WORKSHOP ON EXPLORATION FOR HOT-DRY-ROCK GEOTHERMAL SYSTEMS

Compiled by

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ABSTRACT

Most of the world's geothermal resources are not present in the form of active hydrothermal systems but as hot dry rock (HDR). HDR makes up by far the largest fraction of geothermal regions, but natural fluids are absent and water must be introduced artificially for production of steam or hot water. Recognizing the huge thermal resource available, several countries now have HDR experiments. HDR resources lack the sharp physical and chemical contrasts produced by geysers and hot springs and thus present unusual exploration problems. Exploration for HDR was the subject of a workshop held in Los Alamos, New Mexico, 21-23 June, 1982.

It was apparent that many aspects of HDR exploration comprise basic crustal studies, including continental scientific drilling. Thus, virtually all speakers emphasized a multidisciplinary approach to exploration. The most useful data are obtained from careful measurement of heat flow. Heat flow data may be linked, and the extent of regional thermal anomalies determined, through the use of magnetotelluric surveys and depth-to-Curie point mapping. In particular, there is strong evidence for a correlation between depth to deep crustal electrical conductors and surface heat flow. Gravity data have been used to locate HDR anomalies associated with favorable buried silicic and alkalic intrusive bodies.

A variety of seismic methods can help identify the thermal anomalies, structural features, and depth to potential reservoir rocks in areas with a HDR resource. Geological surveys provide a framework within which data from the geophysical surveys may be interpreted; they also include petrologic, structural, and temporal studies of heat sources. In addition, resource definition calls for evaluation of the stress regime and permeability with depth in HDR reservoir rocks. Several speakers noted that many "hot dry wells" found within the conductive haloes of hydrothermal systems might be used in both exploration and in artificial development of the HDR resource.

All geophysical and geological panels at the workshop agreed that a clearing-house for existing geological and geophysical data is needed for future comprehensive evaluations of the HDR resource.

I. INTRODUCTION

Hot dry rock (HDR) is defined as that part of a geothermal anomaly where the fluids needed for production of steam or hot water are lacking. Most of the world's geothermal resource is not present in the form of natural hydrothermal systems but as HDR. Development of this resource through the use of manmade geothermal systems is in progress in several countries. The largest of these experiments, the Fenton Hill HDR geothermal project, is funded by the U.S. Department of Energy and the governments of West Germany and Japan. This project is located a short distance west of the rim of the Valles Caldera in the Jemez Mountains of New Mexico. As the Fenton Hill experiments progressed it became evident that the location and extent of the HDR geothermal resource in other areas should be evaluated and that potential HDR drilling sites be located as part of a comprehensive program needed to encourage its development. Because the HDR resource lacks the sharp physical and chemical contrasts produced by natural fluids, it presents different exploration problems from those of conventional hydrothermal exploration. The purpose of this workshop, held in Los Alamos, New Mexico, 21-23 June, 1982, was to review geological, geochemical, and geophysical exploration methods currently used for HDR recognition and resource evaluation, and to evaluate new ideas for HDR exploration.

A list of workshop attendees, the agenda, and the papers presented at the workshop are in the Appendix.

II. HEAT FLOW CRITERIA FOR HDR EXPLORATION

Heat flow, because it involves direct temperature measurements, is usually the ultimate standard for evaluating geothermal potential. Its importance increases as the scale of resolution narrows to that of choosing drilling sites.

Crustal heat flux varies between regions of relative geological stability such as eastern or midwestern North America, and the more active regions like western North America where crustal temperatures are usually hotter.

