19/21/86 REM (1) (60) I - 28374 NR 1998-4
SAND86—1923 • Unlimited Release • UC—66
Printed September 1986

Geothermal Technology Publications and Related Reports: A Bibliography January 1984 through December 1985

Dana L. Cooper, Editor

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof or any of their contractors or subcontractors.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A05
Microfiche copy: A01

SAND--86-1923

DE87 000900

SAND86-1923
Unlimited Release
Printed September 1986
UC-66

GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS:

A BIBLIOGRAPHY

January 1984 through December 1985

Dana L. Cooper, Editor
Exploratory Energy Systems Department 6240
Sandia National Laboratories
Albuquerque, New Mexico 87185

Abstract

Technological limitations restrict the commercial availability of U.S. geothermal resources and prevent effective evaluation of large resources, as magma, to meet future U.S. needs. The U.S. Department of Energy has asked Sandia to serve as the lead laboratory for research in Geothermal Technologies and Magma Energy Extraction. In addition, technology development and field support has been provided to the U.S. Continental Scientific Drilling Program. Published results for this work from January 1984 through December 1985 are listed in this bibliography.

The reported research was done by personnel at Sandia or at universities or industry under contract to Sandia. The major support of this work was provided by the Department of Energy Division of Geothermal Energy.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

	<u>Page</u>
I. Geothermal Technology.....	1
A. Rock Penetration Mechanics.....	3
B. Fluid Technology.....	9
C. Borehole Mechanics.....	15
D. Diagnostic Technology.....	21
E. Permeability Enhancement.....	29
F. Systems Analysis/Summaries and Reviews.....	33
II. Magma Energy.....	39
A. Geophysics/Site Selection.....	41
B. Geochemistry/Materials.....	45
C. Energy Extraction.....	47
D. Systems Analysis/Summaries and Reviews.....	49
III. Continental Scientific Drilling Program.....	53
A. Field Research and Support.....	55
B. Reviews and Summaries.....	61
IV. Past Bibliographies.....	67
V. Author Listing.....	69

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

I. GEOTHERMAL TECHNOLOGY

Drilling and completing wells in geothermal resources are 2-5 times more expensive than equivalent depth oil and gas wells because of high temperature, hard and fractured rock, underpressured reserves and corrosive brines. The development of energy programs managed by Sandia Labs involves research to solve geothermal drilling and completion problems in order to expand the resource availability and utilization.

Long-range R&D is carried out in:

1. Rock Penetration Mechanics - interactions of cutters and fluids with rock;
2. Fluid Technology - understanding of thermal transport processes and development of high-temperature drilling fluids;
3. Borehole Mechanics - understanding of lost circulation phenomena and of drill string dynamics;
4. Diagnostic Technology - borehole instrumentation development for hostile environments; and
5. Permeability Enhancement - stimulation research applied to geothermal systems.

A. Rock Penetration Mechanics

THERMAL RESPONSE OF POLYCRYSTALLINE DIAMOND COMPACT CUTTERS UNDER SIMULATED DOWNHOLE CONDITIONS (SAND83-0489), D. A. Glowka and C. M. Stone, Sandia National Laboratories, APE Journal 4/85 pp. 143-156.

An analytical method is developed to predict temperatures in polycrystalline diamond compact (PDC) drag cutters under steady-state and transient downhole conditions. The method is used to determine mean wearflat temperatures for cutters under conditions used in previous experiments to measure cutter wear. A correlation between wearflat temperatures and cutter wear rates is demonstrated, and it is shown that, for the particular rock type tested, cutter wear rates increase significantly above 350°C (662°F). The concept of a critical weight on bit, above which wearflat temperatures exceed this value, is introduced. The effects of several parameters on the critical WOB are examined. These include cutter thermal conductivity, diamond layer thickness, rock properties, convective cooling, bit balling, and transient events such as bit bounce. Preliminary results of thermal stress modeling show that plastic yielding of the cutter structure can occur under certain downhole conditions.

PROGRAM FOR THE IMPROVEMENT OF DOWNHOLE DRILLING MOTORS (SAND83-0130), J. T. Finger, Sandia National Laboratories.

This report describes the work done under contract to Sandia National Labs and to the Department of Energy for improvement of downhole drilling motors. The focus of this program was the development of a better bearing-and-seal assembly that could be used in different kinds of drilling motors in a geothermal environment. Major tasks were: (1) design and construction of seal testing devices, (2) screening and evaluation of candidate seals in a simulated bearing/seal package, (3) tests of the most promising candidates in a full-scale bearing/seal package, and (4) analysis of failed seals after testing. The key results from this program were: (1) identification of seal/shaft/lubricant systems that performed well at high pressure and temperature, (2) identification of other seal designs that should be avoided for similar applications, and (3) evaluation of the test machines' design.

