Proc. 18th Inter. Society Conversion Engineering Conference, Orlando, Florida, August 21-26, Session 79, 6 p. 1983

DIXIE VALLEY, NEVADA: A PROMISING GEOTHERMAL AREA UNDER DEVELOPMENT BY INDUSTRY

Michael D. Campbell, P.G.
Director, Alternate Energy, Mineral, and Environmental Programs
Keplinger and Associates, Inc.
Houston, Texas

Selected subsurface reservoirs located in the Western United States may contain significant geothermal energy, and if development continues, this energy source may provide substantial electrical power or related energy by the year 2,000. Utility management must be convinced of the reliability and cost attractiveness of this energy source. A number of exploration programs are in progress to evaluate the potential of geothermal energy in the United States. For example, numerous exploration methods have been employed in Dixie Valley, Nevada, since 1967 with mixed results. However, with DOE support, additional data have recently become available. We have revised earlier structural models of the basin and have made recommendations for additional investigations that should assist in clarifying the geologic relationships within the reservoir. The principal geologic characteristics of the reservoir that may place limits on project economics appear to be the depth and trend area of producing zones, fluid quality and the amenability of the upper zones to accept large volumes of spent fluids. However, reservoir temperature, flow rates, recharge characteristics, and other factors appear to be acceptable either for electrical power production of more than 1,000 MWe, or for direct applications such as on-site agricultural processing.

INTRODUCTION

Conservative U.S. Department of Energy (DOE) estimates of the domestic geothermal energy available for conversion to electricity range from 1,200 megawatts (MW) to 20,000 MW by the year 2,000. Geothermal energy is presently used to produce electricity on a large-scale commercial basis in The Geysers area, located approximately 90 miles north of San Francisco, California. This geothermal energy is in the form of dry steam, which is produced via wells from a vapor-dominated reservoir for direct feed to drive turbines. Although this type of geothermal energy is uncommon within the United States, other geothermal areas located in many western states contain liquid-dominated (hot water) reservoirs. Such sources of geothermal energy are of significant economic potential and are being actively, although cautiously, pursued by industry.

Expansion of power production from liquid-dominated geothermal reservoirs will depend upon the nature and relationship of the two principal partners within the geothermal industry, [i.e., the producers and the consumers (utilities]. Because utilities are generally held responsible by their rate-payers to minimize both risk and costs, they are not disposed to take on any project involving either new technology or an unreliable energy resource. Producers, the geothermal exploration and development companies, are charged by their stockholders to risk capital on reasonable ventures for developing technology and potential energy sources that could provide revenues in the future. The impetus is compelling to explore and develop an energy resource having strong similarities to oil and gas, thereby using and expanding the technology of oil and gas companies.

In addition to The Geyser's and The Imperial Valley areas of California, exploration has focused on the Basin and Range Physiographic Province of the western United States, an area of some 262,600 square miles (mi^2) encompassing all of Nevada, parts of eastern California, southeastern Oregon, southern Idaho, western Utah, Arizona, and parts of New Mexico (9). The favorable geologic characteristics of the Basin and Range region that have attracted attention during initial geothermal exploration programs designed to locate potential liquid-dominated geothermal reservoirs are as follows: 1) high regional heat flow, 2) thin crust/shallow heat source, 3) extensional faulting, 4) seismicity, 5) thermal springs (fumaroles), 6) thick basin-fill deposits, and 7) young volcanism.

HISTORY OF PROJECT DEVELOPMENT

In 1967, a government-funded study was completed on Dixie Valley which indicated active faulting and other geologic characteristics conducive to a hydrothermal system (23). Numerous hot springs and fumaroles were reported in the area, and very hot water was reportedly responsible for closing of the Dixie Comstock Gold Mine (26). Over the ensuing years, as oil prices increased, the incentive to explore for geothermal energy also increased (15). It should also be noted, however, that as oil prices decrease the economic attractiveness of geothermal energy also decreases.

During the period 1967 to 1976, seismic, microseismic and other geologic studies were completed. Investigations conducted by the U.S. Geological Survey, using hot-spring geothermometry, suggested a subsurface reservoir temperature of less than 150°C, while other regions evaluated exhibited significantly higher geothermetric temperatures, and were deemed to be of higher priority than Dixie Valley (25).

