Mining the Earth's Heat in the Basin and Range

by John H. Sass, U.S. Geological Survey

Abstract

The Geothermal Program of the U.S. Geological Survey (USGS) is revisiting the Basin and Range Province after a hiatus of over a decade. The Basin and Range is a region of Neogene extension and generally high, but regionally and locally variable heat flow. The northern Basin and Range (Great Basin) has higher mean elevation and more intense Quaternary extension than does the southern Basin and Range, and a somewhat higher average heat flow. Present geothermal electric power generation (500+ MW) is entirely from hydrothermal systems of the Great Basin. The USGS is seeking industrial partners to investigate the potential for new hydrothermal reservoirs and to develop the technology to enhance the productivity of existing reservoirs.

Introduction

The Geothermal Program of the U.S. Geological Survey (USGS), in collaboration with DOE's National Laboratories, carried out extensive research into the geothermal parameters of the Basin and Range province during the mid-to-late 1970s and early 1980s. These efforts, which included regional heat-flow and hydrologic studies (see e.g. Lachenbruch and Sass, 1978; Mariner and others, 1983), detailed investigations of Known Geothermal Resource Areas (Olmstead and others, 1986; Sass and others, 1977), and the development and deployment of new and enhanced geophysical and geochemical exploration technologies (Fournier, 1977; Paillet and Keys, 1984; Sass and others, 1981) were complementary to both regional and site-specific exploration efforts by the geothermal energy industry. Because of the intense competition among geothermal operators and the uncertain status of land holdings, coupled with the lack of appropriate mechanisms for industry-government cooperative research, USGS and industry activities were carried out independently of each other. During the 1980s, support for geothermal research declined substantially, and USGS efforts in the Basin and Range largely gave way to studies of the southern Cascades, The Geysers and the Salton Trough. Studies in The Geysers are ongoing, but projects in the Cascades (Guffanti and Muffler, 1995; Muffler and Guffanti, 1995) and Salton Trough (Lachenbruch and others, 1985; Elders and Sass, 1988) are nearly complete. During the present fiscal year (1995), the USGS Geothermal Program is beginning a renewed study of the Great Basin after a hiatus of some 10 to 15 years, during which time, the structural and tectonic interpretation of the region has evolved dramatically (see, e.g., Axen and others, 1993; Catchings, 1992; Humphreys and Dueker, 1994) and considerable geothermal development has occurred (Benoit, 1994). The study is broadly based, and includes plans for geologic, heat flow, hydrologic and various surface-based geophysical studies.

Heat Flow

Constrained by several hundred heat-flow determinations, the average heat flow for the Basin and Range province is high, 92 ± 4 mW m^{-2} (uncertainty in the mean is expressed as 95 percent confidence limits). The distribution of heat flow is decidedly non-uniform and complex, however, (Figure 1; Sass and others, 1994) with large areas of relatively low (≤60 mW m^{-2}) and high (>100 mW m^{-2}) heat flow.

The northern Basin and Range is higher in elevation and more tectonically active than the southern Basin and Range and has somewhat higher heat flow. If only crystalline intrusive rocks for which radioactive heat production has been determined are considered (Sass and others, 1994), the differences are not significant (92 ± 9 and 84 ± 3