INVESTIGATION OF PERCUSSION DRILLS FOR GEOTHERMAL APPLICATIONS (SAND83-2610J), J. T. Finger, Sandia National Laboratories, Journal of Petroleum Technology.

A series of tests were conducted to provide data for an economic evaluation of percussion drilling in geothermal reservoirs. Penetration rate, operation on aqueous foam, and high temperature vulnerabilities of downhole percussion tools are described.

EFFECTS OF THERMAL AND MECHANICAL LOADING ON PDC BIT LIFE (SAND84-0316C), D. A. Glowka and C. M. Stone, Sandia National Laboratories, Society of Petroleum Engineers Annual Meeting, Houston, TX, September 16-19, 1984.

The results of numerical analyses conducted to determine the effects of thermal and mechanical loading on the integrity of polycrystalline diamond compact (PDC) cutters during deep hole drilling are presented. Cutter temperature distributions for several drilling environments are combined with appropriate mechanical cutting loads to predict stress distributions for the study of cutter wear mechanisms. A discussion of wear mechanisms acting on the cutting structure is presented. Suggestions are presented, based on these analyses, for the operation of PDC bits to increase bit life in hard, abrasive rock drilling. Microstructural design considerations for the cemented carbide that supports the diamond layer are also discussed.

THERMAL LIMITATIONS ON THE USE OF PDC BITS IN GEOTHERMAL DRILLING (SAND84-0757C), D. A. Glowka, Sandia National Laboratories, Transactions of the 1984 Annual Meeting of the Geothermal Resources Council (Vol. 8. August 1984, pp. 261-266), Reno, NV, August 26-29, 1984.

Factors affecting the potential for using polycrystalline diamond compact (PDC) drill bits in geothermal drilling are discussed. Pertinent results from previous laboratory and field tests are reviewed. The two predominant failure mechanisms, abrasive cutter wear and catastrophic loss of cutters, are discussed. A temperature-activated mechanism for accelerating cutter wear is identified, and the implications for hard-rock drilling are investigated. An upper bound on drillable rock strength without causing thermally accelerated wear is established for a variety of operating and environmental conditions.

THE EFFECTS OF BINDER THICKNESS AND RESIDUAL STRESSES ON THE FRACTURE TOUGHNESS OF CEMENTED CARBIDES (SAND84-7127C), R. A. Cutler, Terra Tek under contract to Sandia National Laboratories, American Ceramic Society, Annual Mtg., Pittsburgh, PA, May 2, 1984.

Much of the data on WC-Co cermets shows that the fracture toughness increases with increasing WC grain size at fixed

volume fraction of the Co binder phase. It is shown that the origin of this effect can be explained based on the plane stress fracture of constrained Co phase and based on the periodic internal stresses arising due to differential thermal contraction of the two phases. The effect of macroscopic residual stresses, such as those generated by milling WC-Co inserts, on the apparent toughness has also been analyzed. It is shown that for the short-rod type specimen the macroscopic stresses not only affect the maximum load but also the length of the crack at which the maximum occurs.

ANALYTICAL AND EXPERIMENTAL STUDY OF THE ACOUSTICS AND THE FLOW FIELD CHARACTERISTICS OF CAVITATING SELF-RESONATING WATER JETS (SAND84-7142), G. L. Chahine, P. F. Genoux, V. E. Johnson, Jr., and G. S. Frederick, Tracor Hydronautics under contract to Sandia National Laboratories.

Water jet nozzles (STRATOJETS) have been developed which achieve passive structuring of submerged cavitating jets into discrete ring vortices, and which possess cavitation incipient numbers six times higher than obtained with conventional cavitating jet nozzles. In this study we developed analytical and numerical techniques and conducted experimental work to gain an understanding of the basic phenomena involved. The achievements are:

1. A thorough analysis of the acoustic dynamics of the feed pipe to the nozzle;
2. A theory for bubble ring growth and collapse;
3. A numerical model for jet simulation;
4. An experimental observation and analysis of candidate second-generation, low-sigma STRATOJETS.

From this study we can conclude that intensification of the bubble ring collapse and design of highly resonant feed tubes can lead to improved drilling rates. The models here described are excellent tools to analyze the various parameters needed for STRATOJET optimizations. Further analysis is needed to introduce such important factors as viscosity, nozzle-jet interaction, and ring-target interaction, and to develop the jet simulation model to describe the important fine details of the flow field at the nozzle exit.