For stable regions J. Costain (Virginia Polytechnic Institute and State University) cited several geological settings that seemed promising for HDR. These take advantage of the fact that heat flow is the product of thermal gradient and thermal conductivity; therefore, regions of low thermal conductivity can have rather high thermal gradients and hence high temperatures at moderate depths, even though heat flow is only average. Heat flow is further enhanced if local crustal heat generation is high. Hence, two interesting HDR possibilities would be regions of normal gradient but deep, relatively insulating sedimentary rock and regions of high heat generation, such as a granitic pluton overlain by "blanketing" sedimentary layers. W. Hinze (Purdue University) elaborated upon some variations where crustal heat is concentrated by a local good conductor such as a salt dome, by hydrothermal circulation, by residual magmatic heat, or by upper mantle sources whose thermal effects have not yet diffused to the upper crust. Hinze cited thermal anomalies within the Mississippi Embayment as a possible example of "channelling" by a good conductor. K. German (University of Nebraska at Lincoln) attributed high temperatures in western Nebraska to the hydrothermal circulation mechanism, as did D. Hodge (SUNY, Buffalo), to explain high bottom-hole temperatures in basement rock near Auburn, New York.

Hence, from the standpoint of heat flow methods HDR exploration in older "stable" continental crust involves three criteria: (a) locating regions of relatively high heat flow, (b) identifying regions of low thermal conductivity, and (c) determining radiogenic heat production in basement rock.

Because of a far greater density of thermal anomalies, tectonic zones such as the western U.S. have enjoyed a much higher level of geothermal exploration, and many geothermal areas have been identified. Thus, an obvious HDR exploration technique cited by D. Blackwell (Southern Methodist University) and M. Smith (Los Alamos National Laboratory) is to obtain heat flow data in the "conductive haloes" surrounding known hydrothermal sites. Indeed, these areas often have sufficient numbers of "dry holes" to make them more interesting as HDR sites than as conventional sites. Steep geothermal gradients are, of course, direct indicators of high temperatures at accessible depths, but Blackwell indicated the need for a more reliable and easily interpreted way of using heat flow to project thermal effects to great depth. Ground water and hydrothermal water circulation add further complications, including extremely high apparent surface heat flow, but there is a growing body of experience in modeling these situations.

Further Work in Heat Flow Methods

The outlines for adequate heat flow criteria in HDR exploration are given above. However, the panel noted that these criteria could be improved and systematized by some additional efforts.

(1) A higher density of heat flow determinations would be extremely useful; it is particularly important to extend measurements beyond the immediate area of a wet geothermal or HDR site in order to reduce ambiguity in interpretation of heat flow data and to better model convective heat transfer.

(2) Better communication between the academic community and the geothermal industry would be beneficial in obtaining basement temperatures and cores for measurement of basement temperature, thermal conductivity, and heat generation.

(3) The Decade of North American Geology (DNAG) series of maps could serve as the outlet for four additional maps:
   (a) temperature at top of basement,
   (b) basement heat production,
   (c) heat flow at basement surface, and
   (d) surface heat flow.

III. SEISMIC CRITERIA FOR HDR EXPLORATION

If one were to look only at the relatively small effects, due purely to temperature, on seismic velocities, then only subtle variations in seismological observations would be observed. The utility of seismic methods is in determining crustal structure and thermally associated but often indirect phenomena such as the presence of fluids.

Many of the seismic methods are so well established that they are almost taken for granted. W. Laughlin (Los Alamos National Laboratory) described reflection surveys that were used to characterize depth to basement at the first HDR site at Fenton Hill, New Mexico. Magma bodies are potential HDR thermal sources and S. Kaufman (Cornell University) showed how reflection profiles helped define a magma layer intruded beneath the vicinity of Socorro, New Mexico. L. Braile (Purdue University) mentioned the strong structural controls provided by seismic refraction in the Yellowstone-Snake River Plain region; these included substantial velocity decreases, as much as 30%, attributed to fluids. Although the fluids would not themselves be the object of HDR exploration, they could contribute to heating nearby rock in the "conductive halo."

