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UTILIZATION OF INTERMEDIATE-TEMPERATURE GEOTHERMAL BRINES IN THE PRODUCTION OF ELECTRIC POWER*

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ABSTRACT

Existing geothermal electrical generating plants are using power cycles that are economical for only 25% of the known hydro-thermal reservoirs. The University of California Lawrence Berkeley Laboratory has proposed the building of a 10 MW pilot plant using a different type power cycle. This plant will utilize intermediate-temperature (150° C to 230° C) geothermal brine, to demonstrate the feasibility of producing power economically at these temperatures and thereby extending the useful brine temperature range. Data collected from chemical analysis of hot spring waters indicated that Northwestern Nevada would be the most fruitful region in which to begin the initial studies. The area maintains a high heat flow in conjunction with an appreciable temperature at depth. Construction time for the plant will be approximately two years and the project is expected to cost about six million dollars.

An essential part of the proposal addresses itself to a continuing program of research in areas where the development of data will improve geothermal technology. Specific areas are:

1. Geophysical Methods
2. Geothermal Power Extraction Processes
3. Kinetics of Geothermal Silica Precipitation and Dissolution

*Work done under the auspices of the U. S. Atomic Energy Commission.

4. Corrosion Mechanisms
5. Geothermal Reservior Fluid Circulations
6. Properties and Behavior of Rock-Fluid Systems at High Pressure and Temperature
7. Brine Management in Relation to Power-Generation Methods.

It is estimated that the most critical period of the Nation's energy shortage will occur between the present and 1985. Geothermal power production has the potential of making a significant contribution towards reducing the magnitude of this shortage.

The magnitude of the geothermal resources appears to be very large—particularly in the western region of the United States. An estimate is given in the report "Geothermal Energy" (W. J. Hickel, University of Alaska, Sept. 1972) that 132,000 MW of geothermal electrical generating capacity could be operating in the United States by 1985 and 395,000 MW by the year 2000. The present electrical power requirement of the U. S. is about 400,000 MW.

The extent to which these predicted generating capacities can be achieved will be determined, to a large extent, by the degree of priority accorded a national geothermal research and development program supported both by government and by industry.

The goals of the LBL-UCB geothermal research and development program are:

1) To demonstrate the feasibility of economic geothermal power from intermediate-temperature geothermal brines (150° C to 230° C) by the construction and operation of a 10 MW pilot plant.

2) To carry out extensive laboratory and field research to provide necessary data and techniques in support of the development of geothermal power production from brines in the intermediate-temperature region.

PILOT PLANT PROJECT

Geothermal electric power now being generated in the United States utilizes steam for its source of energy. This steam is produced in vapor-dominated hydrothermal reservoirs (such as the Geysers in California) or from flashing very hot brine from a liquid-dominated hydrothermal reservoir. Under existing methods, the brine temperature must be at least 200°C in order for these systems to be economical. Only one in twenty of the known hydrothermal reservoirs is vapor-dominated,* and only 20% of the

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*White, D. E., 1970, Geochemistry applied to the discovery, evaluation, and exploitation of geothermal energy resources: Geothermics, Special Issue 2, vol. 1.

liquid-dominated reservoirs have brine temperatures in excess of 200°C. Thus 75% of all the known geothermal hydrothermal reservoirs contain brines with maximum temperatures less than 200°C. Obviously there is a great need to demonstrate the technology necessary to produce electrical power from this large source of energy.

The proposed pilot plant will use brine at a temperature less than 230°C. This intermediate-temperature geothermal resource occurs over extensive areas of the Great Basin of the western U. S. Operation in this temperature region will require a process differing from the simple brine-flashing system. Power cycles of various types are being analyzed with respect to cost and performance for operation within this temperature range.