IMPLICATIONS OF THERMAL WEAR PHENOMENA FOR PDC BIT DESIGN AND OPERATION (SAND85-0389C), D. A. Glowka, Sandia National Laboratories, Society of Petroleum Engineers 60th Annual Technical Conference and Exhibition, Las Vegas, NV, September 22-25, 1985.

Previous work has suggested that a thermal phenomena can greatly accelerate the wear of polycrystalline diamond compact (PDC) drag cutters under certain conditions. In this paper, the implications of that finding for PDC bit design and operations are examined. An abrasive wear model for cutters is developed and applied to rotary drilling applications to demonstrate the significance of thermally-accelerated wear on bit life. Under conditions where thermal effects are not important, it is concluded that in order to maximize bit life, greater bit weights and lower rotary speeds are preferable over shallow cuts and high speeds. It is found that even under normal abrasive wear conditions, a PDC cutter develops a significant wearflat before one-half its useful life is expended, suggesting that PDC bits should be designed to operate effectively in the worn condition. A cutter placement criterion is presented for designing bits for equal cutter wear. Through analysis of new experimental data, a technique is developed for approximating cutter penetrating forces in the presence of cutter interactions on a bit face and for estimating relative cutter wear. A hypothetical bit designed for equal rock removal volume per cutter is examined to determine the relationship between the equal volume and equal wear criteria for cutter placement. The complex role of thermal wear phenomena in this relationship is also examined for the hypothetical bit in three different rock types.

ROCK BREAKAGE MECHANISMS WITH A PDC CUTTER (SAND85-0443A), D. H. Zeuch and J. T. Finger, Sandia National Laboratories, Society of Petroleum Engineers 60th Annual Technical Conference and Exhibition, Las Vegas, NV, September 22-25, 1985.

The objective of this work was to study the petrographic and fractographic results of passing a single PDC drag-bit cutter through different kinds of rock. These examinations of chip morphology and fracture patterns in the rock have led to a new interpretation of the chip formation mechanism and the stress field induced in the rock by the cutter. Another aspect of this work is an assessment of the effect of predamaged rock on the required cutting forces.

All the rock chip samples used in these studies were collected from a series of experiments performed on a modified milling machine that had a force-instrumented PDC cutter in the tool holder and that traversed the rock past the cutter with the mill table. Other supporting data were comprised of cutter force measurements, thin and polished sections of the cut rock, and sieve size analyses of the cuttings.

The principal conclusions were (1) chip morphologies were quite similar for markedly different rock types, implying that chip formation mechanisms were uniform, (2) cracks in the rock nucleate somewhat in advance of the cutter tip, and (3) predamaged rock does not differ greatly in required cutting force from virgin rock. These results have implications for bit design and for theoretical models of rock breakage.

DESIGN CONSIDERATIONS FOR A HARD-ROCK PDC DRILL BIT (SAND85-0666C), D. A. Glowka, Sandia National Laboratories, Transactions of 1985 Annual Meeting of Geothermal Resources Council, Vol. 9, Part I, August 1985.

This paper discusses the potential for developing a polycrystalline diamond compact (PDC) drill bit for hard-rock applications such as geothermal drilling. It is concluded that in order to use the inherently efficient drag cutting process in such severe applications, measures must be taken to reduce cutter penetrating forces in order to prevent thermally accelerated cutter wear and thereby improve bit life. A procedure is developed for determining the conditions under which waterjets can be effectively used for this purpose by directing them at the rock surface ahead of individual cutters. It is concluded that hard rocks with compressive strengths as high as 30 kpsi (200 MPa) may be drillable with a hybrid PDC/waterjet bit using pressures that conventional oil field pumping technology is capable of providing. Extremely hard rocks might be drilled with such a bit using nozzle pressures well below those required to effectively cut the rock with waterjets alone.

ROCK BREAKAGE MECHANISMS WITH A PDC CUTTER (SAND85-1439C), D. H. Zeuch and J. T. Finger, Sandia National Laboratories, Society of Petroleum Engineers Annual Technical Conference, Las Vegas, NV, September 22-25, 1985.

Some aspects of chip generation by a polycrystalline diamond compact (PDC) cutter moving through a rock can be understood by examining the shapes of the chips and the fracture patterns in the remaining rock. Data from laboratory experiments have led to general conclusions about the uniformity of chip generation mechanisms in different kinds of rock and about crack nucleation position relative to the cutter tip.