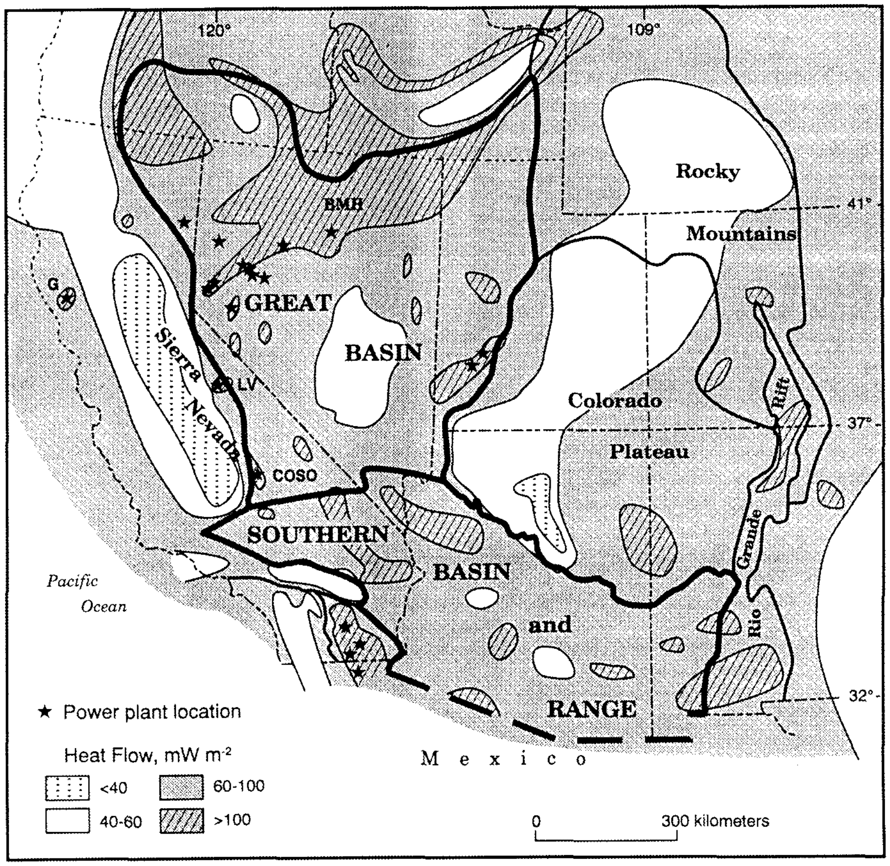

Figure 1. Heat flow in the Basin and Range Province and surrounding terrains, together with locations of presently operating power plants.
BMH = Battle Mountain High
LV = Long Valley
G = The Geysers.

mW m^{-2}). If all 440 heat flows from the Basin and Range are included in the data base, the difference becomes larger; 100 ± 7 mW m^{-2} for the northern Basin and Range versus 83 ± 4 for the southern Basin and Range. Geothermal development to date has been limited to the Northern Basin and Range (Great Basin, Figure 1). All of the geothermal power plants are within or near areas of high (>100 mW m^{-2}) heat flow. The corresponding areas in the Southern Basin and Range should present attractive exploration targets, provided zones of high permeability are present or can be created.

Some Great Basin geothermal energy projects (e.g., Coso and Long Valley) are clearly associated with Holocene extension and intrusive activity. Most, however, lack evidence of young intrusion but are connected with hydrothermal systems resulting from deep circulation of meteoric water in the high-heat flow regimes characteristic of the Battle Mountain High and other zones of anomalously high conductive heat flow. With few exceptions, moreover, the power plants are located near hot springs or other geothermal manifestations.

Implications of Heat-Flow Data

Assuming a maximum economic drilling depth of 4 km (about 13,000 ft) for the foreseeable future, it is seen (Figure 2) that temperatures appropriate to electric power generation (150°C) can be approached at drillable depths even in a "normal" conductive Basin and Range thermal environment. The temperature ranges shown in Figure 2 are extrapolations based on a constant thermal conductivity of 2.5 W m^{-1} K^{-1}, characteristic of crystalline rocks. If the

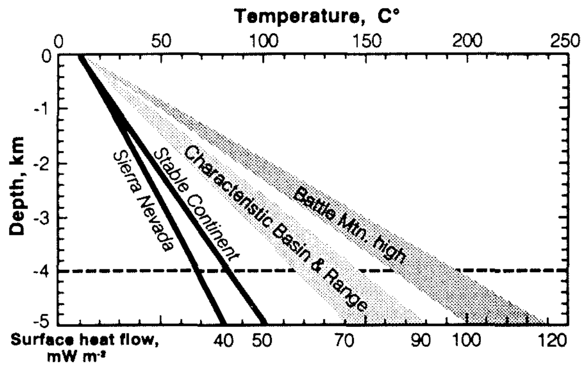

Figure 2. Generalized conductive temperature profiles for the Basin and Range Province *(modified from Lachenbruch and Sass, 1977).* Profiles from the Stable Continent and the Sierra Nevada are shown for reference.