One such system is the so-called "binary-fluid cycle", shown in a simplified form (Fig. 1). Heat from the brine is transferred to a secondary fluid having a low-temperature boiling point. High-pressure vapor, generated in the heat exchanger by the boiling of the secondary fluid, is allowed to expand through a turbine where its heat energy is transformed into mechanical energy. Vapor from the turbine exhaust then passes into a condenser where the waste heat is removed. The condensate is returned to the heat exchanger via a pump to complete the secondary fluid cycle. Choice of the secondary fluid will depend on the specific brine temperature found at the pilot plant site. Typical secondary loop fluids are hydrocarbons such as isobutane or one of the Freons.

Figure 2 shows a comparison between a simple steam flash system and a binary system. The maximum brine enthalpy anticipated at the plant site will be on the order of 400 Btu/lbm. At these lower values of enthalpy, the binary cycle does become the more efficient of the two cycles, as indicated on the graph. In this comparison, the secondary fluid used in the binary cycle is iso-butane. The calculations assume a turbo-generator efficiency of 70% and a condensate temperature of 71°C for both cycles. Other design parameters were optimized to give the lowest unit energy cost.

Although some progress has been made in developing the technology of intermediate-temperature systems, further research on such systems is needed. Therefore, the rationale for this project is to determine what problems exist in these systems and provide a solution to these design problems, thus demonstrating the feasibility of generating electric power from intermediate-temperature brines. Experience gained by operating the pilot

