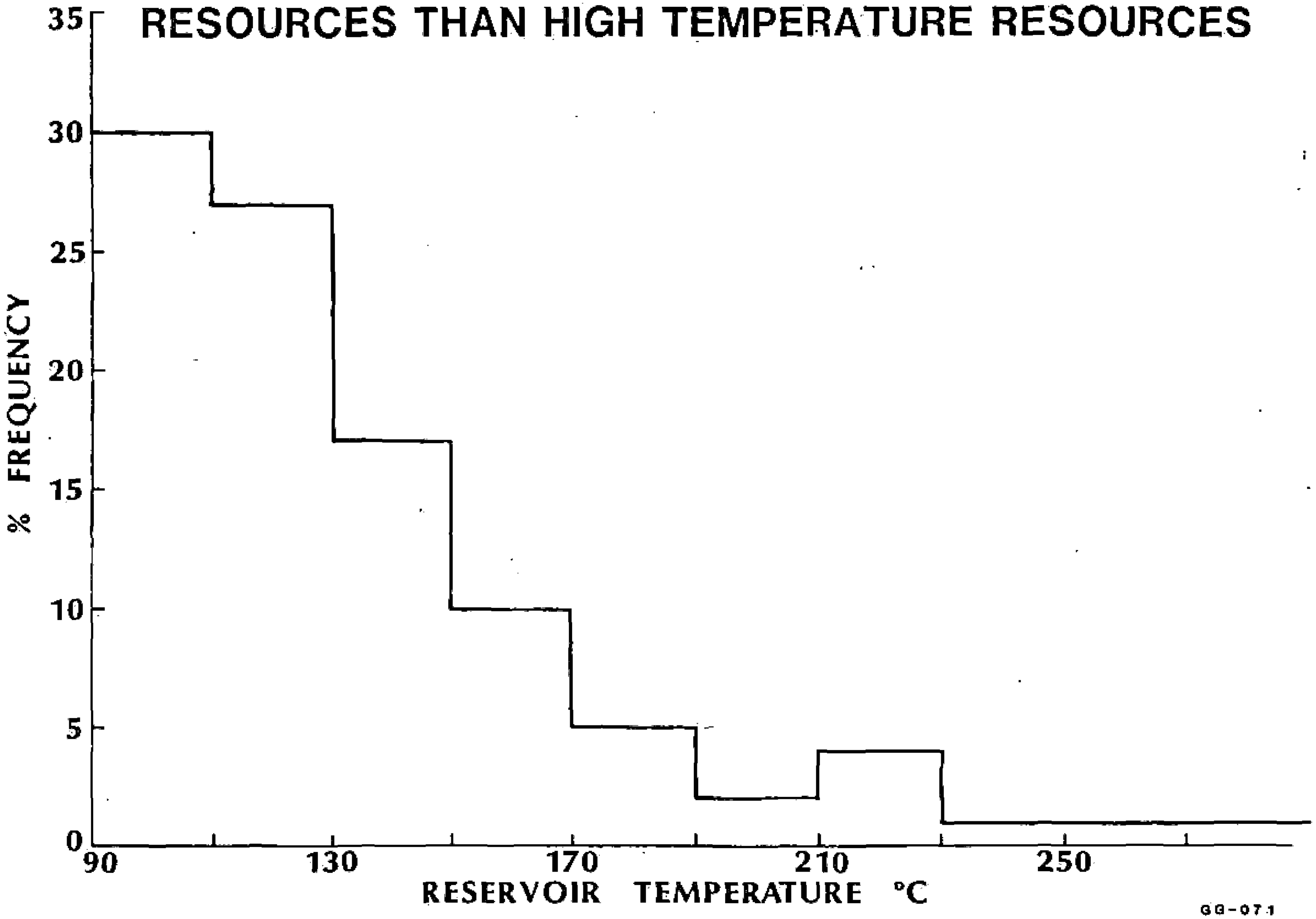
	ESTIMATED USE BY YEAR 2000	
	ELECTRICAL (MW)	DIRECT HEAT (10^{15} BTU)
HYDROTHERMAL	12,800	0.57
GEOPRESSURED	2,000	3.0 (methane)
HOT DRY ROCK	700	0.007

Figure 1

GEOTHERMAL RESOURCES ARE WIDESPREAD



THERE ARE MANY MORE LOW TEMPERATURE RESOURCES THAN HIGH TEMPERATURE RESOURCES



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STATUS OF GEOTHERMAL DEVELOPMENT IN U.S.

- INVENTORY DEMONSTRATES LARGE RESOURCE BASE
- GEOTHERMAL ENERGY NOT YET COMMERCIAL

  (except at a few very high-temperature sites)

  - SMALL NUMBER OF ELECTRICAL DEVELOPERS AND UTILITIES ACTIVE
  - VERY FEW DIRECT-HEAT DEVELOPERS AND USERS ACTIVE
- DOE GEOTHERMAL PROGRAM IS VIABLE
  - ADDRESSES PROBLEMS
  - WORKS WITH INDUSTRY
  - WELL MANAGED
- FY82 HYDROTHERMAL BUDGET HAS BEEN DRASTICALLY CUT, NEEDS RESTORATION

HYDROTHERMAL RESOURCES ARE NOT YET COMMERCIAL

EXCEPT FOR THE FEW VERY HIGH-TEMPERATURE OR VERY SHALLOW RESOURCES

- 912,000 KILOWATTS GENERATED AT THE GEYSERS AREA, Calif.
  10,000 KILOWATTS GENERATED AT IMPERIAL VALLEY, Calif.
- ELECTRICITY SOON TO BE GENERATED AT
  - IMPERIAL VALLEY, Calif. (50,000 kw)
  - ROOSEVELT HOT SPRINGS, Utah (20,000 kw)
  - VALLES CADERA, New Mexico (50,000 kw)
- HOMES & BUILDINGS HEATED BY HYDROTHERMAL ENERGY IN
  - BOISE, Idaho
  - KLAMATH FALLS, Oregon
  - OVER 100 OTHER SITES
- TECHNOLOGY DEVELOPMENT AND DEMONSTRATION NEEDED FOR COMMERCIAL EXPLOITATION AT LOWER TEMPERATURE SITES

PROBLEMS IN HYDROTHERMAL DEVELOPMENT

INSTITUTIONAL BARRIERS

- SLOW FEDERAL LAND LEASING
- INADEQUATE OR RESTRICTIVE FEDERAL AND STATE LAWS AND REGULATIONS
- ENVIRONMENTAL RESTRICTIONS

These Barriers are Rapidly being Mitigated

TECHNOLOGICAL PROBLEMS

- LACK OF CONFIRMED RESERVOIRS
- INADEQUATE EXPLORATION METHODS
- HIGH COST OF DRILLING
- LOW WELL PRODUCTIVITY FOR SOME WELLS
- LACK OF ABILITY TO PREDICT RESERVOIR LONGEVITY
- LACK OF MATERIALS AND EQUIPMENT FOR HIGH-TEMPERATURE, HIGH-BRINE ENVIRONMENT
  - Seals, Drill Bits, Pumps, Heat Exchangers
- LACK OF EFFICIENT TURBINE-GENERATORS FOR TEMPS LESS THAN 400° F