In 1976, industry began exploration in Dixie Valley with a number of preliminary reconnaissance programs. In early 1977, Keplinger and Associates, Inc. conducted a review of the available data on behalf of Millican Oil Company for purposes of evaluating a proposal to acquire an acreage position in Dixie Valley (11). We concluded that on the basis of: 1) recent seismic activity, 2) the presence of hot springs (i.e., the geothermetric model incorporating mixing of meteoric and reservoir waters indicated higher subsurface reservoir temperatures than suggested by U.S. Geological Survey), 3) abnormally high heat flow, 4) presence of active extensional faulting, 5) presence of thick basin-fill deposits, 6) presence of favorable geologic conditions within the valley, and 7) a favorable position of available acreage, Millican Oil Company should: 1) acquire the acreage, 2) attempt to acquire selected acreage along the western side of the valley via a U.S. Government "Known Geothermal Resource Area" (KGRA) bid sale, and 3) actively explore the area, with a view toward forming a joint venture with one of the four major companies actively engaged in exploration in Dixie Valley (12).

In the latter part of 1977, we conducted a geological field reconnaissance program in the Stillwater Range area bordering Dixie Valley to the west (13). One of the objectives of the program was to briefly investigate the range geology and associated structures with a veiw toward defining a preliminary geologic model that could be applied to Dixie Valley where rock types and structural relationships are obscurred by the overlying alluvial and lacustrine sediments.

Millican-Southland Royalty Joint Venture

During late 1977, Millican Oil consumated a joint-venture agreement with Southland Royalty, which had recently acquired adjoining acreage in Dixie Valley. During 1978 and 1979, the joint venture contracted for a series of multi-level and single-level aeromagnetic surveys. Geologic supervision was provided by consultants representing Millican Oil (Keplinger and Associates, Inc.) and Southland Royalty [Energy and Natural Resource Consultants, Inc. (ENRC)]. A magnetotelluric survey covering western Dixie Valley was also conducted by the joint venture. The aeromagnetic survey identified a number of structural features but provided interpretations that conflicted with previous concepts of Basin and Range geology. We reviewed the magnetic interpretations and questioned Senturion Sciences' (20,21) interpretations of key geologic features in the valley such as a young thrust fault postulated in the central part of the valley (14).

During 1977 and 1978, we collected a time-series of ground-water samples from two hot springs and one cold spring. This hydrochemical survey consisted of sampling each of the springs twice a day over a seven-day period and then intermittently through 1978. Seventeen chemical and physical parameters were analyzed or recorded. Standard geothermetric calculations were made using the silica and calcium-sodium-potassium methods (6,7). An indicated minimum reservoir temperature of 175°C was derived using the latter method. However, the methods produced conflicting results and supported the view that the samples were composed of a mix of young recharge water and older thermal waters, i.e., in the area of the hot springs samples (12, 14).

Early Model Development

After a shallow drilling program was completed, a preliminary geologic model of the basin was generated that included the range-front fault system as a significant zone of ground-water recharge from the Stillwater Range to the basin.. Bounding faults of down-dropped blocks to the east of the range front fault zone serve as avenues for upwelling, high-temperature fluids. Some of these faults permit hot fluids to reach the surface, forming hot springs. Although speculative in nature, the model incorporated all available data believed to be reliable at the time. We concluded that two types of geothermal reservoirs could be present, an "upper" hot-water reservoir located in the lower intervals of upper Cenozoic alluvial fill and/or upper intervals of Tertiary volcanics, and a "lower" steam-dominated (?) reservoir at the base of a Jurassic intrusive complex or in Triassic quartz arenites and/or metamorphic rocks.

