Geothermal Research Program of the U.S. Geological Survey

Robert L. Christiansen and L. J. Patrick Muffler

U. S. Geological Survey

ABSTRACT

The USGS Geothermal Research Program is committed to an improved understanding of the nature, distribution, and magnitude of geothermal resources in the United States to help enable a proper role for the Nation's geothermal resources as a significant alternative energy source. Major accomplishments of the Geothermal Research Program include national resource assessments, in-depth studies of prominent geothermal areas, and development of exploration and evaluation techniques. Major activities of the current, reduced program are focused on the Cascade Range, leading towards a resource assessment of that province, and on investigations to characterize the types of geothermal resources associated with young igneous systems, including the development of advanced seismic techniques to identify and characterize magma bodies.

ORIGINS AND GOALS OF THE USGS GEOTHERMAL RESEARCH PROGRAM

Research by the U.S. Geological Survey (USGS) on active geothermal systems started long before formal geothermal programs were established within the Federal Government in the early 1970's. Pioneering geothermal activities by the USGS included inventories in the early 1900's of hot springs in the United States and the World by G.A. Waring and, most especially, the work of D.E. White and his colleagues in the 1950's and 1960's on active hot-spring systems as analogues of metallic ore-depositing processes. The work of White and his collaborators was brought to fruition in several detailed studies at Steamboat Springs (Nevada), Yellowstone National Park, the Imperial Valley (California), and other areas, and still continues.

With changes during the early 1970's in the economics and politics of energy, both in the Nation and in the world, the USGS took on an active role in the explicit Federal entry into the rapidly expanding field of geothermal energy with a vigorous earth-science research program aimed at analyzing the resource part of the geothermal picture.

The USGS Geothermal Research Program since its beginning in 1971 has been committed to a set of long-range goals, based on the premise that a proper role for geothermal energy as a significant alternative energy source for the Nation would be enhanced by an understanding of the nature, distribution, and magnitude of the Nation's geothermal resources. Progress toward these goals is sought mainly through multidisciplinary earth-science research that is designed to characterize the geological, geophysical, geochemical, and hydrological factors that control geothermal systems--their nature, localization, size, and longevity. On the basis of these studies and incorporating other publicly available data, the program seeks to assess the magnitude and distribution of the Nation's geothermal resources for the use of policy planners and industry, including the development of methods suitable for such assessments. In the course of this work, significant interpretive techniques and equipment useful in the exploration and evaluation of geothermal resources have also been developed. In addition, some USGS studies are aimed at illuminating the inevitable questions about geoenvironmental effects that might result from the extraction or injection of geothermal fluids.

FUNDING HISTORY

Given the major domestic and international changes that have influenced National energy policy, it is hardly surprising that the fiscal history of the Federal geothermal program is one of great changes. Particularly in view of the Survey's commitment to long-range goals, however, these fluctuations, combined with an overall long-term decline in program funding, have created significant difficulties in maintaining that commitment. Figure 1 shows the funding history of the USGS Geothermal Research Program from its formal inception to the present, both in terms of appropriated dollars and in terms of dollars as adjusted for long-term inflation. In terms of 1972 dollars, the current program has contracted to what it was in Fiscal Year 1973--the second year of its existence.

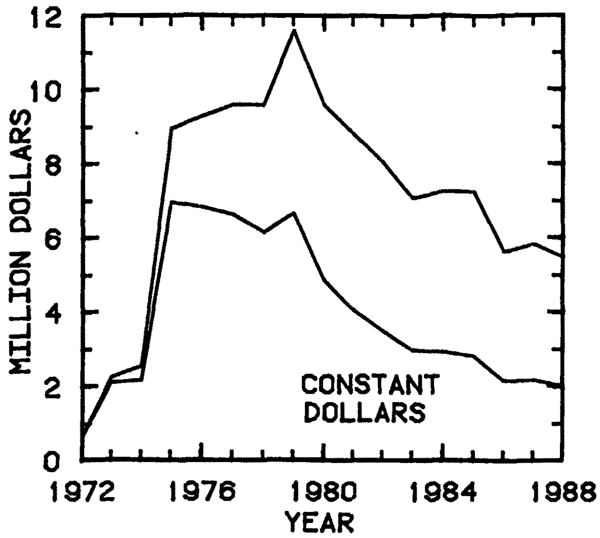

Figure 1. Funding history of the USGS Geothermal Research Program. Upper curve depicts actual appropriations. Lower curve depicts appropriations adjusted to 1972 dollars using the Consumer Price Index.

ACCOMPLISHMENTS

Among the most visible accomplishments of the USGS Geothermal Research Program have been three major nationwide assessments of geothermal resources. In 1975, USGS Circular 726 presented the first comprehensive evaluation of the geothermal resources of the United States, focusing on geothermal resources at temperatures ≥90°C. Circular 790 updated that assessment to 1978. Circular 892, in 1983, presented a quantitative assessment of low-temperature geothermal resources.