LACK OF DIRECT-USE INFRASTRUCTURE

- FOR ELECTRIC POWER GENERATION, MAJOR RESOURCE COMPANIES ARE ACTIVE
- FOR DIRECT USE, FEW DEVELOPERS EXIST, FEW USERS KNOW POTENTIAL

THE FEDERAL GEOTHERMAL PROGRAM
DOE & USGS

- TECHNOLOGY DEVELOPMENT
  - RESERVOIR ASSESSMENT
  - WELL DRILLING
  - ENERGY EXTRACTION, CONVERSION, STIMULATION
  - GEOCHEMICAL ENGINEERING AND MATERIALS
- TECHNOLOGY DEMONSTRATION
  - 50 MWe FLASH STEAM DEMONSTRATION PLANT - BACA, NM
  - 50 MWe BINARY CYCLE DEMONSTRATION PLANT - HEBER CA
  - 3 MWe WELLHEAD GENERATOR DEMONSTRATION PLANT - PUNA, HA
  - 5 MWe BINARY CYCLE DEMONSTRATION PLANT - RAFT RIVER ,ID
- RESOURCE IDENTIFICATION, ASSESSMENT, AND EXPLORATION
  - USGS EVALUATION - CASCADES, - OR & WA
  - INDUSTRY COUPLED CASE STUDY PROGRAM - WESTERN US
  - STATE COUPLED PROGRAM - 28 STATES
  - USER COUPLED DRILLING PROGRAM - 50 STATES
- COMMERCIALIZATION
  - OUTREACH
  - DIRECT HEAT APPLICATIONS
  - FEASIBILITY STUDIES
- GEOTHERMAL LOAN GUARANTY
- ENVIRONMENT

INDUSTRY SUPPORTS DOE'S HYDROTHERMAL PROGRAMS

RESOURCE CONFIRMATION

TECHNOLOGY DEVELOPMENT

GEOTHERMAL LOAN GUARANTY

COMMERCIALIZATION PLANNING

DOE GEOTHERMAL PROGRAM IS VIABLE

- **PROGRAM ADDRESSES CURRENT PROBLEMS**
  - Technology Development and Demonstration
  - Resource Inventory
  - Cost-Shared Exploration and Development
  - Loan Guaranty
- **WORKING RELATIONSHIP WITH INDUSTRY**
  - Program Has Industry Support
- **TOP MANAGEMENT COMPETENT**

HYDROTHERMAL BUDGET FOR FY 82 CUT BY CARTER ADMINISTRATION

- HYDROTHERMAL NEEDS FEDERAL SUPPORT TO BECOME COMMERCIAL

- HYDROTHERMAL HAS MUCH GREATER POTENTIAL FOR POWER ON LINE BY YEAR 2000 THAN GEOPRESSURED OR HOT DRY ROCK

- RESTORATION OF BUDGET RECOMMENDED

NATURE OF GEOTHERMAL ENERGY

Geothermal energy is a clean and safe alternative energy source that can, under proper exploitation conditions, be considered to be renewable. Because the deep interior of the earth is very hot and because of heat generation in the crust of the earth due to decay of natural radioactive elements in rocks, a very large amount of heat is continually conducted to the earth's surface and is radiated away into space. In a number of geological situations this heat becomes concentrated at depths shallow enough that it can be tapped by drilling, to allow hot geothermal fluids to be brought to the surface for generation of electric power or for direct uses of the heat such as industrial heat or space heating.

- Hydrothermal resources include thermal water and steam trapped in fractured or porous rocks. A hydrothermal system is classified as either hot-water or vapor-dominated (steam), according to the principal physical state of the fluid. Hydrothermal resources are presently used both for electric production and for direct applications.

- Geopressured resources consist of water at moderately high temperatures and at pressures higher than normal, hydrostatic pressure due to the fact that they are confined and must support part of the weight of the overlying rock column. In some areas such as the Gulf Coast, this water contains dissolved methane. Geopressured resources in sedimentary formations in Texas and Louisiana are believed to be quite large. Geopressured formations also exist in sedimentary basins elsewhere in the U.S. Commercial-scale utilization of these resources may begin in the late 1980's.

- Hot dry rock resources consist of relatively unfractured and unusually hot rock at accessible depths that contain little or no water. To extract usable power from hot dry rock, the rock must be fractured and a confined fluid circulation system created. A heat transfer fluid (water) is then introduced, circulated, and withdrawn. Commericial-scale utilization of hot dry rock resources may begin in the 1990's.

At the present time, there are few confirmed geothermal reservoirs in the U.S. because of lack of an aggressive exploration and development industry. A few very high-temperature hydrothermal resources can be exploited economically for electric power generation but the vast majority are still uneconomic. Considerable technology development and demonstration are needed in order to decrease exploitation costs, and this topic is discussed further in the pages that follow.

Known areas of geothermal resource potential are shown on Figure 1. The known resources shown on this map are almost exclusively hydrothermal, except for the geopressured resources along the immediate coast of Texas and Louisiana and a few other smaller basins. There is no adequate assessment of the hot dry rock resource base to date. Figure 2 shows the distribution of known resources as a function of temperature. Note that as temperature decreases, the number of resources increases very rapidly (exponentially). Because of this observed distribution it is important to pursue the technology development and demonstration that will allow lower temperature resources to be economically exploited for electrical power production.

Geothermal resources are worldwide in occurrence and are generally present in geologically active areas that are also sites of volcanic and earthquake activity. Table 1 shows the electrical generation capacity for geothermal energy worldwide. All of this production comes from hydrothermal resources. The U.S. is the leader in geothermal electrical power production with 922 megawatts (MWe)[1], 912 of which come from a single field, The Geysers area about 80 miles north of San Francisco, California.

Worldwide use of hydrothermal resources for direct application is considerable. For example, a considerable portion of the homes and buildings in the Paris basin in France are heated geothermally, and the government shares the cost of drilling for geothermal fluids and for installation of surface equipment. In the U.S. there is little direct use of geothermal energy. There is no industry infrastructure to foster its use. Table 2 shows a summary of nonelectric (direct) use on line in the U.S. to the end of 1979.