Federal Government Assistance

By mid-1978, the geologic complexity of the basin was apparent to personnel of the Millican Oil and Southland Royalty joint venture. Conflicting interpretations and inconclusive data regarding the structural model of the basin, and inconclusive data regarding spring hydrochemistry led the joint venture to conclude that a comprehensive, multidisciplinary investigation was required before targets of sufficient merit could be selected for deep drilling. During this period, DOE had announced that the government would support, in part, case studies on northern Basin and Range geothermal systems via a comprehensive geothermal reservoir assessment program through the stage of deep drilling. In response to RFP No. ET-78-R-08-0003, a proposal was presented to DOE as a cooperative venture between Millican Oil, Southland Royalty and the Minerals Research Institute of the Mackay School of Mines, University of Nevada, Reno (MMRI-UNR). A comprehensive, multiphase industry-university effort was proposed with three principal objectives. The first objective was to conduct a major review of all available data and interpretations, and the second was to formulate and conduct an intermediate to deep drilling program.

A contract was awarded to the joint venture, and the investigations and field studies were begun in early 1979 (Contract No. DE-AC0879-ET27006). Millican Oil Company was subsequently purchased by a non-geothermal company and the lands held were transferred to a third party. A series of final reports were issued by the Mackay Minerals Research Institute in 1980 (16). The final report was subsequently compiled and submitted to DOE (4).

GEOLOGICAL INVESTIGATIONS

Based on previous investigations and on the new data provided, the results of an evaluation to assess the state of knowledge that existed on the Dixie Valley geothermal system was presented earlier (3). In summary, Dixie Valley is dominated by extensional structures that may have begun to move as early as 17 million years ago (16), and that are still active today. Figures 1 and 2 illustrate a complex pattern of normal faults that are classically attributable to regional extension (10). We show the probable general configuration of these faults at depth based on surface outcrop, seismic reflection and refraction, magnetic, gravity, magnetotelluric, well, and geomorphic data as well as regional seismicity, microseismicity, and resistivity, e.g., see (16) for summaries.

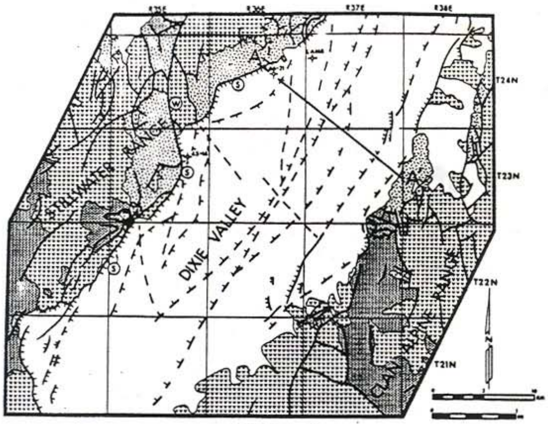
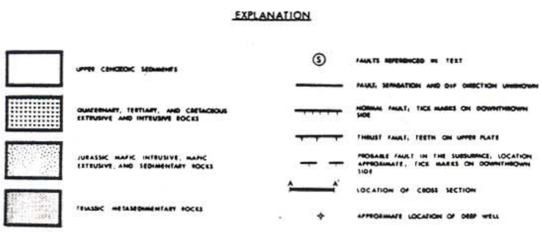


FIGURE 1
GENERALIZED GEOLOGIC MAP OF DIXIE VALLEY, NEVADA



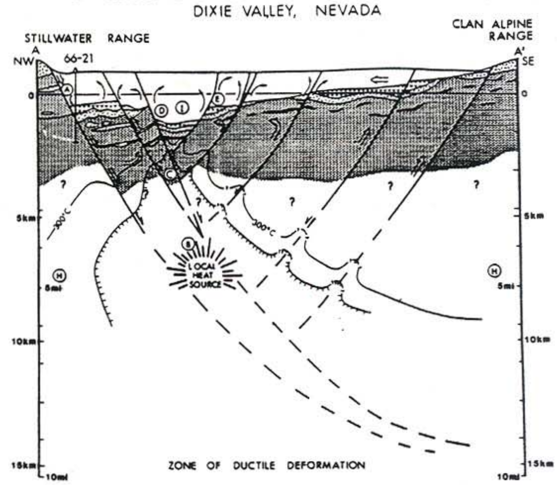
The cross section illustrated in Figure 2 varies significantly from those of previous authors, (16), because we feel that graben-floor and adjacent range assymetry, coupled with all other data, require that most of the brittle deformation be accomplished by movement on listric normal faults on the west side of the valley (see S in Figure 1). Earlier structural events (i.e., thrusting and possible strike slip) have affected the rocks of this region; however, the configuration of the present system is controlled primarily by extensional tectonics (e.g., see Figure 2). We see no evidence for Miocene or younger contractional features as suggested by others (20, 21).