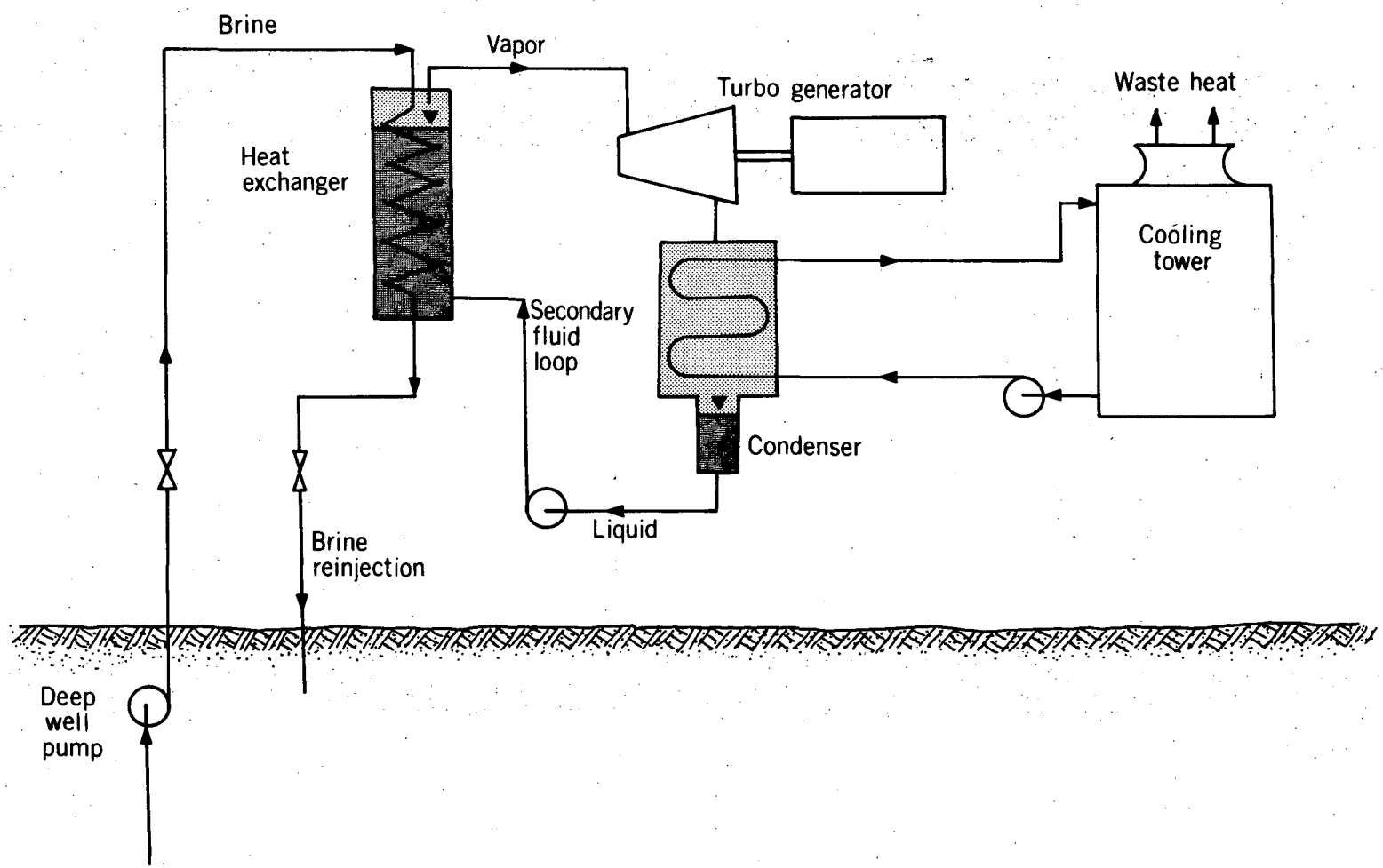

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Fig. 1. Binary fluid cycle.