Seismic methods are particularly well suited to locating disturbed zones that have been heated hydrothermally or by magma. K. Aki (Massachusetts

Institute of Technology) noted that almost all the hot zones currently established as geothermal sites are characterized by deep crustal low-velocity cores. These comprise not only giant systems such as Yellowstone, but also the Jemez Caldera (although velocity surveys inside and outside the caldera did not play a role in originally choosing this HDR geothermal site). Three-dimensional teleseismic P-wave delay studies have strikingly outlined several low-velocity cores that represent hot rock that provides heat both to the local hydrothermal systems and to the halo of hot but dry rock. Seismicity serves to delineate possible HDR reservoirs in a number of ways: it can locate possible intrusions such as the Socorro magma layer; on the local scale it can provide information on stress directions as a guide to drilling. Contrary to the case for conventional reservoirs, seismicity is a negative indicator for manmade systems because of the danger of induced earthquakes and of water loss through active faults.

Some of the applications and information supplied by seismic methods are summarized in Table I.

Further Work in Seismic Methods

Future work in seismic HDR exploration should take advantage of those properties that are most sensitive to crack structure and pore fluids as ways to define the general form of geothermal structures:

(1) Teleseismic S-wave structure to define 3-D structure as done for P-waves.

(2) Determination of S-velocities, Poisson's ratios, and Q^{-1} in refraction surveys.

(3) Controlled surface wave studies to improve resolution of V_s and Q_s^{-1}.

(4) Detailed studies of known conventional hydrothermal and HDR areas to gain experience in seismically defining these reservoirs.

IV. MAGNETOTELLURIC CRITERIA FOR HDR EXPLORATION

Electromagnetic methods, magnetotellurics (MT) in particular, are extremely useful in geothermal exploration because of the sensitivity of rock conductivity to water content and to elevated temperatures. MT can target HDR resources in two important ways. As a regional exploration method, MT can be used to map the crustal deep electrical conductor. M. Ander (Los Alamos National Laboratory) showed five long two-dimensional models developed from approximately 200 MT soundings in Arizona and New Mexico. These models

TABLE I
CHARACTERISTICS OF SEISMIC PARAMETERS RELATED TO HDR EXPLORATION

	Teleseismic Residuals	Reflection Profiling	Refraction Profiling	Seismicity	Surface Wave Studies
Parameters	3-D distribution of Vp	Vp, Vs sometimes measured, f generally 8-50 hz, reflection coefficients, Q^{-1}, Poisson's ratio.	Compressional velocity, sometimes amplitude variations and Q^{-1} structure; f generally 1-20 hz. Parameters may show dependence on temperature although expected to be near limit of resolution. Useful for structural mapping which may relate to HDR potential.	P and S velocities must generally be assumed although P/S velocity ratio can be determined for an area. Earthquake locations and focal mechanisms are determined. Stress directions from focal mechanisms are useful for HDR exploitation. Presence of earthquake activity correlates with major geothermal anomalies associated with tectonically active areas. Not known to be associated with thermal anomalies in cratonic regions. Seismicity may indicate fracture porosity.	Surface wave dispersion is most sensitive to variations in shear wave velocity but can also be used to study Vp and density in ideal circumstances. Two-station techniques can be used to determine Q^{-1}. Relatvely low frequencies are normally used but studies of quarry blasts have successfully determined dispersion curves to periods of approximately 1 sec.
Resolution	Limited mainly by the station spacing, usually poorer than 10 km. The finest resolution so far achieved is 5 km for Coso, which is probably optimal considering the wavelength of typical teleseismic P waves.	Vertical resolution $\sim$100 m ($\lambda/4$) horizontal resolution $\sim$300-500 m.	Bodies on the order of several km or larger may be adequately mapped.	Dependent on seismograph array parameters. If sufficiently dense array available, seismicity associated with thermal anomalies of dimensions on the order of kilometers can be indicated.	Normally surface wave studies are considered to be of low resolution. However, controlled experiments could produce relatively high resolution results in areas where the near surface geology is simple (i.e. flat lying layers). A major limit to resolution is the difficulty of dealing with two-dimensional earth models.
Depths	Depth of probing comparable to the size of aperture.	Entire crust, if sufficient energy penetration.	May be applied to bodies at virtually any depth, certainly within the crust, but resolution generally degrades with depth.	Applicable to any depth.	Surface wave studies can be "tuned" to the depth of interest because the depth of penetration is dependent on frequency. Long period waves (50-150 sec) are routinely used to study the upper mantle. The "ground roll" of reflection surveys can be used to study near-surface layers.