B. Fluid Technology

FOAM DRAINAGE (SAND84-0844), A. M. Kraynik, Sandia National Laboratories

Transient drainage from a column of persistent foam has been analyzed theoretically. Gravity-driven flow was assumed to occur through an interconnected network of Plateau borders that define the edges of foam cells taken to be regular pentagonal dodecahedrons. A small liquid volume fraction and monodisperse cell size distribution were assumed. In the basic model, it is assumed that all liquid is contained in Plateau borders that are bonded by rigid gas-liquid interfaces. The predicted half life, the time required for one half of the liquid to drain from the foam, is inversely proportional to the square of the cell diameter, illustrating the importance of foam structure in drainage. Liquid hold up in the films separating adjacent cells, nonuniform initial liquid volume fraction distribution and interfacial mobility are explored. Border suction due to reduced pressure in the Plateau borders provides a mechanism for film drainage. Simultaneous film drainage and flow through the Plateau borders are analyzed. Sufficient conditions for neglecting film drainage kinetics are obtained. The results indicate that improved foam stability is related to small cells, liquid hold up in the films and slow film drainage kinetics.

ADVANCED WELLBORE THERMAL SIMULATOR GEOTEMP2 USER MANUAL, (SAND84-0857), L. A. Mondy and L. E. Duda, Sandia National Laboratories.

GEOTEMP2 is a wellbore thermal simulator computer code designed for geothermal drilling and production applications. The code treats natural and forced convection and conduction within the wellbore and heat conduction within the surrounding rock matrix. A variety of well operations can be modeled including injection, production, forward, and reverse circulation with gas or liquid, gas or liquid drilling, and two-phase steam injection and production. Well completion with several different casing sizes and cement intervals can be modeled. The code allows variables such as flow rate to change with time enabling a realistic treatment of well operations.

This user manual describes the input required to properly operate the code. Ten sample problems are included which illustrate all the code options. Complete listing of the code and the output of each sample problem are provided.

COMPUTER SIMULATION OF THE COOLING EFFECT DUE TO CIRCULATION
(SAND84-1589), L. E. Duda, Sandia National Laboratories.

Computer calculations of wellbore transient temperatures, using the geothermal wellbore thermal simulator code GEOTEMP2, were made on four well models. The well models studied were from the Baca geothermal area, the East Mesa geothermal area, and a shallow and a deep well from the Salton Sea geothermal area. Calculations for one day of water circulation followed by one day of shut-in at flow rates of 100 gpm, 250 gpm, 500 gpm, and 1000 gpm were made to investigate the cooling effects produced by the circulation. Additional calculations were made using the Baca and Salton Sea well models. In the former, the effect on the cooling due to different soil thermal conductivity values and different circulating fluids (a high viscosity mud and air) was investigated. In the latter, the number of casings in the wellbore and the diameter of the tubing were modified. Plots of the calculated temperatures as a function of circulation and shut-in time and depth are given for each case.

Some conclusions which may be drawn are:

- o Low flow rates, on the order of 100 gpm or less, are particularly ineffective at cooling the wellbore.
- o Low soil thermal conductivity values produce lower wellbore temperatures.
- o High viscosity fluids, such as drilling muds, give lower wellbore temperatures.
- o Air or gasses are ineffective as a cooling fluid.
- o For a purely conductive environment (i.e., no fluid convection into the rock formation), temperatures tend to recover quickly following circulation. Mean temperatures are reached 3-5 hours following shut-in.
- o Downhole temperatures are not directly proportional to circulation time.
- o The shape of the undisturbed temperature profile has a significant effect upon the downhole temperatures.
- o An increased fluid velocity in the tubing tends to decrease the downhole temperatures in the wellbore.

COMPUTER SIMULATION OF WELLBORE COOLING BY CIRCULATION AND INJECTION (SAND84-1922C), L. E. Duda, Sandia National Laboratories, Proceedings of the Tenth Annual Workshop Geothermal Reservoir Engineering, Stanford, CA, January 22-25, 1985.