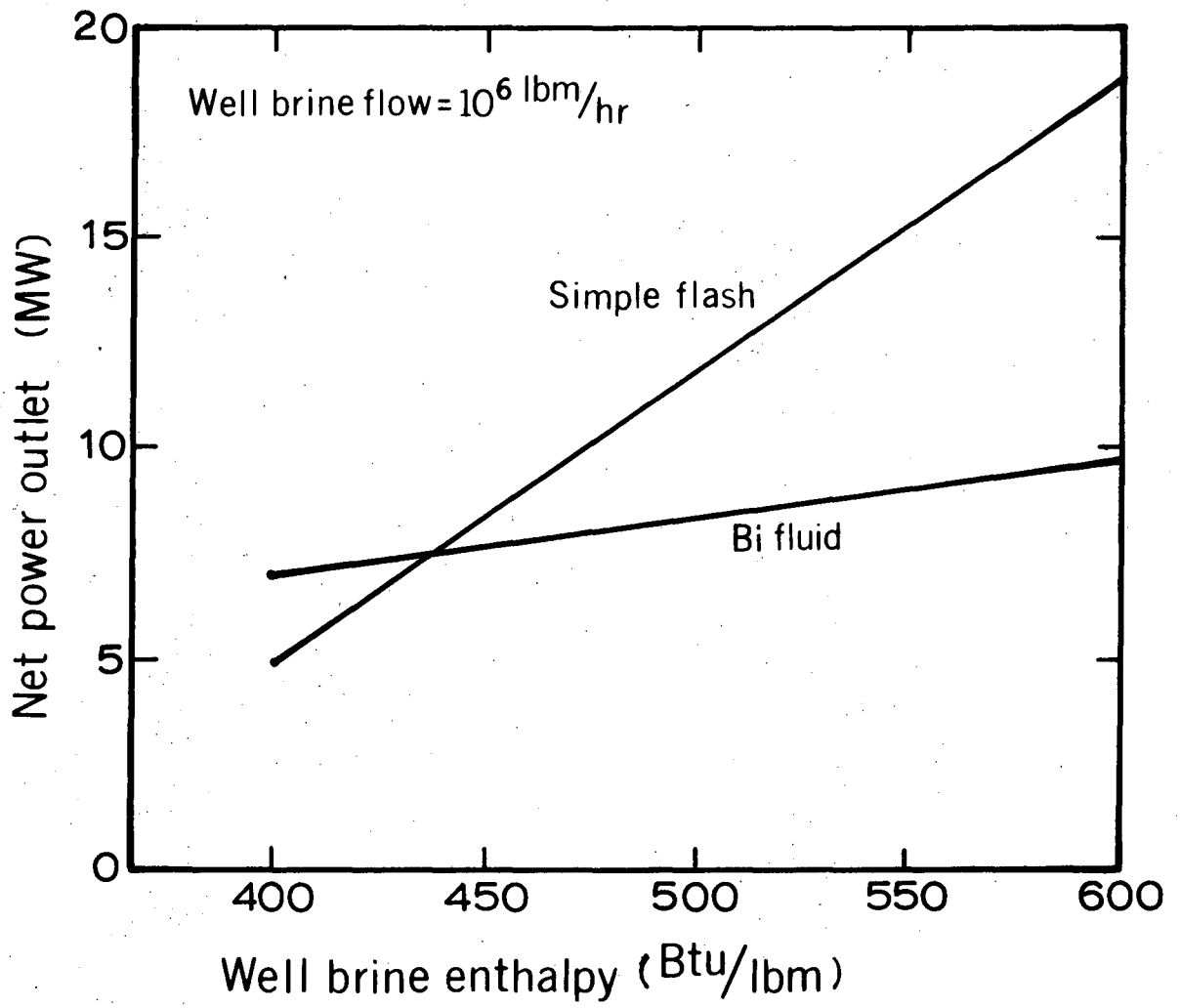

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Fig. 2. Comparison of a simple steam flash system and binary system efficiencies.

plant will greatly reduce the number of "unknowns" that exist today, and thereby lessen the technical risk factor involving future installations of this type.

The initial phase of the project will be concerned with site selection. We have considered regions in which geothermal brines of the desired temperature range (150° C to 230° C) may be economically accessible. In the western U. S. these regions are primarily encompassed by the basin and range geomorphic province, and include most of Nevada, south-central and southeastern Oregon, southern Idaho, western Utah, and southeastern California east of the Sierra Nevada. The Berkeley group, aided by the U. S. Geological Survey, has collected relevant information on the basin and range province, and we have chosen northwestern Nevada as the region for initial studies. The choice was based on data indicating a unity of high regional heat flow with appreciable temperatures at depth determined from chemical analyses of hot-spring waters. (Figure 3 shows regional heat flow in the western U. S.) The U. S. Geological Survey is currently making shallow temperature surveys at several hot spring areas in northwestern Nevada, and members of the Survey have examined, sampled, and analyzed many of the spring systems. The Sierra Pacific Power Company, whose transmission grid serves the region, has encouraged the evaluation and development of geothermal power potential in northwestern Nevada. For these reasons we have chosen this region for initial studies; however, we are not constrained from undertaking cooperative studies in other regions in the future.

Northwestern Nevada is characterized by alternating mountain ranges and valleys, trending approximately north-south. The Southern Pacific and Western Pacific railroads, and U. S. Highway 180 transect the region in a roughly east-west direction. (Figure 4 shows the distribution of promising thermal spring areas and the high heat flow region.) The geologic setting of the thermal spring areas of northwestern Nevada appears to be controlled by the normal-fault systems which bound the valleys. High heat flow (1.5 to 3 times the normal for continental areas) predominates. At locations where geothermal gradients are high (40° C/km or greater) fault systems penetrating to depths of 4 to 5 km or deeper are believed to furnish channelways for downward percolation of meteoric water to temperature regimes exceeding 150° C. The heated water is subsequently transported upward along other parts of the fault zones in a convecting system. The thermal systems are