TABLE I (cont)

	Teleseismic Residuals	Reflection Profiling	Refraction Profiling	Seismicity	Surface Wave Studies
Magmatic Target Characteristics	Molten body or partially molten body of size greater than about 10 x 10 x 10 km^3 having a velocity contrast of a few % from the surrounding rock.	Molten body: seen as large reflection coefficient. Partial melt: possible reflection and velocity anomaly.	Molten body: anomalous P/S velocity ratio, amplitude (wide angle reflection coefficient) and attenuation expected. Low P velocity expected but may not be large enough effect to be measurable. Partially molten body: Same as for molten body but anomalies will be smaller.	Seismic noise studies have also been used to locate both hydrothermal anomalies and magmatic intrusions.	Many anomalous conditions associated with targets are most pronounced in terms of S-wave velocity. Surface waves can be particularly useful for targets that can be expected to substantially affect Vs.
Solid HDR Target		Probably not	If temperature contrast is large enough (on the order of 100°C) as compared with adjacent rocks, similar anomalous seismic wave parameters as those described for molten rock may be observed.	Absence of seismicity.	Probably not
Remarks	The method has so far detected low-velocity-bodies (most likely partially molten) in the crust and upper mantle beneath all the studied geothermal areas in the western U.S. except under volcanoes in Cascades. Method could conceivably be applied to attenuation and S-wave velocities.	Satisfactory statistics, suitable energy source, and adequate velocity information required.			

indicate strong evidence for a correlation between the depth to deep electrical conductor and surface heat flow as well as with regional tectonics. One of these models, from Seligman to Yuma, Arizona, was used in a presentation by C. Aiken (University of Texas) and M. R. Hong (University of Texas) to indicate a correlation between the depth to the deep crustal conductor and the depth-to-Curie point. M. Ander and T. Shankland (Los Alamos National Laboratory) showed results of a correlation study of worldwide MT field data and crustal temperature obtained from surface heat flow. A pronounced result of their study was that even the most resistive crustal regions have conductivities several orders of magnitude better than laboratory samples and that this is easily explained by the presence of volatiles, water in particular. Most importantly, the data could be well represented by a straight line fit on a log vs 1/T plot indicating an excellent correlation between crustal electrical conductivity and crustal temperature. G. R. Jiracek (San Diego State University) suggested that the deep crustal electrical conductive horizon may occur where an impermeable, ductile cap traps pore fluids beneath. Ductile flow mechanisms are thermally activated processes that involve charge defects, lattice dislocations, or atomic diffusion, all of which enhance solid state electrical conduction. If active magma injection destroyed the integrity of the ductile cap, trapped fluids would escape, resulting in an overall decrease in conductivity. The final electrical signature would depend on thermal gradient, relative impermeability of the cap, extent of the pore fluids beneath, and amount of magma intrusion. Because temperature would likely be the major variable in a given geologic province, Jiracek also felt that the depth of a conductive layer, even if caused by a ductile layer, would provide a measure of the thermal gradient. Therefore it is likely that estimates of crustal temperature and regional heat flow can be obtained from estimates of the depth to crustal electrical conductor.