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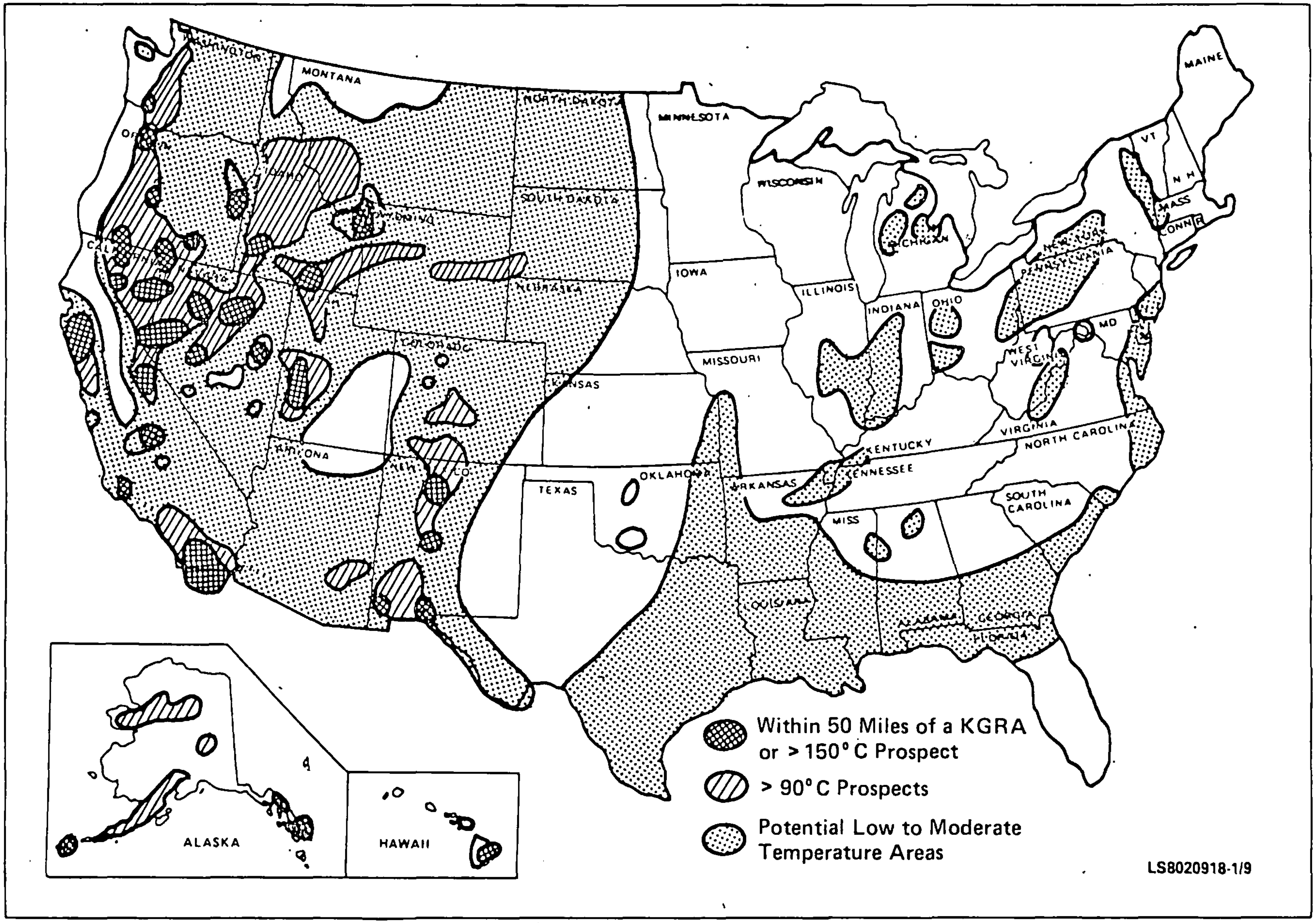
[1] 1 megawatt = 1 MWe
= 1 million watts

Figure 1

GEOTHERMAL RESOURCES ARE WIDESPREAD



THERE ARE MANY MORE LOW TEMPERATURE RESOURCES THAN HIGH TEMPERATURE RESOURCES

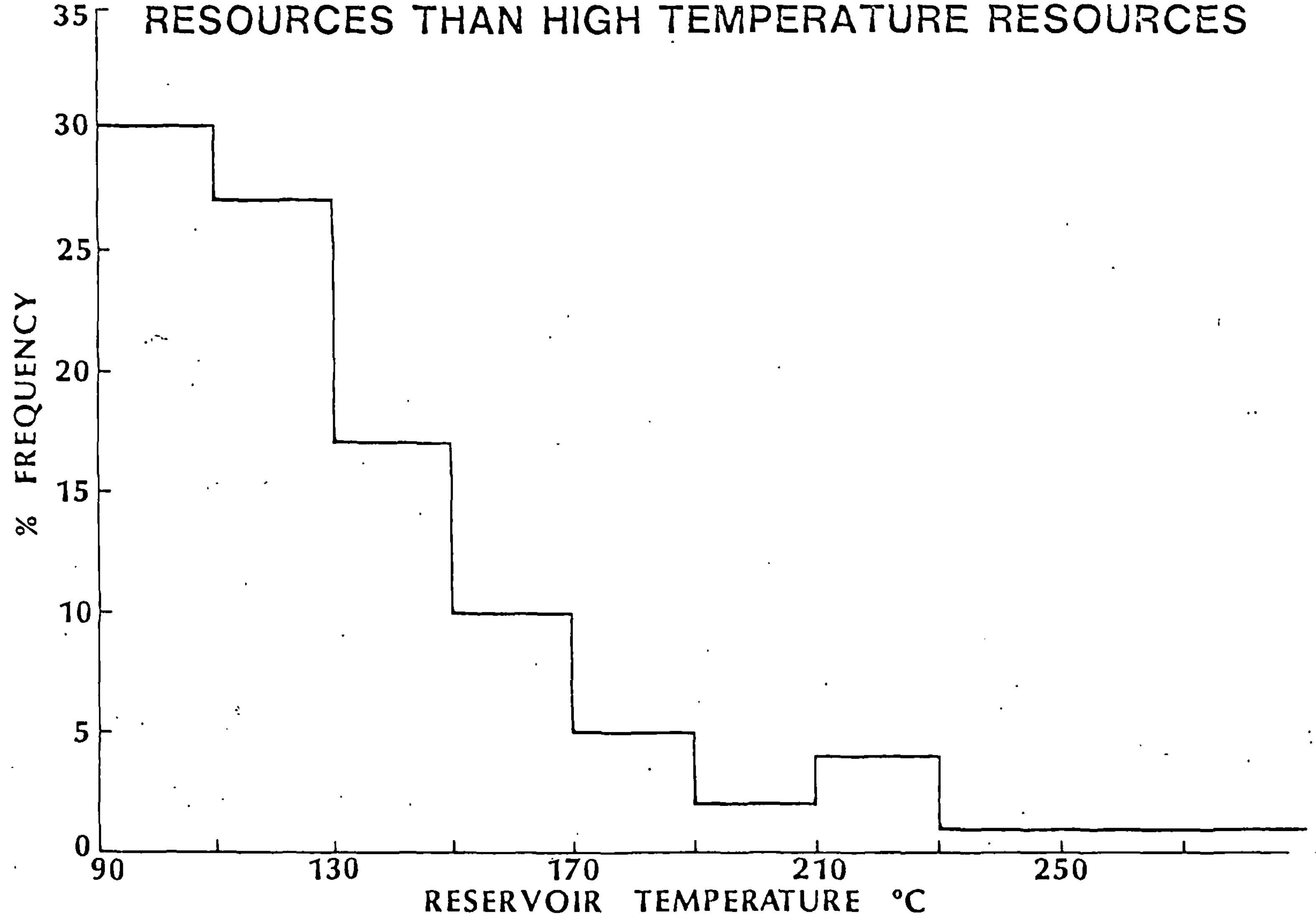


Table 1

WORLDWIDE GEOTHERMAL ELECTRICITY GENERATION
(to 1985)

Country	Present Capacity (MWe)	Planned Expansion (MWe)
China	4.5	--
El Salvador	60.0	385.0 -- 240 guaranteed
Iceland	62.0	--
Indonesia	0.3	--
Italy	420.6	400.0 -- 100 guaranteed
Japan	165.0	367.0 -- 255 possible -- 112 guaranteed
Kenya	--	35.0
Mexico	150.0	150.0 -- 100 possible -- 50 guaranteed
New Zealand	202.6	150.0
Philippines	224.2	710 planned
Taiwan	0.3	--
Turkey	0.5	14.0
USSR	5.0	58.0
United States	922.0	1401.0
TOTAL	2217.0	3670.0
GRAND TOTAL		5887 MWe

PROBLEMS IN GEOTHERMAL DEVELOPMENT

A number of problems currently exist in development of geothermal resources and these can be broadly classed as 1) institutional, 2) technological, and 3) infrastructure. Each type of problem adversely affects the economics of geothermal utilization, and each needs to be solved in order for an aggressive geothermal industry to develop in the U.S.