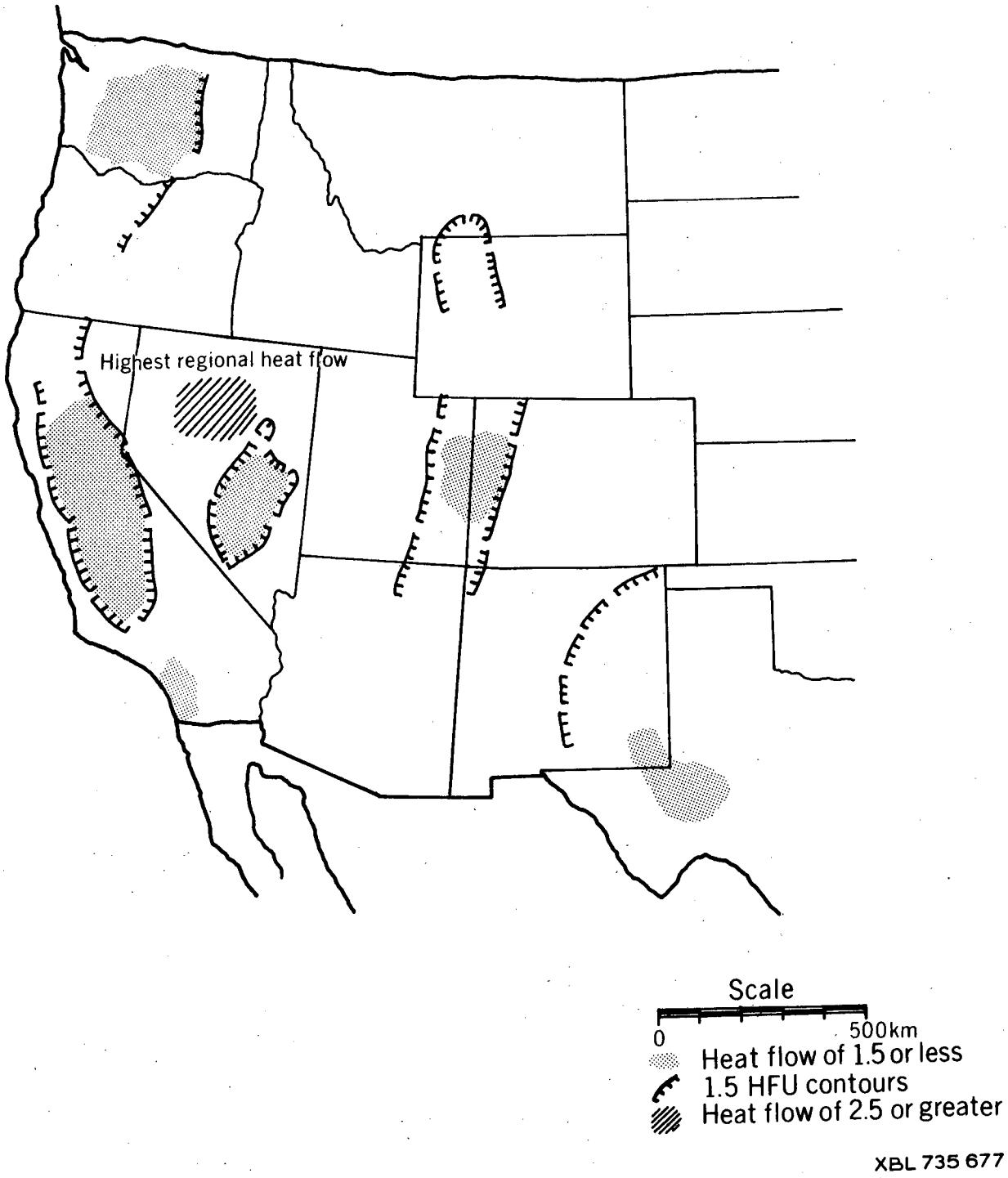

Fig. 3. Regional heat flow in Western U. S. (Modified from J. H. Sass et al., 1971, J. Geophysical Res., Vol. 76, No. 26, p. 6376.)