The high temperatures existing within a geothermal well preclude the use of most logging instrumentation which is necessary to study the wellbore and surrounding rock matrix. Possible solutions to this problem include cooling the wellbore and the surrounding rock by circulating fluid in the wellbore and by injecting fluid directly into the rock matrix. The latter method, however, is not preferred since it contaminates the formation a considerable distance from the wellbore. The potential cooling effects of both these methods are investigated using the computer code, GEOTEMP2, which simulates heat transfer from the wellbore to the surrounding rock formation. Two different wells from the Salton Sea Known Geothermal Resource Area (KGRA) are simulated. The first is a shallow, hot well having a depth of 1400 m and a bottom hole temperature of 330°C. The second is a deep well of depth greater than 3000 m and a bottom hole temperature of 380°C. Circulation of several different fluids for one day at flow rates of 16, 32, 47, and 63 l/s, followed by a shut-in period, is simulated to study the effect of different fluid properties and flow rates. Also, the temperatures obtained by using two different flow rates, each for one day, are compared to the temperature found when using only the lower flow rates. Finally, the temperature recovery in the wellbore is investigated when fluid injection occurs at the bottom of the hole.

Heat conduction is the only heat transfer mechanism considered to warm the wellbore. Following steady-rate circulation, the wellbore temperatures were found to warm quickly after shut-in, approaching the undisturbed formation temperature within one day. Temperature recovery had a half-life on the order of six hours. Furthermore, the use of a higher initial flow rate did not significantly reduce the temperatures below those for the lower flow rate alone. Injecting fluid a relatively short distance into the formation was found to substantially decrease the rate of warming in the wellbore following injection.

COMPUTER SIMULATION OF THE COOLING EFFECT DUE TO CIRCULATION IN SOME SELECTED GEOTHERMAL WELLS (SAND84-2211A), L. E. Duda, Sandia National Laboratories.

Computer calculations of wellbore transient temperatures, using the geothermal wellbore thermal simulator code GEOTEMP2, were made on selected well models from the Baca, East Mesa, and Salton Sea geothermal areas. Calculations for one day of fluid

circulation using flow rates of 100, 250, 500, and 1000 gpm followed by shut-in of the well were made to study the cooling effect produced by the fluid circulation. The effect of different soil thermal conductivities and fluid viscosities were investigated. Low flow rates, on the order of 100 gpm or less, were found to be very ineffective at cooling the wellbore. Low values of the soil thermal conductivity and high fluid viscosities were found to produce lower wellbore temperatures. For a purely conductive environment (i.e., no fluid convection in the rock formation) temperatures tend to recover quickly following circulation reaching a mean temperature within 3-5 hours following shut-in.

FACTORS AFFECTING THE BEHAVIOR OF BENTONITE FLUIDS AND THEIR IN-SITU CONVERSION INTO CEMENT (SAND84-7170), N. Guven, L. L. Garney, F. Malekhamadi, and L. J. Lee, Texas Tech University.

Bentonite is the common viscosifier and fluid loss control additive in water base drilling fluids. Bentonite, however, creates its own problem due to gelation at high temperatures while drilling, completing, or cementing deep oil and gas wells or geothermal wells. Furthermore mud contamination from the formation solids and formation fluids may also affect the performance of bentonite muds. It is therefore rather important to develop a basic understanding of the effects of common salts, hydroxides, and other mud additives on the rheology and other functions of bentonite fluids. For this purpose, bentonite fluids containing these additives were autoclaved at the temperature range 70 to 600°F, and under a pressure of 17,000 psi. Subsequently, the high-temperature rheology of the fluids was measured with a FANN 50C viscometer. Other fluid properties such as plastic viscosity, gel strength, yield point, pH, CEC, and fluid losses were also determined before and after autoclaving of the fluids. The high-temperature reactions occurring in these fluids were studied with x-ray diffraction and electron microscopy.

A pure Na-bentonite fluid becomes highly viscous in the temperature range 260-450°F, leading to the gelation of the fluid when bentonite concentration reaches about 4% in the fluid. The addition of low molecular weight polymers seems to control the viscosity only in the limited temperature range 300-400°F, but not at higher temperatures. NaCl or NaOH at 1% concentration in the fluid tremendously increases the "osotic" swelling of the bentonite and hence increases the fluid viscosity to undesirably high values. Potassium salts and hydroxide effectively control the fluid gelation at high temperatures by promoting the conversion of (swelling) smectite in the fluid to a (less-swelling) phase of illite/smectite mixed-layers. Salts

and hydroxide of calcium depress the fluid visocisity at all temperatures.

Another costly problem in drilling technology is related to the poor cement bonding of the casing to the formation. As a solution to this troublesome situation, the in-situ conversion of bentonite fluids into cement has been studied. This conversion of bentonite fluids into cement has been studied. This conversion has been successffully achieved by the addition of lime to bentonite fluids at above 300°F.