As a local exploration method MT can be used to map the structure of resistivity changes at a potential HDR site. This requires high-quality MT data and a tight MT station spacing. For both the regional and site specific exploration, problems exist in modeling and in interpreting the field results. A. Orange (Emerald Exploration, Inc.), S. Park (Massachusetts Institute of Technology), and D. Chambers (Woodward-Clyde Consultants, Inc.) discussed the nature of some of the pitfalls of MT interpretation in both two- and three-dimensions. MT interpretation is a complex art, even in many cases where the data appear straightforward; recognition of this complexity is a major step towards the realization of the method's full capabilities. Intense study of a wide variety of two- and three-dimensional models will provide the interpreter with valuable, critical insight. Most importantly MT surveys should be planned using this insight.

Further Work in Electromagnetic Surveys

The electromagnetics working group had several specific recommendations for further work.

(1) In the past decade well over 5000 MT soundings have been completed in the United States. These represent an extraordinarily valuable data base for determining the depth to the deep electrical conductor. It was suggested that these data be compiled in a single data base and analyzed. An international project to do this has been endorsed already by the National Academy of Science. This would be of value in further confirming the correlations between electrical conductivity, heat flow, depth-to-Curie point, and regional tectonics.

(2) A continuous exploration program using electrical methods should be directed toward locating conductivity anomalies in the United States. These could be either hydrothermal or HDR systems. The distribution of heat flow and electrical properties may well be useful in differentiating the two types of systems.

(3) A major uncertainty exists in knowing how to interpret enhanced electrical conductivities in the crust. Possible mechanisms are numerous. Although we have some measure of understanding of these effects, there is insufficient information to judge how these effects persist over time. For instance, can pore fluids persist in enhancing conductivity over geologic time at temperatures of several hundred degrees or do they form hydrated minerals and hence change rock conductivity? In addition, long-term measurements of electrical conductivities in rocks need to be undertaken at geologic temperatures and pressures to understand changes with time.

V. GRAVITY AND MAGNETIC CRITERIA FOR HDR EXPLORATION

There are many ways in which gravity and magnetic methods can be applied to exploration for HDR resources. Gravity analysis is well suited for mapping depth to rocks with low permeability. Magnetic methods are not usually as well suited for this because magnetic "basement" seldom coincides with geologic "basement." Gravity can be used to some minor extent in studying the nature of the sedimentary blanket. Both gravity and magnetic surveys are important methods for delineating both regional and local structure in the Phanerozoic and the basement. They are particularly good for locating faults, suture zones, and old rift structures. Magnetic surveys may be used to determine depths to the Curie isotherm. A shallowing in the depth to the Curie isotherm may suggest a thermal upwelling and therefore a possible HDR target area.

J. Costain, L. Glover (Virginia Tech), D. Hodge, and K. Fromm (SUNY, Buffalo) described the use of gravity data in targeting HDR sites in the eastern U.S. while W. Hinze, L. Braile, R. von Frese (Purdue University), G. R. Keller, R. Roy (University of Texas at El Paso), and P. Morgan (Lunar and Planetary Institute) described gravity applications in the midcontinent U.S. In these studies, gravity and magnetic data covering broad regions have been observed, compiled, and in some cases filtered to enhance particular attributes of the anomaly field. These maps are proving useful reconnaissance tools in mapping tectonic/lithologic regimes that serve as guides to localize more detailed geophysical and geologic studies. In particular, gravity and magnetic surveys have helped in investigations of silicic and alkalic intrusive bodies, which are potential radiogenic heat sources. Silicic intrusives are commonly characterized by gravity minima of the order of a few tens of milligals and negative magnetic anomalies. However, some plutons studied in the midcontinent are associated with relatively high magnetite contents resulting in strong localized magnetic anomalies. The gravity signature of these high-magnetite plutons is absent or slightly positive. By contrast, alkalic intrusives are generally marked by both intense positive gravity and magnetic anomalies.

In two separate papers, I. Won (North Carolina State University), C. Aiken and R. Hong discussed the inversion of magnetic data to determine the depth-to-Curie point isotherm. Aiken and Hong described how depth-to-Curie point estimates they made along a profile from Yuma to Seligman, Arizona, correlated with estimates of depth to deep crustal electrical conductor made along the same profile by M. Ander using MT data.