Institutional Problems. These have to the present time included: a) slow leasing schedules for geothermal lands by the Bureau of Land Management and the Forest Service; b) federal laws, regulations and tax structure that were not conducive to development; c) state laws and regulations that are, in many states, either inadequate, nonexistent or unnecessarily restrictive and often make ownership of the resource difficult to determine (in some states geothermal fluids are treated as a water resource whereas in others they are treated as a mineral resource); and d) environmental regulations that are unnecessarily restrictive. Recent changes in laws and regulations and directives for streamlining by President Carter have made substantial progress in removing these barriers, but more remains to be done, particularly on a state level.

Technological Problems. Recent economic studies by companies involved in hydrothermal electrical power generation have indicated that only the very few highest-temperature resources can be economically exploited today. Public Service Company (PSC) of New Mexico, which is involved in construction of a 50 MWe flash steam demonstration plant at Baca in north-central New Mexico, along with Union Oil Company and DOE, have projected their power generation costs to be 36 mills/kwh in levelized constant dollars. This plant will become operational in 1982 on a resource whose temperature is 550°F. By contrast, power that will be generated by DOE's other large demonstration plant, an organic binary cycle power plant in the Imperial Valley of California, is projected by San Diego Gas and Electric (SDG&E) to cost 75 mills/kwh on the same levelized constant dollar basis. Power costs being reported for coal and nuclear generation are both in the range 30 to 44 mills/kwh on the same basis. This makes the Baca plant cost competitive, but not the Imperial Valley plant. The reasons for high costs on the proposed SDG&E binary plant are straightforward. At 365°F, the binary plant requires approximately 2-1/2 times the brine flow rate as the 550°F flash plant. This higher brine flow dictates larger piping, valves and reinjection pumps. The lower temperature necessarily means a 20 percent lower thermal efficiency, which requires approximately 20 percent larger condensers, cooling towers, water-circulating pumps and 20 percent more make-up water. In addition, the lower vapor pressure of the 365°F brine causes wells to be low in productivity unless they are pumped. The binary plant will use approximately 5MWe of parasitic power for downhole pumps which are not required for the 550°F resource, plus an additional 2MWe of parasitic power for injection pumps. Capital costs for downhole pumps add $2.5 million in initial cost and will require frequent maintainance and replacement. It is clear that moderate-temperature resource utilization with current technology is not competitive with coal or nuclear.

High hydrothermal costs can be attributed primarily to high drilling costs, low reservoir temperature (requiring more wells) and/or low well productivity. The prospect for improving economics through technological progress is excellent, especially for the moderate-temperature resources (which constitute 80% of the inferred 140,000 MWe recoverable resource). Better exploration techniques, better ways to predict reservoir lifetime, materials development for use in geothermal equipment, drilling technology development, reservoir stimulation for the purpose of increasing well flow, downhole pumps and more efficient conversion systems have a realistic potential for cutting moderate temperature utilization costs in half, which is why the development of geothermal technology is an important part of the Federal geothermal program.

There is very little use presently being made of low- and moderate-temperature hydrothermal resources for direct heat purposes. The main reasons for this appear to be 1) lack of enough knowledge of the resource itself to attract users, and 2) the present high risk level and high costs associated with reservoir confirmation. By contrast, utilization of a low-temperature hydrothermal resource, once it is discovered and confirmed, usually consists of reasonably straightforward engineering.

<u>Lack of resource knowledge</u> occurs on two levels of detail: 1) on a regional scale, the locations of low- and moderate-temperature resources are poorly known; 2) on a site-specific scale, the lateral limits, depth, temperature, productivity, and longevity of very few low- and moderate-temperature hydrothermal reservoirs are known. Very little surface exploration and drilling have been done by the private sector.

The present high risk level for reservoir confirmation stems partly from the lack of resource knowledge stated above and partly from the fact that present surface surveying techniques are not well enough developed to ensure a high level of probability that a drill hole will intercept a resource. Hydrothermal reservoirs are never uniform or continuous, and dry holes can be drilled in the middle of the best of resources. Better techniques for and more experience in siting wells are needed to decrease the risk of drilling an unproductive well.

The high costs of reservoir confirmation result mainly from the high cost of drilling, as discussed previously. Drilling costs have been increasing faster than the inflation rate over the past several years.

Infrastructure (Direct Heat Uses)

Present developers of electrical power generation from high-temperature reservoirs are generally large companies that can finance reservoir confirmation by spreading the high risk and cost over many projects. However, these large companies are usually not interested in development or utilization of lower temperature reservoirs because of the relatively small scale of such projects. Small developers, the ones most likely to be interested in low- and moderate-temperature geothermal resources, are unable to spread risk and cost in the same way that a large company can. A single unproductive well can mean financial disaster for them. For these reasons, it is not expected that the direct heat user in the private sector will be able to perform needed reservoir confirmation for low- and moderate-temperature hydrothermal resources by himself in the near future. Without federal assistance there will continue to be very little use of this large hydrothermal resource base that exists in the United States.

HISTORY OF THE FEDERAL GEOTHERMAL PROGRAM

Although geothermal energy has been used in the United States since 1894, serious commercial interest did not begin until the late 1960's. The genesis of Federal geothermal activity can be said to have been the U.S. Geological Survey's (USGS) limited assessment, in 1969, of geothermal resources. This assessment was drawn from basic research conducted by the USGS on a limited scale since 1945 as a part of its charter to assess national resources. At about the same time, the Bureau of Reclamation was looking at geothermal resources as a means of mineral extraction.

By 1971 there was momentum enough to start a geothermal program in the Atomic Energy Commission. The AEC Act had been amended to mandate research into energy sources other than nuclear power. The Division of Applied Technology included Coal, Electrical Storage, Solar, and Geothermal offices. Even though the main emphasis was placed on geothermal technology, there was an attempt to relate the program to industrial applications. At approximately the same time, the National Science Foundation considered geothermal energy in its Research Applied to National Needs project. NSF thereafter became the lead agency for geothermal activities. In 1973 the USGS, AEC, and NSF prepared the first coordinated Federal geothermal program plan.

In early 1975 all of AEC's and the bulk of NSF's programs were transferred to the Energy Research and Development Administration (ERDA), created by the Energy Reorganization Act of 1974. The Non-Nuclear Energy Research and Development Act of 1974 gave ERDA considerable additional authority, including incorporation of the geothermal program previously established by the Geothermal Research, Development, and Demonstration Act of

1974. ERDA was given programmatic geothermal functions, and also was given the authority to coordinate all geothermal activities of Federal agencies. DOI retained its traditional role of national resource assessment and leasing of Federal lands.