The addition of lime increases the fluid pH and promotes the high-temperature reaction between lime and smectite. Consequently, tobermorite, which is a cement mineral, precipitates in the fluid. The addition of free silica to the bentonite/lime fluids does not increase the rate of tobermorite precipitation. The addition of CaCl_2 , however, to the bentonite/lime fluid enhances the in-situ formation of cement minerals in bentonite fluids. The addition of magnesia proves to be detrimental both to the cement conversion and to the rheology of the fluid but it provides a buffer for maintaining high pH in the fluid. Lignosulfonates do not seem to cause any noticeable retardation of the cement reaction in bentonite/lime fluids.

INVESTIGATION OF WELLBORE COOLING BY CIRCULATION AND FLUID PENETRATION INTO THE FORMATION USING A WELLBORE THERMAL SIMULATOR COMPUTER CODE (SAND85-0651C), L. E. Duda, Sandia National Laboratories, Transactions of the Geothermal Resources Council 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.

The high temperatures of geothermal wells present severe problems for drilling, logging, and developing these reservoirs. Cooling the wellbore is perhaps the most common method to solve these problems. However, it is usually not clear what may be the most effective wellbore cooling mechanism for the given well. In this paper, wellbore cooling by the use of circulation or by fluid injection into the surrounding rock is investigated using a wellbore thermal simulator computer code. Short circulation times offer no prolonged cooling of fluid in the wellbore, but long circulation times (greater than ten or twenty days) greatly reduce the warming rate after shut-in. The dependence of the warming rate on the penetration distance of cooler temperatures into the rock formation (as by fluid injection) is investigated. Penetration distances of greater than 0.6 m appear to offer a substantial reduction in the warming rate. Several plots are shown which demonstrate these effects.

DEVELOPMENT OF SEALS FOR A GEOTHERMAL DOWNHOLE INTENSIFIER--A PROGRESS REPORT (SAND85-0849C), K. M. Captain and A. C. Harvey, Foster-Miller, Inc., and B. C. Caskey, Sandia National Laboratories, GRC Transactions, 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.

A system using high-velocity fluid jets in conjunction with a rotary diamond bit is currently considered as the best candidate for reducing the cost of drilling geothermal wells. Technical, safety, and cost considerations indicate that the required jet supply pressure can best be established by a down-hole pressure intensifier. Key intensifier components are the check valve and plunger seals, which must prevent leakage of the high-pressure, high-temperature abrasive fluid (drilling mud). To achieve the required performance, novel ceramic seals are currently being developed. The check valve seal includes a tapered polymeric plug and ceramic stop acting against a ceramic seat. The ceramic plunger seal is a variant of the "stepped-joint" piston ring and is designed to minimize contact pressure and abrasive wear. Initial testing of these seals in the laboratory shows encouraging results; design refinement and further testing is in progress.

C. Borehole Mechanics

GEODYN - A GEOLOGICAL FORMATION/DRILL STRING DYNAMICS COMPUTER PROGRAM (SAND84-0314C), B. C. Caskey and C. M. Stone, Sandia National Laboratories, Proceedings Society of Petroleum Engineers 59th Annual Technical Conference & Exhibit, Houston, TX, September 16-19, 1984.

This paper describes a computer program, called GEODYN, developed to simulate the dynamic interaction behavior of a rotating PDC bit and the downhole formation. The developmental effort was motivated by a desire to better understand the drilling process. The modeling capabilities provided by GEODYN are illustrated in the paper. GEODYN models the 3-dimensional physical and numerical complexities arising from the intermittent, nonlinear interaction between PDC cutters and the downhole formation. As such, GEODYN supports the modeling of an irregular wellbore formation topology and material characterization. It utilizes distinct, individual PDC cutter definitions to facilitate the description of cutter contact, variable cutter-formation penetration, and selective cutter removal. These effects may be simulated for different user-defined upstring boundary constraint and load histories. The solution procedures (i.e., time step size, convergence criteria, etc.) are controlled in an interactive manner by the user. Significant analytical modeling flexibility is possible, and is obtained in a very efficient manner by employing a model superposition reduction scheme to the bit-drill string finite element model. Further efficiency has been obtained within the formation model by the elimination of an extensive formation point search to ascertain the cutter penetration position. GEODYN, and the analytical techniques themselves, have been verified via a series of experimental qualification tests. The predicted response obtained from GEODYN for a series of illustrative examples is provided in the paper to demonstrate the modeling flexibility obtainable. Ongoing developments, supported by continued experimental qualification testing, will result in the ability to simulate transient dynamic bottom hole assembly behavior.