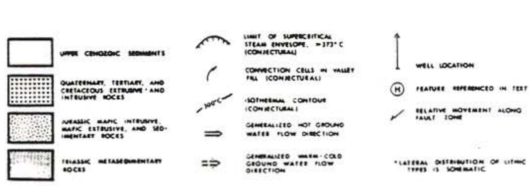
Geothermal Reservoir Model

Because of the general nature of the stratigraphy and structure of the Dixie Valley area is now known with some degree of confidence, we are able to construct a reasonably well constrained model of the geothermal reservoir. The geologic cross section shown in Figure 2 serves to illustrate our general view of the Dixie Valley geothermal system.

The reservoir is recharged by ground water descending along the major range-front fault zone and associated fractures bounding Dixie Valley on the west (see A in Figure 2. Other important areas of recharge include ground-water movement from the northeast an southwest through the Cenozoic sediments of the valley fill, and from the east through both the valley fill and fractures in bedrock. The ground water is heated at depth, possibly by "local heat sources (see B in Figure 2), and rises along permeable fault zones and fractures (see C in Figure 2) until it either meets a barrier to vertical migration (see D in Figure 2) or reaches the surface via hot springs. If the fluids

FIGURE 2
GENERALIZED CROSS SECTION*
AND CONCEPTUAL GEOTHERMAL CONVECTION SYSTEMS
DIXIE VALLEY, NEVADA





meet a barrier to vertical migration, they then move laterally through highly fractured rock, such as the Tertiary extrusives, or are trapped by permeability barriers such as the lateral pinchout of fractured rock. The normal faults near D are sealed possibly as a result of the development of cataclastic gouge in the felsic volcanics, whereas these same faults may have produced a permeable gouge in the Triassic-age siliciclastics (slates). A probable barrier to vertical migration in Dixie Valley consists of altered "red clay" at the base of the valley fill and at the top of the younger volcanics (see D in Figure 2). This seal may consist of altered lacustrine clay and/or of volcanics that have been altered by the hot reservoir fluids.

Interpretation of Drilling Data

With this reservoir model, we can now explain the general distribution of hot fluids and lithic types for three deep wells in Dixie Valley (i.e., see Wells 45-14, 66-21, and "Lamb" in Figure 1 (16). Well 45-14 encountered: 1) approximately 1,000 ft. of upper Cenozoic sediments, 2) no altered red clay, 3) about 1,000 ft. of Tertiary (?) volcanics, 4) no major body of Jurassic intrusive rocks, and 5) roughly 6,000 ft. of Triassic metasedimentary rocks. The reported bottomhole temperature (i.e., 196°C), pressure, and flow rate were apparently below "commercial" minimums. This well intersected the major range-front fault zone on the west side of Dixie Valley at a depth of approximately 4,800 ft.

Well 66-21 (see Figure 1) encountered: 1) about 4,000 ft. of upper Cenozoic sediments, 2) an altered red clay zone at the base of these sediments and at the top of a 1,000 ft. interval of Tertiary volcanics, 3) about 1,000 ft. of Jurassic intrusive rocks, and 4) approximately 3,000 ft. of Triassic metasedimentary rocks. Fluid temperatures and pressures were relatively high in the volcanics although not unusually high at the base of the red clay (i.e., 118°C; 35.5 psig; flow test: 70,000 pounds/hr). The range-front fault was intersected by this well at a depth of about 6,500 ft. A bottom-hole temperature of 219°C was reported, but mass-flow tests apparently were not conducted.

Sunedco's "Lamb" well reportedly encountered: 1) approximately 5,000 ft. of upper Cenozoic sediments, and 2) an altered red clay near the bottom. Little direct information is available for the lower intervals of this well because such data are apparently considered proprietary in nature. However, fluid reservoir temperatures of 235°C to 275°C, very high pressures and an attendant low water-steam ratio have been reported by a local operator.