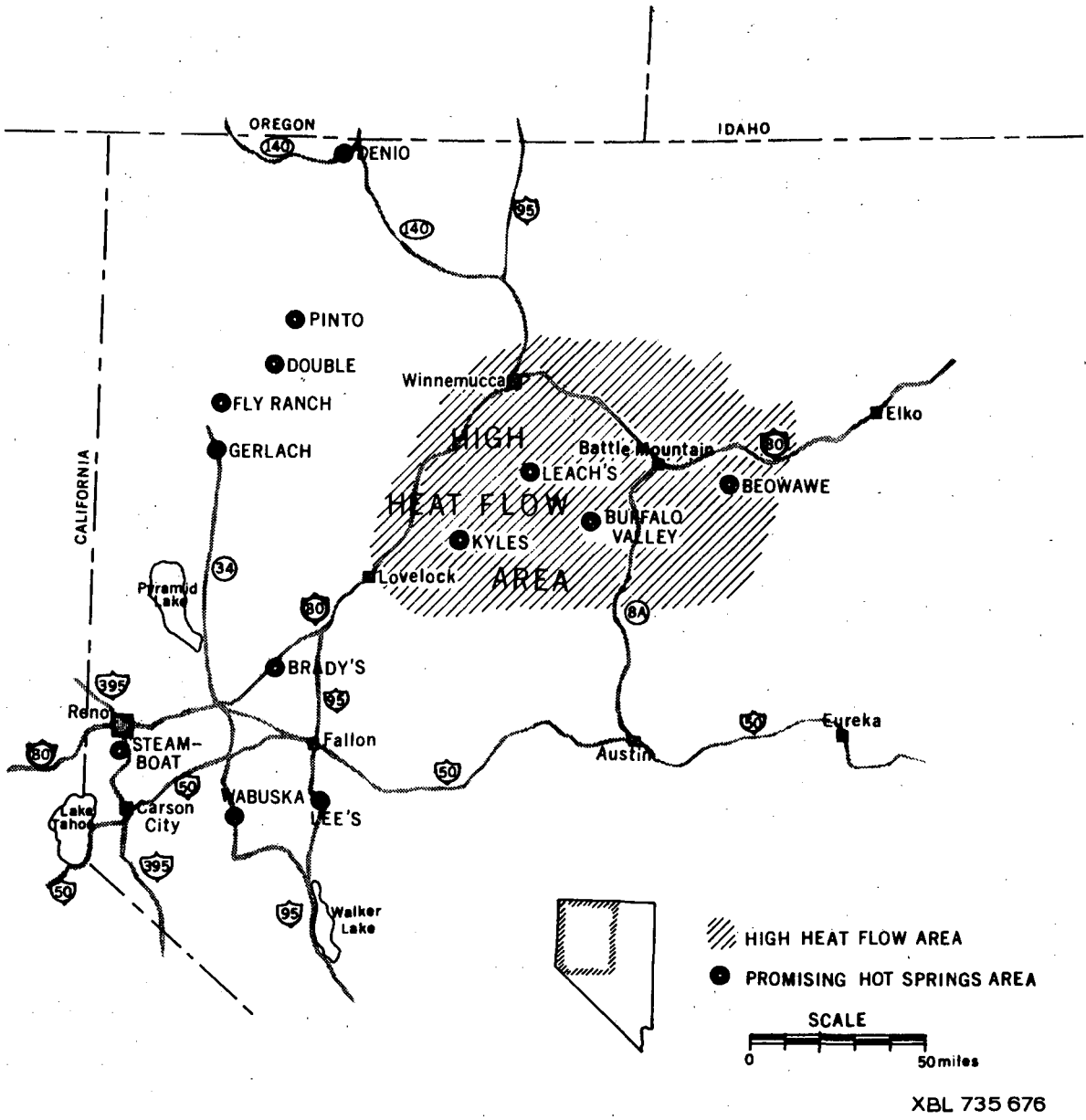

Fig. 4. Distribution of promising thermal spring areas and the high heat flow region in northwestern Nevada.

most likely liquid-dominated, and temperatures at depth are probably in the range 150° C to 260° C.

We intend to start site evaluation with geophysical measurements which may indicate, without actual drilling, the approximate location, shape, and depth of a potential geothermal reservoir. Among the geophysical methods, techniques to measure deep electrical resistivity hold great promise. Monitoring of micro-earthquakes may aid in the delineation of fault-zone channelways at depth. The target area outlined by the geophysical surveys will be drilled to determine its heat-flow pattern.

When a reservoir of apparently acceptable size has been located, two or three test wells will be drilled. The permeability and porosity of the reservoir rock will be measured to give information on the productive capability of the reservoir. Down-hole temperature, electric, and radiometric data will be combined with laboratory determinations of brine chemistry to better define the reservoir characteristics. When the extent, temperature, and brine chemistry of the reservoir have been established, the design of the pilot plant will begin.