Originally ERDA's orientation to geothermal energy was primarily technological. Although demonstration projects were envisioned, no funds were appropriated by Congress for them. The ERDA activities were aimed at electric power production, almost entirely to the exclusion of direct heat, nonelectric uses. A formal commercialization program was established only with the organization of the Department of Energy (DOE) in 1977; however, the concept of involving industry in geothermal development had been implicit from the beginning of Federal involvement in geothermal activities. In 1975, ERDA's Division of Geothermal Energy (DGE) had started to phase in commercialization activities with industry, but kept these activities closely tied to basic research. In 1979, the Division of Geothermal Resource Management was created under the Assistant Secretary for Resource Applications of DOE; research and development continued in DGE under the Assistant Secretary for Energy Technology. Late in the year, it was announced that DGE would be moved to Resource Application as well, and one group was once again formed. This one group, known as the Division of Geothermal Energy exists today in Resource Applications.

Other Federal entities also have certain responsibilities for geothermal energy development, and these are summarized in Table 2 with details shown in Table 3. Table 4 shows funding levels for these Federal programs.

Table 2

SUMMARY OF NONELECTRIC USE ON-LINE, 1979*

AREA OF USE	NUMBER OF USERS	FUNDING ($000) FEDERAL	STATE	LOCAL	PRIVATE	BTU/YEAR (10^9)
SPACE AND PROCESS USES	180	63,992	6,692	6,014	1,071	1,386.2
BATHS AND POOLS	90		2	9	73	51.8
ENHANCED OIL RECOVERY	1				unknown	10,000.0
TOTAL	271	63,992	6,694	6,023	1,144	11,438.0

*Based on data in the Geothermal Progress Monitor, Issue Number 1, December 1979.

Table 2

BASIC RESPONSIBILITIES OF FEDERAL AGENCIES

Produce Energy

- DOE/RA
- DOC/EDA
- DOD
- HUD
- USDA/FmHA

Stimulate Energy Production

- DOE/RA
- DOC/EDA
- HUD
- USDA
- DOT

Support Energy Production (Institutional Aspects)

- DOE/RA
- DOE/Env
- DOE/FERC
- EPA
- DOI/BLM
- DOI/USGS
- DOI/FWS
- USDA/FS

Make Federal Geothermal Resources Available

- USDA/FS
- DOE/RA
- DOI/BLM
- DOI/USGS

Reduce Costs and Risks (Research and Development)

- DOE/RA
- DOE/ER
- DOE/Env
- EPA
- DOI/BOM
- DOI/USGS
- DOI/FWS
- DOD

Improve Resource Estimates

- DOE/RA
- DOI/USGS
- DOI/WPRS

Table 3

DETAILED ACTIVITIES OF FEDERAL, NON-FEDERAL AND PRIVATE SECTORS

ACTIVITY	FEDERAL AGENCY'S ROLE	STATE AND LOCAL GOVERNMENT'S ROLE	PRIVATE ROLE
PRODUCE ENERGY	DOE/RA o Guarantee Loans o Cost-Share Field Demonstration Projects	o Cost Share Projects o Construct Facilities	o Cost Share Projects o Construct Facilities
	DOC/EDA o Award Grants on Projects		o Provide Capital
	DOD o Construct Facilities For Own Use		o Provide Management
	HUD o Award Grants for Projects		
	USDA/Farmers Home Administration o Award Grants for Projects		
STIMULATE ENERGY PRODUCTION	DOE/RA o Disseminate Information o Give Technical Assistance o Award Planning Funds to States o Provide Reservoir Confirmation Assistance	o Disseminate Information o Plan o Provide Appropriate State Geothermal Rights Laws	o Broker Projects
	DOC/EDA o Award Grants for Planning	o Provide Tax Incentives	
	HUD o Allocate Planning Funds		
	USDA o Allocate Planning Funds		
	DOT o Administer Tax Incentives		

Table 3 (Con't.)

ACTIVITY	FEDERAL AGENCY'S ROLE	STATE AND LOCAL GOVERNMENT'S ROLE	PRIVATE ROLE
SUPPORT ENERGY PRODUCTION (INSTITUTIONAL ASPECTS)	DOE/RA o Provide Environmental Assessments and Impact Statements on DOE Projects (including Loan Guarantee Projects) o Make Recommendations on New Legislation o Facilitate International Technology Exchange	o Formulate State Environment Regulations o Issue Required Permits and Approvals o Formulate Public Utility Commission Regulations and Decisions	o Provide Environmental Data Requested o Apply for Permits and Approvals
	DOE/Environment o Review EAR's and EIS's o Write Environmental Development Plans o Write Area Environmental Assessments	o Cooperate with Federal Environmental Review Processes	
	DOE/FERC o Issue Power Production Decisions on Geothermal Power Projects	o Cooperate with Federal Permitting Procedures	
	EPA o Formulate Environmental Regulations		
	DOI/BLM o Undertake Environmental Reviews before Leasing		
	DOE/USGS o Monitor Environmental Impacts after Leasing		
	DOI/FWS o Provide Environmental Reviews as Requested by DOE, BLM, USGS, and FS		

Table 3 (Con't.)

ACTIVITY	FEDERAL AGENCY'S ROLE	STATE AND LOCAL GOVERNMENT'S ROLE	PRIVATE ROLE
REDUCE COSTS AND RISKS (RESEARCH DEVELOPMENT AND DEMONSTRATION) Con't.	DOE/Energy Research • Perform A Basic Research DOE/Environment • Environmental Technology EPA • Develop Environmental Technology DOI/Bureau of Mines • Perform Geothermal Brine Research • Develop Standard Test Methods for Geothermal Materials • Field test Site-specific Materials DOI/USGS • Improve Resource Assessment and Exploration Concepts DOD • Perform Construction Materials/ Corrosion Research		
IMPROVE RESOURCE ESTIMATES	DOE/RA • Explore Potential of Hot Dry Rock Resources • Conduct Cost-Shared Hydrothermal Reservoir • Assessment with States DOI/USGS • Characterize various types of geothermal systems • Assess resources on a regional basis and update and refine national inventory DOI/WPRS • Explore Resources	• Conduct State Resource Assessments • Cost-share Federal Reservoir Assessments	• Conduct Reservoir Assessments • Cost-Share Federal Reservoir Confirmation • Provide Wells of Opportunity

Table 3 (Con't.)

ACTIVITY	FEDERAL AGENCY'S ROLE	STATE AND LOCAL GOVERNMENT'S ROLE	PRIVATE ROLE
SUPPORT ENERGY PRODUCTION (INSTITUTIONAL ASPECTS) Con't.	USDA/FS o Provide Environmental Reviews and Assessments for Forest Service Lands o Consent to Leasing on FS Lands o Review Development Permits and Approvals		
MAKE FEDERAL GEOTHERMAL RESOURCES AVAILABLE	DOE/RA o Set Production Goals o Promulgate Regulations	o Cooperate with Federal Leasing Procedures	o Apply for Lease Applications
	DOI/BLM o Leasse Competitive BLM and FS land o Process Noncompetitive Lease Applications	o Issue Permits and Approvals	o Bid on Competitive Leases
	DOI/USGS o Review Development Plans o Provide Permits and Approvals o Evaluate Resource Areas to Determine Competitive Lease Sales		o Meet Requirements for Permits and o and Approvals
	USDA/FS o Process Noncompetitive Lease Applications o Review Permits and Approvals		
REDUCE COSTS AND RISKS (RESEARCH DEVELOPMENT AND DEMONSTRATION)	DOE/RA o Build Hydrothermal Demonstration Plants	o Conduct Research	o Conduct Research
	o Undertake Materials Research and Development		o Provide Insurance
	o Undertake Drilling Research and Development		
	o Develop Environmental Technology		o Assume Risks
	o Develop Geopressured Technology		
	o Develop Hot Dry Rock Technology		
	o Undertake Geochemical Engineering Research and Development		
	o Improve Reservoir Evaluation and Exploration Technology		