ANALYZING THE DYNAMIC BEHAVIOR OF DOWNHOLE EQUIPMENT DURING DRILLING (SAND84-0758C), J. A. Baird, Jordan, Apostol, Ritter Assoc., Inc. and B. C. Caskey, Sandia National Laboratories, Transactions of 1984 Annual Meeting of Geothermal Resources Council (Vol. 8, August 1984, pp. 243-247), Reno, NV, August 26-29, 1984.

Advanced geothermal drilling systems will require a bottom hole assembly (BHA) which utilizes sophisticated electronic and

mechanical equipment to accomplish faster, more trouble-free, "smarter" drilling. The bit-drill string/formation interaction during drilling imposes complex, intermittent dynamic loading on the downhole equipment. A finite element computer code, GEODYN, is being developed to allow analysis of the structural response of the downhole equipment during drilling and to simulate the drilling phenomena (i.e., penetration, direction, etc.). Phase 1 GEODYN, completed early in 1984, provides the capability to model the dynamic response of a polycrystalline diamond compact (PDC) bit interacting with a nonhomogeneous formation. Succeeding development phases will allow inclusion of stabilizers and, eventually, the entire drill string in addition to facilitating drill ahead simulation.

LOST CIRCULATION TECHNOLOGY WORKSHOP (SAND85-0109), B. C. Caskey, Editor, Sandia National Laboratories, October 9-10, 1984.

This report summarizes the presentations and discussions of a workshop on lost circulation technology, sponsored by Sandia National Laboratories under the auspices of the U.S. Department of Energy. The workshop identified and defined lost circulation problem areas in field operations, materials, mud effects, and standards. Problem solution needs were also categorized as requiring analytical evaluation and procedure, instrument, and material development.

PLUGGING MECHANISMS IN A LOST CIRCULATION MODEL (SAND85-0316C), R. D. Givler, Sandia National Laboratories, Transactions, Vol. 9, Part 1, August 1985.

The problem of lost circulation during the drilling of geothermal wells is recognized to be a serious impediment to well completion. A viable solution, in terms of an "engineered" plugging material, will be enhanced via analytical cognizance of possible down-hole plugging mechanisms. This paper investigates several plugging strategies that result from rudimentary, mathematical models of the mud rheology (with and without dispersed particulate). Moreover, this analytical modeling effort serves to augment the current experimental research at the Lost Circulation Test Facility of Sandia National Laboratories (Loeppke and Caskey, 1983).

EFFECTS OF ARTIFICIAL FRACTURE GEOMETRY ON GEOTHERMAL WELL PRODUCTION (SAND85-0571C), D. A. Glowka, Sandia National Laboratories, Geothermal Resources Council Annual Meeting, August 26-30, 1985, Kailua-Kona, Hawaii.

This paper examines the effects of various artificial and natural fracture systems on geothermal well productivity. Two-dimensional finite element porous flow computer models are constructed and exercised under a variety of conditions. The model is verified for a planar fracture system created with hydraulic stimulation by comparing the results with an analytical solution. It is confirmed that fractures that penetrate deeply into the formation are needed to significantly improve well productivity in low-permeability matrix formations. In high-permeability matrix or fractured formations, multiple artificial fractures of even limited length are more effective. This is particularly true for reservoirs that contain large, highly conductive natural fractures that the wellbore passes near but fails to penetrate. These results demonstrate that a stimulation technique capable of producing multiple fractures may be beneficial to geothermal well production.

QUALIFICATION OF A COMPUTER PROGRAM FOR DRILL STRING DYNAMICS, (SAND85-0633C), C. M. Stone, T. G. Carne, and B. C. Caskey, Sandia National Laboratories, Transactions of the Geothermal Resources Council 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.

A four point plan for the qualification of the GEODYN drill string dynamics computer program is described. The qualification plan investigates both modal response and transient response of a short drill string subjected to simulated cutting loads applied through a polycrystalline diamond compact (PDC) bit. The experimentally based qualification shows that the analytical techniques included in Phase 1 GEODYN correctly simulate the dynamic response of the bit-drill string system.

LOST CIRCULATION IN GEOTHERMAL WELLS: RESEARCH AND DEVELOPMENT STATUS (SAND85-0783C), B. C. Caskey, Sandia National Laboratories and J. V. Satrape, Meridian Corporation, Transactions of the Geothermal Resources Council 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.