The actual detailed design of the plant will be done by an engineering and construction firm, such as the Bechtel Corporation or Stone and Webster Corporation, in conjunction with the Lawrence Berkeley Laboratory, with responsibility for all major design decisions resting with LBL. The cost of the pilot plant and the production wells will be approximately six million dollars. Design and construction time will be about two years if normal contractual and construction procedures are followed. This time may be somewhat reduced if construction funds are made available early enough so that preliminary planning can commence during the period of site selection. There are certain areas of the plant—such as the switchyard—that will be unaffected by the type of plant cycle. A detailed design could be completed in these areas before the final site has been selected.

Concurrent with the design of the pilot plant, a production-size well will be drilled. Flow tests will be run in order to determine the capability of the reservoir to sustain a commercially acceptable flow. When acceptable flow characteristics have been demonstrated, the ordering of major plant components, site-preparation construction, and the installation of busyard type equipment, such as transformers and switch gear, will commence. Transmission-line construction to the site could also begin at this time.

Upon completion of construction, initial testing and start-up operations will commence. Plant operations will be performed by the electrical utility company serving the area. If one of the Nevada sites is chosen this would be the Sierra Pacific Power Company; Sierra Pacific has been very helpful in our early investigations and expressed a willingness to operate the pilot plant, build a transmission line to the site, and purchase the power.

An experimental program will be initiated when plant testing and start-up operations have been successfully completed. This program will involve reservoir monitoring by chemical, microseismic, temperature, and electrical measurements, in order to detect possible changes that may take place within the reservoir system. Corrosion rates of different materials will be studied under various brine conditions of temperature, pressure, and flow velocity. The nature and rate of precipitation build-up on heat transfer surfaces will be studied in order to develop scale-removal processes. Plant load tests will be run under various conditions of temperature and pressure in order to develop design data on this type of power cycle.

RESEARCH PROGRAM

A primary, basic, and essential part of the LBL-UCB project is a continuing program of research in areas where the development of data and methods will improve geothermal technology and thereby enhance abilities to make proper site selections and to solve the varied problems that will arise during the operation of geothermal power-producing systems. Specific research areas are as follows.

1. Geophysical Methodology and Analysis

A number of geophysical methods are being used in geothermal exploration, including resistivity, microseismic, and gravitational techniques. Their level of precision and power has recently become much higher, but improvements are also required in interpretation of the resulting geophysical data. Research is needed also to simplify the measurements and reduce the number of probing methods required for resource evaluation.

Some specific research needs are:

a) Improvement of computer programs to minimize calculating time in determinations of electrical resistivities at depth in 2- and 3-dimensional arrays.

b) Improvement of statistical methods to differentiate between relevant and extraneous data.

c) Improvements in analysis of effects of nonuniformities of underground parameters with particular reference to the presence of highly conductive solids and cool waters.

2. Research Related to Geothermal Power Extraction Processes

Although geothermal power production is technically feasible, many of its aspects are relatively crude and require considerable research in order to bring this technology to an economically and environmentally satisfactory state.

Outstanding needs are:

a) Chemical studies related to the problem of removal and disposal of noxious gases.

b) The chemistry of recovery of valuable minerals and gases.

c) Development of computer techniques based on thermo-economic principles to provide basis for process optimization.

d) Study of the chemistry of mineral solutions at different temperatures, aimed at improvement of mineral solubility control.

3. Chemical Kinetics of Geothermal Silica Precipitation and Dissolution

Silica scaling constitutes a threat to economical operation of geothermal plants, yet practically nothing is known about the rates of formation and dissolution of silica scales under practical operating conditions. Savings in capital and operating costs would be possible if silica scaling can be controlled in equipment exposed to geothermal fluids.

The following should be investigated:

a) The rate of precipitation and the extent of supersaturation that will occur under varying fluid conditions encountered in geothermal operations. Studies would include silica-sodium chloride-water phase diagram determinations, backed by X-ray and other methods of determining rate and form of mineral depositions.

b) The chemistry of silica-scale solubility should be studied, so that processes for scale removal can be developed at lowest costs.

c) Basic research is needed on crystal growth, involving studies of solubility, crystal structure, and statistics. These studies would increase our understanding of, and hence probability of success in, crystal-seeding methods of avoiding silica deposition on equipment surfaces.