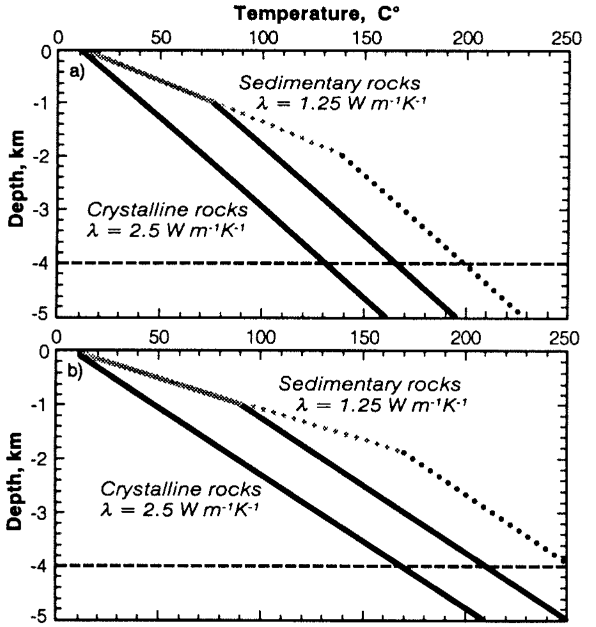

Figure 3. Conductive temperature profiles for the Basin and Range Province illustrating the thermal blanketing effort of basin sediments, (a) Typical Basin and Range (heat flow of 80 mW m^{-2}); (b) Battle Mountain High (heat flow of 100 mW m^{-2}).

basement rocks are blanketed by low-conductivity sediments (Figure 3), temperatures of economic interest are reached at even shallower depths. For example, in a high-heat flow region blanketed by 2 km of low conductivity sediments (Figure 3b) temperatures of nearly 200°C could be reached within 2.5 km (8,200 ft) without the aid of deep circulation and hydrothermal convection. It should be noted, however, that in most basins that have been intensively studied, the thermal regime is characterized by some degree of hydrothermal convection.

Limitations on Geothermal Development

With much of the Basin and Range Province having temperatures of 150°C or greater within easy reach of the drill, why don't we see 10 or even 100 times the electrical production that is presently occurring (500+ MW)? The one-word answer is permeability, although other factors like the market and available water also play significant roles. Virtually all commercial geothermal production is from naturally occurring hydrothermal systems. Spent thermal fluids and condensates are routinely injected back into or near the reservoirs, but with present technology, only a minuscule fraction of the heat in the rock is actually exploited during the life of a given system. Many wells are drilled into hot but impermeable rocks within or surrounding known productive reservoirs. With present technology, this drilling investment is lost and adds significantly to the operator's production costs.

Thus, despite its demonstrated positive environmental attributes (Duffield and others, 1994), geothermal energy development in the Basin and Range Province stands at a technological crossroad. It occupies an "Energy No Fan's Land" (Tenenbaum, 1995). The industry has shown considerable ingenuity in adapting to current market conditions, both in improving conversion technology and in custom-designing its power plants to make maximum use of the specific natural reservoirs above which they are situated. Given the realities of today's energy market, it would seem that a significant increase in the position occupied by geothermal will require both the discovery of additional hydrothermal systems and advances in reservoir technology to decrease costs and increase production significantly from existing or marginally productive prospective reservoirs.

Reservoir Enhancement

The potential for reservoir enhancement can be visualized in a qualitative manner by considering a spectrum of reservoir rocks (Figure 4) ranging from those that are currently being produced commercially ("Productive Hydrothermal") through hot, but lower permeability rocks, to hot, impermeable rocks Hot Dry Rock (HDR). HDR technology has been the subject of much research over the last 20 years, but it still is in a developmental phase in that no commercially viable project has been built to date.