Table 4

FEDERAL FUNDING FOR GEOTHERMAL ENERGY
(in $ thousands)

ORGANIZATION UNIT	ACTUAL FY 1977	ACTUAL FY 1978	ACTUAL FY 1979	ESTIMATED FY 1980	REQUESTE FY 1981
Department of Agriculture					
U.S. Forest Service	40	678	775	750	739
Department of Defense					
Navy	758	542	924	17,100	17,800
Air Force	15	0	13	21	2,400
DOD Total	773	542	937	17,121	20,200
Department of Energy					
Energy Technology	53,326	105,962	142,637	138,428	142,000
Resource Applications			9,737	9,026	10,000
Office of Energy Res.	1,900	2,800	3,200	3,400	4,000
Environment	3,862	3,896	3,167	2,303	2,949
Geothermal Loan Guaranty Fund (Administrative Expenses)	380	410	189	1,180	1,091
DOE Total	58,468	113,068	158,930	154,534	160,040
Department of Interior					
Fish and Wildlife	200	200	200	74	74
Bureau of Land Mgmt.	2,500	2,300	2,585	2,600	2,600
Bureau of Mines	528	550	1,050	800	400
Water and Power Res.Serv.	2,557	1,800	555	910	60
Geological Survey, Geothermal Res. Program	9,384	10,184	12,043	10,092	7,569
Geological Survey, Geothermal Evaluation and Lease Regulation	1,512	1,854	2,194	1,994	1,994
DOI Total	16,681	16,888	18,627	16,470	14,423
Environmental Protection Agcy.	600	670	750	750	750
National Science Foundation	200	175	70	0	0
Total Federal Geothermal Program Budget	76,782	132,021	180,089	189,696	196,152

THE FEDERAL PROGRAM

(Emphasis on the DOE Geothermal Program)

The principal barriers to development of geothermal energy by industry are: 1) the lack of confirmed reservoirs; 2) uncertainty about reservoir performance during extended production; 3) the lack of economic technologies for all but the highest quality resources; 4) the ambiguous status of ownership of geothermal fluids; 5) the slow pace of current leasing, permitting and licensing procedures; 6) the site-specific acceptability of waste fluid disposal and other environmental control measures; and 7) user inexperience with the resource. Divided among various agencies and offices, the Federal geothermal program works, whenever possible, in close communication with energy companies and other potential users of the geothermal resource.

Technology Development

Methods for geothermal exploration has been adopted from those used in mining and petroleum exploration, and so no cost-effective, geothermal-specific exploration architecture yet exists. Once a resource is discovered, there are not adequate methods to assess reservoir producibility or lifetime, and these uncertainties make it difficult for developers and utilities to obtain development capitol. Geothermal energy recovery is accomplished with technology similar to oil and gas industry technology, but geothermal temperatures and fluid characteristics, exceeding those for which oil field equipment was designed, shorten equipment lifetimes and pose safety hazards. Surface heat recovery equipment adapted to geothermal use from existing steam technology is expensive and inefficient especially for lower resource temperatures. And environmental problems cause unique difficulties.

Technology specifically tailored to geothermal conditions is needed. The objective of the geothermal technology development program is to solve these problems. The program consists of four major areas: reservoir assessment technology, well drilling and completion technology, energy extraction and conversion technology, and geochemical engineering and materials.

The purpose of reservoir assessment technology is to more accurately predict, locate, and measure reservoirs. Relying on the industry to point out key technical problems, the government carries out research in exploration technology, reservoir engineering, and logging instrumentation and interpretation.

The purpose of well drilling and completion technology is to reduce the cost of geothermal drilling and to improve well completion techniques. In stage one, improvements in drill bits, downhole motors, and drilling fluids will demonstrate the technology that will make a 25 percent reduction in drilling costs possible by 1983. In stage two, a new drilling system is expected to enable a 50 pecent reduction in geothermal drilling costs by 1986.

The purpose of energy extraction, conversion, and stimulation technology is to reduce electric generating costs, particularly for moderate-temperature geothermal fluid. Extraction and conversion technologists improve performance and reduce costs of binary heat exchangers. Stimulation technologists develop new equipment and techniques for use in high-temperature geothermal environments, to improve formation permeability and therefore well productivity.

Numerous studies have determined that binary cycles, which use an organic working fluid to transfer heat from the geothermal fluid to the turbine-generator, offer the greatest potential for reducing the costs of generating electricity from the moderate-temperature geothermal resource; thus the DOE conversion technology program is heavily oriented toward binary conversion cycles. Direct contact heat exchangers and advanced design are areas of particular interest. The gravity head binary system is expected to yield a significantly higher utilization efficiency by improving heat transfer characteristics and reducing parasitic loads consumed by feed pumps.

The extraction of heat from geothermal fluids requires the handling and disposal of large volumes of water. Because the chemistry of geothermal waters is to a large extent site-specific, the problems of scale control, erosion, and corrosion require a detailed design to balance technical and economic subsystems for each potential site. The purpose of geochemical engineering and materials technology, therefore, is to address the special character of geothermal fluids and their interaction with other materials.

Fluid chemistry programs develop monitoring and control instruments, fluid control technology, and economic fluid disposal procedures that reduce scaling and cost of use. Materials development programs tailor borehole and conversion equipment to geothermal use. As noted above, oil field equipment is poorly suited to geothermal use; this is primarily because materials are degraded by the high temperatures and fluid chemistry.

Technology Demonstration

DOE builds and tests facilities to demonstrate that the use of hydrothermal resources is technically feasible, economically sound, and environmentally acceptable. Demonstration products also foster the business infrastucture necessary for the private sector to continue Federal without initiatives.

50 MWe Flash Steam Demonstration Plant. In FY 77, Congress, authorized DOE to carry out a geothermal demonstration project using a hot water hydrothermal resource. The project entails construction and operation of a commerical-scale (50 MWe gross output) electric power plant. The plant will also serve as a "pathfinder" for the regulatory process and other legal and institutional aspects of geothermal development. A cooperative agreement between DOE, Union Geothermal of New Mexico, and Public Service Company of New Mexico was signed in August 1979. The final EIS was prepared for release in January 1980. Plant design is under way at Baca Ranch, (NM) and an order for a turbine has been placed. The plant is scheduled for start-up in 1982.

50 MWe Binary Demonstration Plant. This project entails design and construction of a power plant that uses an organic fluid (for example, isobutane) as the turbine working fluid. Because certain organic fluids vaporize at lower temperatures than does water, high efficiency use can be made of lower temperature geothermal resources in this way. To date no successful large scale geothermal binary plant has been operated for an extended period, and yet engineers believe that development of binary technology is key to economic utilization of the more abundant, lower

temperature geothermal resources (300°F to 450°F). DOE's demonstration plant will be built at Heber, CA, in the Imperial Valley, and is being cost shared with San Diego Gas and Electric and Chevron.