Further work on gravity and magnetic methods

The gravity and magnetic working group identified several areas for further work in applying gravity and magnetic methods to HDR exploration.

(1) More case studies are needed.

(2) Petrophysical studies are needed to obtain precise measurements of density and magnetization of rocks of interest. Studies addressing the magnetization of rocks as a function of temperature for extended times are considered especially important.

(3) Gridded filtered data sets must be generally available.

(4) Although magnetic maps are widely available, digital magnetic data are not. It would be useful to make such data available.

(5) It would be profitable to further study the correlation between the depth-to-Curie isotherm estimates and surface heat flow and the depth to the deep crustal electrical conductor.

VI. GEOLOGIC METHODS FOR HDR EXPLORATION

Geologists attending the workshop all emphasized a multidisciplinary approach to HDR exploration. Their role is to provide the geological framework for geophysical data in regional HDR surveys and to characterize the genesis and thermal history of heat sources within geothermal areas associated with recent volcanism or older silicic plutons. The geologist's role has changed little since the Hot Dry Rock Resource Evaluation Panel (HDRAP) of the Energy Research and Development Administration defined the variety of geological surveys needed for HDR exploration and development.

Within igneous systems, which make up most of the known geothermal resource areas (KGRA's) of the United States, the geologist's role in defining the HDR resource is substantial. To understand the extent and magnitude of hydrothermal and HDR components of an igneous system requires detailed information on the structural setting, ages, distribution, volume, and composition of volcanic units, and the hydrologic setting and chemistry of rock-water interactions within the system. The rate of fracture formation and fracture healing within these systems must be determined. All of this resource definition requires drilling and careful analysis of cores, cuttings, and geophysical well logs.

One of the most useful data sets for the geologist is from the many wells drilled for hydrothermal development that have high temperatures but no production of fluids. By keeping records of "hot but dry" wells within KGRA's, the high-grade HDR resource may be best evaluated.

Examination of regional thermal anomalies is mostly in the realm of geophysical surveys. However, the characterization of HDR reservoir rocks depends upon good physical and petrologic studies.

E. Padovani (National Science Foundation) discussed the utility of petrology of xenoliths from young volcanic rocks as a tool for geothermal evaluation. It is possible to use mineralogic geobarometers and geothermometers to calculate thermal gradients; these serve well as supplements to measured heat flow.

A major problem in HDR resource evaluation is determination of changes in the stress regime and permeability with depth in a variety of geologic settings. These data are needed for identification of rock units to serve as HDR reservoir rocks.

Compilation and evaluation of existing geological and geophysical data would be easier if there were a clearinghouse for published and proprietary information. Also needed are better curatorial facilities for the preservation of drill cores and cuttings; perhaps such facilities could be established through a continental scientific drilling program.

VII. CASE STUDIES

W. Laughlin and M. Smith described the process of selecting the first hot dry rock geothermal site in the Jemez Mountains, New Mexico. Of primary importance to site selection was the published data available on the extent, age, and nature of the Valles Caldera. Heat flow measurements along the western edge of the caldera, structural mapping and a slim exploratory drill hole to the Precambrian "basement" were key factors in site selection. Determination of the degree of faulting and jointing within the plutonic-metamorphic reservoir rocks was not possible and could be determined only by drilling. Drilling slim exploratory holes, with numerous cores, provides many of the answers and appears to be the best local site evaluation technique; it certainly was at the New Mexico site.

Hodge and Fromm used heat flow, temperature gradients, and gravity surveys to search for hidden thermal anomalies in the northern Appalachian basin. Initial results indicate that variations in temperature gradients are due to heat generation in granitic plutons in the basement (similar to the anomalies described by J. Costain in the Atlantic coastal plain). Recent drilling in western New York state has indicated that not all thermal anomalies are related to buried granitic plutons; some appear to be the result of hydrothermal circulation along faults and fractures within the basin.