If reservoir enhancement strategies analogous to those pioneered by the petroleum industry could be developed (for example, targeted injection and hydrofracture) the productivity of existing fields might be increased significantly, and presently uneconomic prospects could be brought on line. If this strategy were to be pursued aggressively throughout the Basin and Range, as well as other regions of high heat flow, we might ultimately see geothermal accounting for 10 to 15 percent of U.S. energy needs, a position that would bring it out of the "No Fan's Land." Based on short-term economic projections, the major U.S.

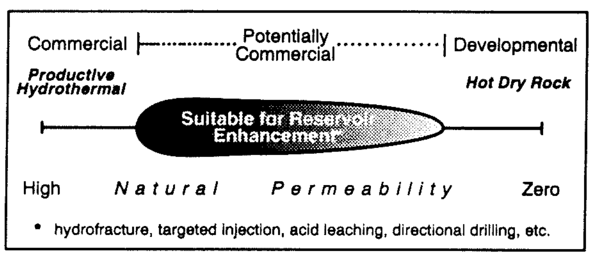

Figure 4. Diagram illustrating the permeability fields for commercial, potentially commercial, and developmental geothermal reservoir technology.

energy companies have either disposed of their geothermal operations completely or moved them overseas, resulting in a very limited pool of available research and development funds within the private sector. It thus seems unlikely that major technical breakthroughs in geothermal reservoir enhancement will occur without some incentives to the industry.

Industry-USGS Partnerships

Recent federal legislation has provided both a mandate and a mechanism for including industry in these investigations without some of the drawbacks traditionally associated with cooperative studies. In particular, the USGS has been instructed by PL 102-486 (the Energy Policy Act of 1992) to enter into partnership with industry and other governmental agencies to assess the potential of heat mining (specifically HDR) on federal lands. In addition, the Technology Transfer Act (PL 99-502) provides for the establishment of "Cooperative Research and Development Agreements" (CRADAs) between federal laboratories (of which the USGS is one) and industrial or other non-governmental parties. The chief advantages of a CRADA over previous cooperative agreements lie in the specific safeguards to proprietary data and intellectual property that the non-government partner brings into the agreement. In particular such data and property are exempt from Freedom of Information Act requests by actual or potential competitors. There is also considerable flexibility and negotiating room regarding patents, copyrights, licensing and disclosure of information developed jointly under the agreement.

The USGS is actively seeking partnerships with the geothermal industry to help assess and delineate the potential for additional hydrothermal systems within the Basin and Range Province. Those interested in teaming up with experienced Basin-and-Range geologists, geophysicists, hydrologists and heat-flow specialists should contact the Geothermal Program Manager: Manuel Nathenson, U.S. Geological Survey, Mail Stop 910, 345 Middlefield Road, Menlo Park, CA 94025; phone: (415) 329-5228; fax: (415) 329-5203; Internet: mnathnsn@mojave.wr.usgs.gov.

In addition, the USGS is involved in site-specific reservoir assessments, and thermal- and stress-related measurements aimed at assisting in the design of reservoir-enhancement strategies. We can deploy high-temperature logging tools (both slickline and surface-reading) to depths of up to 20,000 ft. Also, through agreements with associates in the national laboratories and academe, we are prepared to perform hydrofractures and associated tests related to the enhancement of reservoir capacities.

For further information, contact: John Sass, Heat Mining Studies Project, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001; phone: (520) 556-7226; fax: (520) 556-7169; Internet: jsass@iflag2.wr.usgs.gov.

Acknowledgements

Susan Priest prepared the illustrations and the camera-ready copy. I thank Wendell Duffield, Paul Morgan, Patrick Muffler, Sue Priest, Metro Sass, Michael Sorey and Colin Williams for their comments on the manuscript.

References

Axen, G.J., Taylor, W.J. and Bartley, J.M, 1993. Space-time patterns and tectonic controls of Tertiary extension in the Great Basin of the western United States, *Geological Society of America Bulletin*, v. 105, p. 56-76.