Based on the reservoir model illustrated in Figure 2, we suggest that the lack of high-temperature/pressure fluids in wells 45-14 and 66-21, and the lack of altered red clay in well 45-14 is directly related to the possibility that these wells were drilled through a major recharge zone for the system (i.e., the range-front fault zone). The high-fluid temperatures/pressures encountered in the "Lamb" well are related to its structural position on the fractured, down-dropped side of two faults east of the major range-front fault zone. Furthermore, the upwelling of hot fluids along the second or third fault to the east of the range-front fault has caused the formation of an altered red clay seal, thus providing favorable reservoir conditions. In the model proposed, we do not imply that all fluid movement along the range-front fault zone is downward because lateral variations in fluid movement certainly exist. If the essential elements of this model are correct, then the eastern side of the central graben in Dixie Valley may also be prospective (see E in Figure 2).

Location of Heat Source

This model includes only one principal heat source. The results of previous magnetotelluric investigations (22) indicate heat sources at depth below the western and eastern margins of Dixie Valley (see H in Figure 2). If the magnetotelluric method permits definition of deep heat sources, such sources must first heat the ground water located within fault blocks of the Stillwater and Clan Alpine Ranges (see H in Figure 2). Then this hot water must move laterally into the basin. This situation, however, appears unlikely because the up-thrown block of most normal faults tends to be less fractured than the down-thrown block and permeability is usually greatest parallel to fault zones rather than perpendicular to them. An alternate explanation must be sought which would account for the indicated anomalies in the electromagnetic field in these locations.

Future Investigations

A number of questions generated by recent investigations (16) remain to be answered in detail. For example, the White Rock Canyon fault, postulated to be a crustal-scale, strike-slip, post-Jurassic feature (see W , Figure 1), may indeed be a controlling factor in the development of a refined geothermal reservoir model (16). If the fault is a major basement-involved structure it may have been reactivated during the Miocene, or later, as an extensional feature. Reactivation of older strike-slip faults as grabens by later extension is known in other parts of the world, e.g., Cevennes fault of southern France, (12). Hot springs do not occur south of this fault and hydrochemical data obtained by previous investigations from both sides of the fault are significantly different (16). However, aeromagnetic and well data are either problematical or too sparce to convincingly demonstrate the existence of this proposed type of fault. In addition, we have been unable to find evidence for the smaller-scale structures that usually characterize this deformational style (e.g., en echelon features, synthetic and antithetic shear fractures that are consistent with the proposed left slip, horizontal slickensides, etc.). Additional work is clearly needed on both the fault systems and related hydrochemical relationships.

Future investigations in Dixie Valley should also focus on obtaining reliable fluid samples for isotopic analysis from either existing wells or from wells to be drilled. In addition, detailed seismic surveys are required to establish the structural relationships within Dixie Valley. The additional work recommended for Dixie Valley would be a timely and cost effective venture because drilling of deep wells may appear to be the next stage of development on some properties. However, the cost of one improperly located deep well would pay for most, if not all,of the above-mentioned investigations. Although the urge is compelling to drill before a suitable geological and hydrogeologic foundation has been established, the gain in terms of overall cost effectiveness would be substantial if these investigations were conducted to more clearly define the Dixie Valley geothermal system before additional deep drilling is undertaken. The need for establishing an acceptable geologic foundation for Dixie Valley becomes apparent when a preliminary economic assessment is conducted.