Heat flow measurements, bottom-hole temperatures in oil and gas wells, and residual Bouguer gravity maps were the basis of a geothermal resource assessment of Nebraska by Gosnold and German (University of Nebraska). Two areas within the state have high heat flow. Within the panhandle of Nebraska the anomalies appear to be due to updip flow of deep aquifers from the Denver-Julesberg basin. High heat flow within north-central Nebraska is more difficult to explain; it may be related to water flow along fractures into the Dakota group or to buried granitic plutons. More drilling into Precambrian basement rocks is needed to evaluate the HDR geothermal resource of Nebraska, but its potential seems high.

Geothermal exploration strategies used in the Rhine graben by the European Communities were presented by B. Hoffers (Los Alamos National Laboratory and Gerwerkschaft Walter). These include: (1) work on the gneisses and schists of Hercynian age, granites of Carboniferous age, and Paleozoic sedimentary rocks, (2) bottom-hole temperatures and heat flow measurements, (3) Bouguer gravity anomalies, and (4) tectonic analysis. Diapiric rise of mantle under the Rhine graben and higher temperature gradients were identified through the use of, in addition to those surveys described above, refraction and reflection seismic profiles, MT surveys, aeromagnetic surveys, and electrical surveys.

APPENDIX

ATTENDEES, AGENDA, AND PAPERS PRESENTED AT WORKSHOP ON EXPLORATION OF HOT DRY ROCK GEOTHERMAL SYSTEMS

ATTENDEES

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Ihn J. Won
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AGENDA

HOT DRY ROCK EXPLORATION WORKSHOP

National Security and Resources Study Center
Los Alamos National Laboratory

Monday, June 21, 1982

Opening Remarks

Session I: P. Morgan, Chairman

M. Smith, Hot Dry Rock is Where you Find It
D. Blackwell, Heat Flow - The Technique for Hot Dry Rock Exploration and Evaluation
J. Costain, Geothermal Energy in the Eastern United States: The Radiogenic Model

M. Ander, Magnetotellurics Applied to Hot Dry Rock Geothermal Exploration in Arizona and New Mexico
G. Jiracek, Interpretation of Magnetotelluric Soundings for Hot Dry Rock Prospecting

Session II: F. Goff, Chairman

A. Orange, Some Effects of Two and Three-Dimensional Structure on Magnetotelluric Data
I. Won, Determination of Depth to the Curie Isotherm from Aeromagnetic Data
K. Aki, 3-D Seismic Velocity Anomalies in the Crust and Upper Mantle Associated with Geothermal Areas in the Western United States

S. Kaufman, Continental Structure
G. Heiken, Hot Dry Rock Geothermal Site Selection
A. W. Laughlin, Fenton Hill Site Selection and Evaluation: A Case History.

Tuesday, June 22, 1982

Session III: C. Aiken, Chairman

W. Hinze, Geophysical Exploration for Hot Dry Rock in the Midcontinent
L. Braile, Seismic Methods of Hot Dry Rock Exploration
D. Hodge, Geothermal Anomalies in the Northern Appalachian Basin; Western and Central New York

K. German, Geothermal Investigations in Nebraska
B. Hoffers, Geothermal Exploration in the Rhine Graben (West Germany and France)
T. Meidav, Parametric Exploration for Hot Dry Rock

Meetings of Working Groups
- J. Costain, Chairman, Heat Flow - University House
- W. Hinze, Chairman, Gravity and Aeromagnetism - Study Center
- G. Keller, Chairman, Electromagnetic Methods - University House
- L. Braile, Chairman, Seismology - Study Center
- E. Padovani, Chairman, Geology and Geochemistry - University House

Reports of Working Groups

Wednesday, June 23, 1982

Field Trip to Fenton Hill Hot Dry Rock Geothermal Site