H G P-A Geothermal Wellhead Generator. This project will evaulate the feasibility of using a wellhead generator to produce baseload electrical power. The generator will use the geothermal fluid from geothermal well H G P-A in the rift zone of an active volcano in the Puna District of Hawaii. The major power plant components will be mounted in such a way that they can be moved to other sites at some future date. The project is expected to lead to commerical applications of wellhead generators in remote areas of the western continental United States and Hawaii. It is scheduled for operation in April 1981.

Raft River Facility. A pilot plant now being built has a 5 MWe turbine generator with a binary Rankine power cycle, and will use energy from a moderate-temperature hydrothermal resource (150°C) to generate electricity for a utility power grid.

Resource Identification, Assessment, and Exploration

The objectives of the Federal resource identification program are to

- Characterize the geological nature of each type of geothermal system and the reservoirs within these systems
- Estimate the location, distribution, and energy content of individual geothermal systems and reservoirs
- Inventory the identified portion and predict the undiscovered portion of the nation's geothermal resources

- Confirm the existence and commercial potential of high- and moderate-temperature reservoirs suitable for electric power generation
- Confirm low- and moderate-temperature prospects that show potential for direct heat applications.

To achieve these objectives, DOE and the U.S. Geological Survey (USGS) undertake national, regional, and in cooperation with individual states, site-specific assessments of the geothermal resource (with emphasis on the hydrothermal resource). In addition, exploratory drilling programs have begun in several regions where a strong interest in direct heat has been exhibited, but where appropriate resources have not yet been confirmed.

Industry Coupled Case Study Program. To accelerate confirmation of geothermal reservoirs with apparent commercial electric potential, the Industry-Coupled Case Study program was begun in FY 78. DOE shares exploration and drilling costs with industry, in exchange for public release of data; these data help in finding successful techniques for exploration, well drilling, and completion. In FY 79, nine companies participated. The program was extended to northern Nevada, where 12 candidate sites are being investigated for exploratory drilling in FY 80. Although this program has been strongly supported by industry, Congress has not appropriated further funds. The program is a needed element in DOE's efforts, and should be reinstated.

State-Coupled Program. Low- and moderate-temperature resources are being defined in cooperation with nearly all 37 states that have identified resource potential. The effort consists of two phases. Phase 1 analyzes existing geological and geophysical data to establish the size and distribution of hydrothermal resources. Phase 2 assesses target areas in detail and may drill heat flow measurement holes to confirm the existence and nature of the resource.

User Coupled Drilling Program for low- and moderate-temperature resources. Competitively selected teams composed of a developer and a user share the cost of surface exploration and drilling to locate and confirm reservoirs that could be commercially developed for direct heat applications as identified by the user.

USGS Assessment. A comprehensive, multi-year study of the Cascade Mountains of Washington, Oregon, and northern California is under way to determine the character and extent of geothermal resources of the region. It is being conducted by the USGS, state agencies, several universities, and several private firms. Reconnaissance studies have been initiated and will be followed by selection of a few areas for concentrated studies. In a related effort, DOE and USGS are jointly evaluating the resource potential of Mount Hood, Oregon.

Ice-Breaker Plants

A new initiative that DOE/DGE is considering is the cost-sharing with industry of "ice-breaker" plants on certain geothermal reservoirs. These plants would be 10 to 20 MWe in size and would enable the developer and utility to gather data on resource temperature and producibility in a production setting without commitment to the cost of a large-scale plant.

Industry favors this approach and indeed is proceeding in just this way with development of the high-temperature resource at Roosevelt Hot Springs, Utah.

Commercialization

The hydrothermal commercialization program of DOE seeks to accelerate commercial utilization of hydrothermal resources for electric power and for direct heat applications, thereby displacing fossil fuels. This program formulates geothermal commercial development plans, develops a national progress monitoring system, assesses the market penetration potential for hydrothermal resources, and identifies direct heat markets suitable for early penetration. Further activities encompass development planning in cooperation with local and state officials and potential users, support for economic and engineering feasibility studies, continuing interagency coordination and policy development, and outreach programs to acquaint potential users with the availability and competitive cost of hydrothermal energy and with the availability of financial assistance through various Federal programs. The program also seeks to make States a principal partner in implementing the Federal program by funding State commercialization and planning teams.

Outreach. Except for a small group of technical specialists, few people understand the range of possible applications of geothermal energy. DOE/DGE has an outreach program to mitigate this barrier. One phase aims to inform potential users and developers and their support groups of geothermal energy's costs, benefits, safety, reliability, and environmental effects. A second phase reaches out to the general public, trade, industrial, and professional associations, and other large groups capable of making primary financial commitments to geothermal development.

Direct Heat Applications. The principal goal of the direct heat applications program in DOE is to build a direct-use infrastructure by funding selected direct heat applications. The first solicitation for direct use field experiments was issued in 1977; 22 proposals were received. Eight of these proposals were selected for contracts, with the Federal share of the cost varying from 46 percent to 80 percent. A second solicitation was issued in FY 78, resulting in 40 proposals, of which 15 were selected for initial FY 79 funding.

Of the 23 contracts underway in FY 79, the majority are for space and district heating, while three are directed at agriculture, and three involve industrial processing. The equivalent of 900,000 barrels of oil per year would be displaced if each of these projects succeeds.

Feasibility Studies. This program funds studies to determine the technical and economic feasibility of proposed hydrothermal applications. These are done in conjunction with potential users. Since the geothermal program began, 23 such studies have been completed--7 of space and district heating, 10 of industrial processing, and 6 of agribusiness or aquaculture. Results from 17 completed studies were analyzed for factors influencing decisions to invest in direct use processes. The cost of energy from geothermal sources was shown to be competitive with fuel-oil-based energy if at least 20 percent of the energy from the wells is used.

Environment

The Federal environmental program includes acquisition of baseline data, monitoring, and research related to air and water quality, ecology, noise, ground subsidence and induced seismicity, health effects and socioeconomic problems; regional and site specific assessments of the environmental, health, and socioeconomic impacts of the development of geothermal resources; development and assessment of environmental control technologies; and the promulgation of regulations to protect the environment from the adverse effects of exploiting geothermal resources.

The DOE, EPA, and DOI have been the principal supporters of the environmental program, with DOE sponsoring most of the research activities. DOE and EPA have increased their funding for cooperative projects over the past few years.

Geothermal Loan Guaranty Program (GLGP)

On January 5, 1979, DOE published its proposed regulations for GLGP for comment from interested parties (44FR 1568). The proposed regulations incorporated GLGP amendments in P.L. 95-238, which in summary:

- Pledge the full faith and credit of the United States to the payment of these guarantees
- Allow DOE to borrow funds from the Department of the Treasury, if balances in the Geothermal Resources Development Fund are insufficient to carry out guaranty and other responsibilities
- Authorize DOE to help the borrower pay the loan principal
- Allow DOE to complete and operate a plant acquired through

default

- Provide for loan guarantees up to 75% of estimated project cost for up to 30 years.
- Limit loans to $100 million per project and to $200 million per qualified borrower
- Limit to 1 percent the guaranty fee to be imposed annually on the outstanding guaranteed debt, and permit fee collection to be deposited in the Geothermal Resources Development Fund
- Authorize DOE to reimburse qualified public agencies and Indian tribes for a portion of the interest when a holder of the debt guaranteed under this regulation is required to include that income under Chapter 1 of the Internal Revenue Code
- Authorize certain forms of community impact for loans over $50 million.