IMPACT ON PROJECT ECONOMICS

Based on available information, the characteristics of the Dixie Valley geothermal reservoir have not yet been sufficiently defined to permit a sound economic assessment of its commercial potential for either electrical generation or direct industrial application. The factors that will be important to future economic assessments of the prospect area are as follows: 1) wellhead temperature and pressure, 2) well yield, 3) fluid enthalpy, 4) depth to producing zones, 5) area of producing zones, 6) fluid quality, 7) amenability of reservoir to accept waste fluids. Any of these factors could limit project development. In general, a relatively shallow reservoir of moderate temperature (200°C) containing fluids of less than 5,000 ppm TDS is more attractive in terms of operational suitability than a deep, high temperature (300°C) reservoir of high salinity. However, the cost of producing electric power declines with increasing fluid temperature. High temperature wells produce fluid (a water-steam mixture) at greater flow rates than low-temperature wells; consequently, less fluid is required to generate the same amount of power at the plant, and fewer wells are required to supply the fluid. Under staurated conditions, four of the factors (i.e., wellhead temperature and pressure, and fluid enthalpy and water-steam ratio) are interdependent (1). The fluid yield (or mass flow) will differ from well to well and from field to field, and must be determined by well-test measurements. Such measurements will vary with wellhead pressure and will be dependent upon the temperature at depth and upon the resistance to flow encountered within the aquifer and up the well.

Well costs are depth dependent and principal contributors to the producer's cost of production. The effect of well cost is much greater on a project utilizing low and intermediate temperature fluid than on high temperature resources. In general, well cost is one of the most important factors in determining the economic attractiveness of an intermediate temperature reserovir. Well spacing also affects the producer's cost and depends upon the area within which production of acceptable characteristics can be generated. A well spacing of 10 to 20 acres is typical in presently operating systems (8).

The effects of severely corroding or incrusting fluids may cause frequent well replacement, either due to damaged well structures, formation plugging or pipeline scaling. The useful life of a well is usually considered to be approximately 10 years. Because of the effects of well and reservoir "aging", declines in productivity can be expected and allowances must be made for such declines, if related to the well. In some areas, the initial flow rate may decline by as much as 20 percent over the first year of operation and by five percent over the ensuing years until a production rate of approximately 50 percent of the initial rate is reached. Subsequent production would tend to stabilize. In other areas, the initial flow rate remains stable for a number of years and then declines at a rate of about three percent per year, depending upon the nature of the reservoir. Well replacement would usually be required within ten years in either case because of scaling in the vicinity of the well and subsequent decrease in flow.

ASSESSMENT OF CONDITIONS

Production testing is underway in Dixie Valley. Bottom-hole temperatures of 235°C to 275°C and a total mass flow of 500,000 pounds/hr. have been reported by local operators. High pressure and a low water-steam ratio have also been reported; estimated enthalpy and mass flow appear to be favorable. With regard to fluid quality, data derived from reliable sampling of the reservoir water are not yet available. However, in assessing the available information and the hydrogeological setting, fluid quality and recharge also appear to be favorable.

The four geologic factors that may restrict large-scale development are: 1) depth to producing zones, 2) area of production, 3) produced fluid quality, and 4) effectiveness of disposing large volumes of waste fluid, presumably injected into intervals of the valley fill above the producing zones. Based on the reservoir model illustrated in Figure 2, two of the four potentially limiting geologic factors (i.e., depth and area of production) appear to be favorable in certain areas of Dixie Valley. Well depths of up to 10,000 ft., within an area of approximately 6,000 to 10,000 acres (10 to 15 mi^2), appear to be highly prospective. The area to the northeast also appears to offer significant potential. A postulated depth of production in excess of 10,000 ft. may be a project limiting factor, although testing is continuing in Dixie Valley. Such testing will provide significant data on which detailed economic evaluations will be made.

The third potentially limiting geologic factor involves the quality of the fluids produced during project development. Very little direct information is presently available, but with additional sampling, combined with other hydrogeological investigations, the chemical nature of these fluids will be defined, both in terms of the scaling potential of the produced fluids and the amenability of the waste fluids to subsurface re-injection.

The fourth potentially limiting geologic factor involves waste-fluid disposal. Large volumes of "spent" waste fluids are produced as a result of utilizing liquid-dominated geothermal energy sources. These fluids must either be treated to produce relatively fresh water for consumption and irrigation, (5), or be disposed of via surface water courses or via injection wells. Some elements contained in many geothermal waste streams are toxic to some plants, even in very low concentrations, (i.e., ppb and ppm range). For example, a boron content of approximately 1.0 ppm may pose a problem if the waste water were used for irrigation.