The USGS has also carried out several comprehensive, multidisciplinary studies of major geothermal areas, including The Geysers, Long Valley, and Coso in California, and Yellowstone National Park in Wyoming. These in-depth studies were complemented by reconnaissance studies of larger regions such as the Cascade Range, the Snake River Plain, the northern Basin and Range Province, and Alaska. Numerous topical studies have also been carried out at geothermal areas throughout the United States.

The USGS has been active in the development of methods for geothermal exploration. The interpretation of water and gas analyses to predict subsurface temperatures grew from original investigations by Donald E. White and has culminated in the research of Robert O. Fournier and Alfred H. Truesdell. In addition, Truesdell has been a leader in applying geochemistry to elucidate the behavior of geothermal reservoirs during production. The USGS has also played an extensive role in developing electrical and electromagnetic techniques to determine the geometry of geothermal systems and in developing and refining active and passive seismic techniques to investigate hydrothermal systems and underlying magma bodies. Finally, the USGS has contributed extensively to the development of mathematical hydrologic models to describe the behavior of geothermal systems.

The results of USGS geothermal investigations have been systematically published in the open literature or, when appropriate, released as USGS Open-File reports. A list of publications from 1972 to 1986, comprising approximately 1,700 entries, can be obtained from the USGS Geothermal Coordinator in Menlo Park, California. Only publications just released or in press are cited specifically in this paper.

CURRENT PROGRAM

The current USGS Geothermal Research Program is divided into 5 major components:

1. A multiyear, multidisciplinary program of studies to characterize geothermal resources of the Cascade Range (Muffler, this volume):

- Compilation of a geologic map at 1:500,000 of the Cascade Range (Smith, this volume; Sherrod, this volume).
- Publication of regional gravity maps of the Cascade Range (Finn and others, 1987).
- Geologic, volcanologic, and petrologic studies of volcanic systems that include Crater Lake in Oregon, Medicine Lake, Lassen Peak, and Mount Shasta in California, and Mount Adams in Washington.
- Integration of geologic, geophysical, and geochemical studies of Newberry volcano, Oregon, and Medicine Lake volcano, California.
- Hydrologic analysis to help evaluate whether undiscovered deep hydrothermal systems exist in the Cascade Range but are masked by overlying cold ground water in permeable young volcanic rocks.
- Integration of temporal and spatial data on volcanic vents with earthquake and magnetotelluric data into a tectonic analysis of the Cascade Range (Guffanti and Weaver, this volume).
- Development of a methodology for assessment of undiscovered geothermal resources of the Cascade Range, based on a model that integrates the tectonic, volcanologic, thermal, and hydrologic data.

2. Investigations to understand the dynamics and evolution of hydrothermal systems:

- Isotopic and chemical studies aimed at refining geothermometers, elucidating hydrothermal processes, and determining the origin of chemical consitutuents in geothermal fluids.
- Development of chemical and isotopic methods as reservoir-engineering tools.
- Development of electrical and electromagnetic techniques for determining the location and geometry of hydrothermal convection systems.

- Development and testing of logging equipment and analysis techniques to provide geophysical information on the properties of rocks and fluids in geothermal boreholes.
- Development of mathematical models to aid in understanding the physics of single- and multi-phase fluid flow in porous media.
- Analysis of the physics of geyser eruptions and of fluid flow through well bores.

3. Regional geological, geophysical, and hydrological studies:
- Interpretation of magnetic maps of Nevada in terms of Curie-point isotherms (Blakely, in press).
- Preparation of a 1:100,000 geologic map of the Island of Hawaii.
- Descriptive synthesis of post-Laramide geology, tectonics, and magmatism in the Western United States (Christiansen and Yeats, in press).
- Continuation of heat-flow studies in the Western United States.
- Completion of reports on hydrogeology of selected geothermal fields in Nevada, including Beowawe, southern Grass Valley, and the Carson Sink-Bradys Hot Springs area.

4. Investigations to characterize and assess the types of geothermal resources associated with young igneous systems:
- Development of advanced seismic techniques to identify and characterize magma bodies (Sanders, this volume).
- Detailed geologic studies of Long Valley, California (Bailey, in press).
- Reconnaissance geologic studies of young volcanic systems in Alaska (Miller and Smith, 1987).
- Theoretical analysis of volume-age relations of igneous systems and of cooling paths of magmatic bodies.

5. Investigations to understand the interactions of magma and geothermal fluids in the roots of hydrothermal systems.
- Geochemical, petrologic, and geophysical investigations in selected deep holes drilled by others into geothermal systems.
- Interpretation of the extensive borehole logging conducted in the Salton Sea Scientific Drillhole (Paillet, 1986).
- Cooperation with the Department of Energy in scientific direction and interpretation of the Shady Rest drillhole in Long Valley (Wollenberg and others, 1987).
- Co-leadership in planning a program to drill into the vent of the 1912 Novarupta eruption, in the Katmai region of Alaska (Eichelberger and Hildreth, 1986).