4. Research on Corrosion Mechanisms

Although corrosion is one of the most serious problems related to geothermal power, little is known about the basic corrosion mechanisms of geothermal brines. Basic research studies will lead to a number of approaches to corrosion control, including selection of materials, removal of oxygen or other aggressive chemicals, provision of sacrificial materials, and protection by electrical currents. Some specific research areas are:

a) Identification of corrosion mechanisms by electrochemical measurements and theoretical analyses. Typical systems include interactions of brines with homogenous metals, dissimilar metals, and scale-covered metals. Fluid velocity, temperatures, diffusion rates, acidity, aggressive agent concentration, inhibitor concentrations, and electrical potential differences are among the parameters that must be studied.

b) Investigation of theoretical bases for improvement of corrosion resistances of construction materials. Typical considerations include claddings, heat and/or work treatments, and alloying materials.

c) Establishment of methodology for economic optimization of corrosion control in geothermal systems.

5. Geothermal Reservoir Fluid Circulation Studies

An understanding of geothermal reservoir systems is required if conservative use of the energy is to be made. The mechanisms of thermal energy transport from hot intrusions in the upper crust to commercially interesting concentrations of geothermal energy ("anomalies") as hot water, steam, or hot dry rock are particularly important. In many cases convective circulation of pressurized water is responsible for the formation of liquid-dominated reservoirs, whereas leakage of steam through fissures probably accounts for steam reservoirs, while conduction may explain the

occurrences of unusually hot rock near the surface.

It is proposed to investigate the effects of geological conditions on the formation of geothermal anomalies. The following specific studies are suggested:

a) Analytic and laboratory-scale experimental investigations of the optimal and limiting conditions for the formation of geothermal reservoirs of practical interest, including surrounding temperature gradients, porosities, and permeabilities.

b) Mathematical modeling of steam and liquid-water systems by means of computer models that can be modified to predict 2- and 3-dimensional heat- and fluid-flows in nonhomogenous porous materials.

6. Properties and Behavior of Rock-Fluid Systems at High Pressures and Temperatures

The interpretation of data from seismic and sonic underground probing involves the velocity of propagation of waves through the earth's crust. Temperature gradient interpretations rely on thermal conductivity. Compressibility data on hot rock at temperatures of 500° C or higher are needed to predict compaction and subsidence which might occur because of fluid withdrawal and to predict crack formation during cooler water injection.

The following studies are needed in order to improve the methods for finding and using geothermal reservoirs:

a) Thermal conductivity studies of rocks over the temperature range from 200° C to 400° C , pressure range from 0 to 15,000 psi, and fluid content of rock pores from 0 to 100%. Theoretical analyses of the influence of the individual parameters are required in order to aid in understanding and to allow interpolations as a means of reducing the large number of measurements that would otherwise be needed.

b) Compressibility measurements over the temperature, pressure, and fluid ranges cited above.

c) Dilatational and shear velocities over the same ranges.

7. Brine Management in Relation to Power-Generation Methods

Practical techniques for the long-term injection of used geothermal brine into underground strata will be required if large-scale power production is to be achieved. Similarly, techniques for circulating fluids through hot rock will be needed to exploit the very large amounts of thermal energy stored in rock. The following studies are required to lay the basis for development of these injection and circulation techniques:

a) Theoretical and experimental studies of water treatments that may be employed to prevent clogging of passages in typical rock formations that receive brines of various concentrations and differences of temperature relative to the rock.

b) Solubility-equilibrium studies of the brine-hot rock systems anticipated in recirculating heat-extraction systems. Particular attention must be given to avoiding the fouling of surface equipment and also the possibility of deleterious effects on rock permeability.

c) Studies aimed at developing methods of extracting valuable minerals from the geothermal brines.

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