Benoit, Dick, 1994. Review of geothermal power generation projects in the Basin and Range Province, 1993, *Geothermal Resources Council BULLETIN*, v. 23, p. 173-178.

Catchings, R.D., 1992. A relation among geology, tectonics and velocity structure, western to central Nevada Basin and Range, *Geological Society of America Bulletin*, v. 104, p. 1178-1192.

Duffield, W.A., Sass, J.H. and Sorey, M.L., 1994. Tapping the Earth's natural heat, *U.S. Geological Survey Circular*, v. 1125, 63 p.

Elders, W.A. and Sass, J.H., 1988. The Salton Sea scientific drilling project, *Journal of Geophysical Research*, v. 93, p. 12,953-12,968.

Fournier, R.O., 1977. Chemical thermometers and mixing models for geothermal systems, *Geothermics*, v. 5, p. 41-50.

Guffanti, Marianne and Muffler, L.J.P., 1995. Geothermal potential of diverse volcanotectonic settings of the Cascade Range, U.S.A., *Proceedings of the World Geothermal Congress*, Florence, Italy, International Geothermal Association, May 1995 (in press).

Humphreys, E.D. and Dueker, K.G., 1994. Physical state of the western U.S. upper mantle, *Journal of Geophysical Research*, v. 99, p. 9,635-9,650.

Lachenbruch, A.H. and Sass, J.H., 1977. Heat flow in the United States and the thermal regime of the crust, in The Earth's Crust, *American Geophysical Union Geophysics Monograph*, v. 20, p. 626-675.

Lachenbruch, A.H. and Sass, J.H., 1978. Models of an extending lithosphere and heat flow in the Basin and Range Province, *Geological Society of America Memorandum* v. 152, p. 209-250.

Lachenbruch, A.H., Sass, J.H. and Galanis, S.P. Jr., 1985. Heat flow in southernmost California and the origin of the Salton Trough, *Journal of Geophysical Research*, v. 90, p. 6,709-6,736.

Mariner, R.H., Presser, T.S. and Evans, W.C. 1983. Geochemistry of active geothermal systems in the northern Basin and Range Province, *Geothermal Resources Council Special Report No. 13*, p. 95-119.

Muffler, L.J.P. and Guffanti, M., 1995. Are there significant hydrothermal resources in the U.S. part of the Cascade Range?, 20th Stanford Geothermal Reservoir Engineering Workshop, in press.

Olmstead, F.H., Welch, A.H. and Ingebritsen, S.E., 1986. Shallow subsurface temperatures in the Basin and Range Province, U.S.A., - 1, Review and Evaluation, *Geothermics,* v. 15, p. 251-265.

Paillet, F.L. and Keys, W.S., 1984. Applications of borehole geophysics in characterizing the hydrology of fractured rocks, National Water Well Association, Symposium on Surface and Borehole Geophysical Methods in Groundwater Investigations, San Antonio, TX, p. 743-761.

Sass, J.H., Kennelly, J.P. Jr., Wendt, W.E., Moses, T.H. Jr. and Ziagos, J.P., 1981. *In-situ* determination of heat flow in unconsolidated sediments, *Geophysics,* v. 46, p. 76-83.

Sass, J.H., Lachenbruch, A.H., Galanis, S.P. Jr., Morgan, P., Priest, S.S., Moses, T.H. Jr. and Munroe, R.J., 1994. Thermal regime of the Basin and Range Province: 1. Heat flow from Arizona and the Mojave Desert of California and Nevada, *Journal of Geophysical Research,* v. 99, p. 22,093-22,119.

Sass, J.H., Ziagos, J.P., Wollenberg, H.A., Munroe, R.J., di Somma, D.E. and Lachenbruch, A.H., 1977. Application of heat-flow techniques to geothermal energy exploration, Leach Hot Springs area, Grass Valley, Nevada, United States Geological Survey Open-File Report, p. 77-762.

Tenenbaum, David, 1995. Tapping the fire down below, *Technology Review,* v. 98, p. 38-47.