Disposal via surface water is usually not possible for environmental reasons. Injection of waste fluids into shallow subsurface reservoirs is usually considered to be the most acceptable method of disposing of such fluids for the following purposes: 1) recharge to reservoir to conserve "waste" heat and fluids, and 2)recharge to reservoirs to minimize surface subsidence. Subsurface waste water injection systems in geothermal applications require special attention to: 1) well location, especially in terms of locating injection wells in areas that will not significantly affect fluid production temperatures, 2) injection zone selection, in terms of assuring that zones of optimum thickness and permeability are selected, 3) well design, 4) waste fluid compatability with the mineral assemblages within the rocks and contained fluids of the injection zone, in terms of the chemical and physical factors that may promote injection zone plugging, and 5) operation and maintenance of the injection system over the life of the project. An extensive review was published on the technology associated with waste fluid injection systems (24). Before such systems are designed, the nature of the hydrogeological systems present in Dixie Valley should be determined to ensure efficient disposal of fluids without negative consequences, either to the shallow water resources or to the producing geothermal system. The need to conduct detailed hydrogeological investigations in Dixie Valley is pressing and, when accomplished, will provide information on the geothermal system as well as on the amenability of the produced fluids to subsurface disposal.

DEVELOPMENT ALTERNATIVE

In the event such factors as well depth, flow rate, temperature, fluid quality, or waste water disposal limit the economic attractiveness of electrical production in Dixie Valley, the reservoir appears to be suited to direct thermal use in such applications as agricultural processing. Large areas could be developed in certain highly permeable, shallow intervals of the reservoir (see I, in Figure 2), assuming the indicated favorable economic conditions can be confirmed. A trend toward relocating related industries in remote areas of the western United States is apparent (18, 17).

REFERENCES CITED

(1) Armstead, H.C.H., 1978, Geothermal Energy, John Wiley & Sons, New York, 357 p.

(2) Bodeur, Y., 1976, Evaluation de l'amplitude du decroche-ment Cerenol par decalage des facies refaux portlandiens des environs de Ganjes (herault); C.R. Acad. Sc., Paris, Vol. 282, pp. 961-963.

(3) Campbell, M.D., and C.C. Wielchowsky, 1982, A Review of the Dixie Valley, Nevada, Liquid-Dominated Geothermal Re-source and Relationship of Selected Geologic Characteris-tics to Potential Geothermal Production, in Proc. Am. Inst. Chemical Engineers Annual Converence, Anaheim, Paper 18C, 43 p. URL (more).

(4) Denton, J.M., E.J. Bell, and R.L. Jodry, 1980, Geothermal Reservoir Assessment Case Study -Northern Dixie Valley, Nevada; Final Report by Southland Royalty Company to U.S. Dept. of Energy, November, Report No. DOE/ET/ 27006-1, 495 p.

(5) Fernelius, W.A., 1975, Production of Fresh Water By Desalting Geothermal Brines - Pilot Desalting Program at the East Mesa Geothermal Field, Imperial Valley, California; in Proc. 2nd United Nations Sym. On Development and Use of Geothermal Resources, San Francisco, May 20-29, pp. 2201-2208.

(6) Fournier, R.O., 1973, Silica in Thermal Waters: Laboratory and Field Investigations, in International Sym. on Hydrogeochemistry and Biogeochemistry, Japan, Proc. Vol. 1, Hydrogeochemistry: Washington, D.C., J.W. Clark (ed.) pp. 122-139.

(7) Fournier, R.O., and A.H. Truesdell, 1973, An Empirical Na-K-Ca Geothermometer for Natural Waters; Geochim. et Cosmochim, Acta, Vol. 37, pp. 1255-1275.

(8) Goldsmith, K., 1976, Economic Aspects of Geothermal Development, in Proc. 2nd United Nations Sym. on Development and Use of Geothermal Resources, San Francisco, Ca., May 20-29, pp. 2301-2303.

(9) Grose, L.T. and G.V. Keller, 1979, Geothermal Energy in the Basin and Range Province; Proc. RMAG-UGA Basin and Range Symposium (G.W. Newmand and W.D. Goode (eds.), pp. 361-369.