6. Evaluation of selected geoenvironmental concerns related to geothermal development:
- Monitoring and analysis of earthquakes in The Geysers geothermal field, California.
- Hydrological and geochemical monitoring programs to evaluate the extent to which natural thermal features might be affected by possible geothermal development in adjacent areas.
- Scientific counsel to the Secretary of the Interior, the Bureau of Land Management, and the National Park Service concerning the possible effects of geothermal development outside parks on designated thermal features within parks (Section 115 of the Public Law 99-591).

7. Investigations supported in part by other Federal agencies:
- Application of geochemical techniques to analyze reservoir performance at Cerro Prieto (Stallard and others, this volume) and Los Azufres, Mexico, under funding from the Department of Energy.
- Intrusion-emplacement modeling of basaltic and andesitic volcanoes, under funding from the Department of Energy.
- Geological and geochemical studies of geothermal prospects in Honduras (Truesdell and others, this volume; Goff and others, this volume; Bargar, this volume) and Costa Rica (funded by USAID in cooperation with Los Alamos National Laboratory).

FUTURE GEOTHERMAL RESOURCE ASSESSMENTS

Within the USGS Geothermal Research Program, consideration is being given to how geothermal resource assessments should be conducted over the next few years. For at least the intermediate term, it seems that major revisions of the broad, national resource assessments of USGS Circulars 726, 790, and 892 might not be fruitful. Certainly, the figures for identified reservoir thermal energy could be refined, but significant improvement of the estimates for undiscovered resources will require new, innovative approaches. The most significant assessments over the next decade or so might be of different types than previous efforts. One such type might be topical, addressing particular geologic environments or types of geothermal systems. Another type might be regionally focused, addressing a coherent geologic province of uncertain geothermal potential, particularly a province for which diverse previous estimates have not been based on comprehensive geologic models. The USGS plans a prototype regional assessment for geothermal resources of the Cascade Range.

The methodology for these geothermal resource assessments requires significant development. For example, one thread running through many possible future assessments is the fundamental problem of analyzing the amounts and types of geothermal energy related to young igneous systems. A basic conceptual framework for such systems has been proposed by Smith and Shaw (1975; 1979). There remains, however, a clear need for further focused research on how convective hydrothermal systems are linked to magmatic heat sources, how thermal budgets are partitioned in nature between various heat-transfer processes, and how each of these contributes to the accessible geothermal resource base. Further development of this conceptual framework must play a crucial role in significantly improved regional, topical, or national geothermal-resource assessments.

REFERENCES CITED

Bailey, R.A., in press, Geologic map of Long Valley caldera and Mono-Inyo craters volcanic chain and vicinity, eastern California: U.S. Geological Survey Miscellaneous Investigations Map, scale 1:62,500.

Blakely, R.J., in press, Estimation and tectonic implications of the Curie-temperature isotherm of Nevada: Journal of Geophysical Research.

Christiansen, R.L., and Yeats, R.S., in press, Post-Laramide geology of the Cordilleran region [with contributions by S.A. Graham, W.A. Niem, A.R. Niem, and P.D. Snavely, Jr.], in Burchfiel, B.C., Lipman, P. W., and Zoback, M.L., eds., The Geology of North America, vol. G-3, The Cordilleran Orogen; Conterminous U.S.: Boulder, Colorado, Geological Society of America, Decade of North American Geology.

Eichelberger, J.C., and Hildreth, Wes, 1986, Research drilling at Katmai, Alaska: Eos (American Geophysical Union Transactions), v. 67, p. 778-780.

Finn, Carol, Williams, D.L., Couch, R.W., Danes, Z.F., Pitts, G.S., and Phillips, W.M., 1986, Gravity anomaly and terrain maps of the Cascade Range, California, Oregon, Washington, and British Columbia: U.S. Geological Survey Geophysical Investigations Map GP-972, scale 1:2,500,000.

Miller, T.P., and Smith, R.L., 1987, Late Quaternary caldera-forming eruptions in the eastern Aleutian arc, Alaska: Geology, v. 15, p. 434-438.

Paillet, F.L., ed., 1986, Preliminary report on geophysical well logging activity on the Salton Sea Scientific Drilling Project, Imperial Valley, California: U.S. Geological Survey Open-File Report 86-544, 99 p.

Smith, R.L., and Shaw, H.R., 1975, Igneous-related geothermal systems, in White, D.E., and Williams, D.L., eds., Assessment of geothermal resources of the United States--1975: U.S. Geological Survey Circular 726, p. 58-83.

Smith, R.L., and Shaw, H.R., 1979, Igneous-related geothermal systems, in Muffler, L.J.P., ed., Assessment of geothermal resources of the United States--1978: U.S. Geological Survey Circular 790, p. 12-17.

Wollenberg, H.A., Sorey, M.L., Farrar, C.D., White, A.F., Flexser, S., and Bartel, L.C., 1987, A core hole in the southwestern moat of the Long Valley caldera: early results: Eos (American Geophysical Union Transactions), v. 68, no. 20, p. 529-534.