To date 16 applications for loan guaranty have been received and 6 have been granted for a total of $136 million.

THE PROMISE OF GEOTHERMAL ENERGY

Inventories by the U.S. Geological Survey (Muffler, 1978) show that the geothermal resource base in the U.S. is large indeed. In the identified hydrothermal areas, excluding the national parks, it is estimated that 23,000 MWe of electrical energy and 42 Quads of beneficial heat could be developed if these areas were fully exploited. In addition, USGS scientists believe that there is a large undiscovered resource base that could contribute an additional 72,00 to 127,000 MWe and 184-310 Quads of beneficial heat (Table 11, Muffler, 1978). These figures give probable upper bounds for the hydrothermal energy resource base as presently understood. Of course not all of this resource base could be economically developed, even by the end of this century.

In a sophisticated study done over the past year, DOE has assessed the share of the electric market likely to be captured by hydrothermal power by the year 2000 (Anon., 1980). The study was performed in such a way that the effect of DOE's present and proposed programs, and of hypothetical changes in programs, could be determined. Tables 5, 6 and Figure 7 show the results of this study. If Federal program elements are continued it is more than 50% likely that by the year 2005, 12,800 MWe of electrical power generation will be developed from hydrothermal resources. By this time the estimated contribution from geopressured resources is 2,700 MWe (from the thermal energy) and from hot dry rock resources is 1,300 MWe.

A companion study is presently being performed to estimate the contribution of direct heat geothermal resources to our energy needs.

Preliminary analysis shows that at least 0.5 Quads will be on line by 2000, where 1 Quad = 10^{15} BTU. For comparison the current energy consumption for all forms including transportation is about 80 quads/year.

Geothermal energy is indeed a promising and viable energy alternative.

TABLE 5

NATIONAL ELECTRIC POWER ESTIMATE
(With Federal Program)

YEARS	PROJECTED NUMBER OF GIGAWATTS WITH A LIKELIHOOD			
	> 0%	> 10%	> 50%	> 90%
1980	1.0	1.0	1.0	1.0
1985	1.8	1.8	1.7	1.7
1990	3.8	3.8	3.7	3.6
1995	9.1	8.9	7.9	7.1
2000	17.0	16.8	12.8	10.8

TABLE 6

COMPARISON OF HYDROTHERMAL ESTIMATES FOR POWER
ON LINE (MW_e) THROUGH 1987

REGION	MARKET SHARES TASK ESTIMATE		EPRI - UTILITY SURVEY (1980)		DOE TELEPHONE SURVEY ANNOUNCED PLANS (1980)
	>90% LIKELIHOOD	>50% LIKELIHOOD	ANNOUNCED	PROBABLE	
NORTHERN CALIF.	1780	1780	1113	1424	2418
SOUTHERN CALIF.	540	660	689	854	308
OREGON & WASHINGTON	0	0	10	45	0
NEVADA	40	40	17	75	60
UTAH	220	260	0	130	20
ARIZONA	0	0	17	25	0
IDAHO, MONTANA, WYOMING	0	20	10	20	0
COLORADO	0	0	0	0	0
NEW MEXICO	40	40	18	80	45
TOTAL	2620	2800	1873	2643	2851

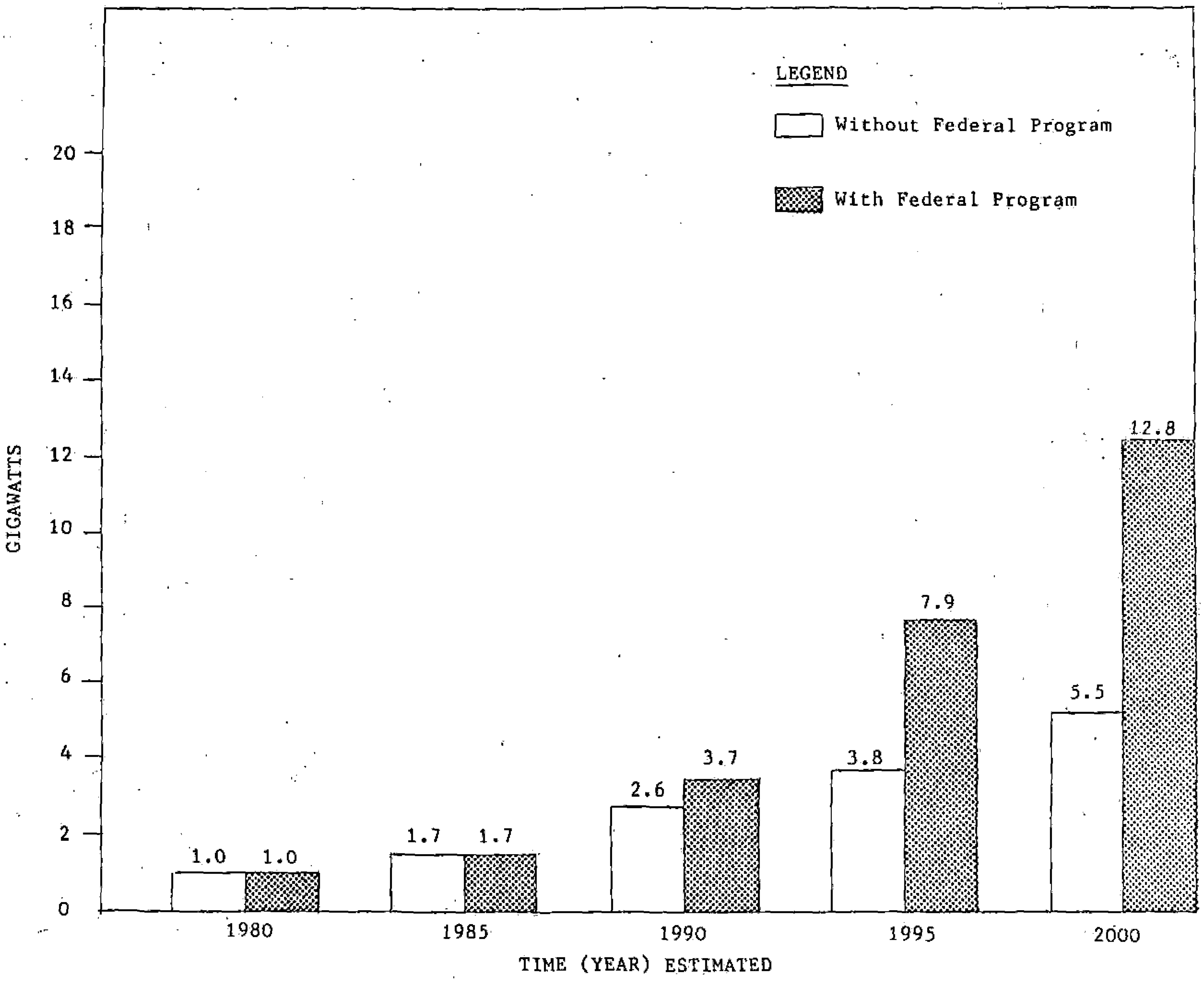


FIGURE 3

COMPARISON BETWEEN ESTIMATED POWER-ON-LINE WITH FEDERAL/DOE PROGRAM AND POWER-ON-LINE WITHOUT FEDERAL/DOE PROGRAM AT >50% LIKELIHOOD