(10) Harding, T.P., and J.D. Lowell, 1979, Structural Styles, Their Plate-Tectonic Habitat, Hydrocarbon Traps in Petroleum Provinces; Bull. Am. Assoc. Petroleum Geologists, Vol. 63, pp. 1016-1058.

(11) Keplinger and Associates, Inc., 1977a, A Preliminary Fvaluation of the Hughes Geothermal Properties in Churchill County, Nevada; for Millican Oil Company, Houston, April, 61 p.

(12) Keplinger and Associates, Inc. 1977b, Phase II Preliminary Evaluation of Dixie Valley, Nevada: Geothermal Potential and Associated Economics; for Millican Oil Company, Houston, september, 45 p.

(13) Keplinger and Associates, Inc., 1977c, Phase 1 Geological and Mineral Reconnaissance of the Eastern Front of the Stillwater Range from I.X.L. to Cottonwood Canyons: Dixie Valley Area, Churchill County, Nevada; for Millican Oil Company, Houston, October, 80 p.

(14) Keplinger and Associates, Inc., 1978, Interim Evaluation of Exploration and Development Status, Exploration and Development Status, Geothermal Potential and Associated Economics of Dixie Valley, Nevada; for Millican Oil Company, Houston, September, 110 p.

(15) Keplinger, C.H., 1976, OPEC Oil Prices Enhances U.S. Geothermal Development; World Oil, August, 4 p.

(16) Mackay Minerals Reserach Institute - University of Nevada, Reno (MMRI-UNR), 1980, Goethermal Reservoir Assessment Case Study, Northern Basin and Range Province, Northern Dixie Valley, Nevada; for Southland Royalty Company, Fort Worth, Texas under U.S. Department of Energy Contract No. DE-AC08-79ET27006, January 31, 250 p.

(17) Packer, M.B., B.B. Mikic, H.C. Meal and H.G. Guillamon-Duch, 1980, A. Method for Evaluating the Potential of Geothermal Energy in Industrial Process Heat Applications; Mass. Institute of Technology, for U.S. Department of Energy, May, Report No. LMP/MRP - 80-04, 415 p.

(18) Reistad, G.M., 1978, Direct Application of Geothermal Energy; Oregon State University for U.S. Department of Energy, Report No. DOE/ET/120501-T1, 72 p.

(19) Sacrato, D.M. 1976, State Policies for Geothermal Development; National Converence State Legislators, Rpt. NSF/RA-760230, Denver, 94 p.

(20) Senturion Sciences, Inc., 1977, High-Precision Multi-level Aeromagnetic Survey over Dixie Valley, Part I; for Southland Royalty Company, October, 15 p.

(21) Senturion Sciences, Inc., 1978a, High-Precision Multi-level Aeromagnetic Survey over Dixie Valley, Part II; for Southland Royalty Company, 13 p.

(22) Senturion Sciences, Inc., 1978b, South Dixie Valley, Nevada, Scalar Magnetotelluric Survey Report; for Southland Royalty Company, 45 p.

(23) Thompson, G.A., Meister, L.J., Herring, A.T., Smith, T.E., Burke, D.B., Kovach, R.L., Burford, R.O., Salehi, A., and Wood, M.D., 1967, Geophysical Study of the Basin-Range Structure, Dixie Valley, Region, Nevada, U.S. Air Force Cambridge Research Labs., Spec. Report 66-848, 350 p.

(24) Warner, D.L. and M.D. Campbell, 1977, An Introduction to the Technology of Subsurface Waste Water Injection; U.S. Environmental Protection Agency Report #EPA-600/ 2-77-240, NTIS PB-279-207, Chapters 6, 7, 8 and 10, pp. 188-328.

(25) White, D.F. and D.L. Williams (eds.), 1975, Assessment of Geothermal Resources of the United States - 1975; U.S. Geol. Sur. Circ. 726, 155 p.

(26) Willden, R., and R.C. Speed, 1974, Geology and Mineral Deposits of Churchill County, Nevada; Nevada Bureau of mines and Geol. Bull. 83, 125 p.