The most common severe problems encountered in drilling and completing geothermal wells are lost circulation (loss of fluid returns in the surface), stuck pipe, and inadequate cementing. Lost circulation is the single most costly and troublesome well development problem; it may also cause or aggravate stuck pipe and cementing problems. Sandia National Laboratories is conducting an aggressive research and development program aimed at understanding and solving lost circulation problems. The program is aimed at finding and characterizing loss zones, modeling the dynamics of zone plugging, testing materials and techniques in the laboratory, and developing holistic solutions

for combating lost circulation. Significant work has been completed in instrumentation, materials testing, and numerical modeling. Work devising an "expert" system for fluid loss control has begun.

SELF-CONTAINED RIGID-FOAM PLACEMENT TOOL FOR PLUGGING LOST-CIRCULATION ZONES (SAND85-0937C), G. Polk, NL Baroid/NL Industries, K. Baughman, Poly Plug, Inc., and G. E. Loeppke, Sandia National Laboratories, Transactions of the Geothermal Resources Council 1985 International Symposium on Geothermal Energy (Vol. 9, Pt. I, August 1985, pp. 141-145), Kona, Hawaii, August 26-30, 1985.

A solution to the lost-circulation problem in well-drilling operations has been sought for years without establishing a universally satisfactory technique or material. Recently, laboratory investigations of polyurethane foams examined their potential for plugging loss zones in geothermal wells. The data from these tests indicated that rigid foams with excellent properties for use in plugging operations could be produced under geothermal conditions. Subsequently, a concept for a family of tools for in-hole mixing and placement of rigid foams was designed; and in 1984, a prototype tool was fabricated and successfully demonstrated. After the demonstration, specifications were established for a field prototype tool for use in geothermal wells along with the development of suitable high-temperature chemical formulations. Field application of the tool began in a Known Geothermal Resource Area in the Spring of 1985.

DESIGN AND EVALUATION OF LOST CIRCULATION MATERIALS FOR HIGH TEMPERATURE APPLICATIONS (SAND85-1485A), G. E. Loeppke and B. C. Caskey, Sandia National Laboratories, IADC/SPE 1986 Drilling Conference, Dallas, TX, February 10-12, 1985.

Sandia National Laboratories is actively involved in research leading to the solution of lost circulation problems for the geothermal drilling community. To this end, a large-scale Lost Circulation Test Facility (LCFT) has been built to evaluate candidate lost circulation materials capable of withstanding the pressures and high temperatures of the most severe drilling applications. New materials are being developed, evaluated, and compared in performance to some established lost circulation materials.

Laboratory screening tests (e.g. Section 7b of API RP 13I) are run to select promising materials which are then evaluated in the large facility which can provide cross-flow pumping veloci-

ties up to 200 feet per minute in an 8-inch o.d. simulated wellbore annulus, differential formation pressure up to 100 psi, and temperature to 400°F. The CTF, a much more powerful tool for lost circulation material evaluation than has been available heretofore, shows some substantially different test results compared to those from the recommended practice of API RP 13I.

Data will be presented on materials that have been tested and new material formulations that are being designed and evaluated in the LCTF for use as drilling additives where the most severe and troublesome lost circulation problems occur.

GEODYN2: A BOTTOM HOLE ASSEMBLY - GEOLOGICAL FORMATION DYNAMIC INTERACTION COMPUTER PROGRAM (SAND85-1604C), J. A. Baird, Jordan Apostol, Ritter Assoc., B. C. Caskey, Sandia National Laboratories, D. N. Wormley, Massachusetts Institute of Technology, and C. M. Stone, Sandia National Laboratories, Society of Petroleum Engineers Annual Technical Conference and Exhibition, Las Vegas, NV, September 22-25, 1985.

This paper describes the current development of the three-dimensional transient dynamic finite element computer program, GEODYN2, capable of simulating the behavior of a rotating bottom hole assembly (BHA) interacting with a non-uniform formation. The GEODYN2 Program facilitates a very detailed analysis/simulation of the behavior of a BHA with a polycrystalline diamond compact (PDC) bit and various stabilizer designs. The basic drill string mechanics implemented within the program, the overall algorithm, and the more pertinent modeling features which permit this level of analysis are briefly outlined. The implementation of these features and how they allow calculation of the response behavior of the bottom hole assembly are demonstrated. Although the development and enhancement of modeling capabilities within GEODYN2 is ongoing, it is anticipated that the preliminary verification results thus far generated will further the understanding of the response behavior of BHAs.

D. Diagnostic Technology

A HIGH-TEMPERATURE PROTOTYPE INSTRUMENT FOR DOWNHOLE ACOUSTIC SENSING (SAND-82-2893J), H.-T. Chang, Sandia National Laboratories.

This paper presents the design for an acoustic instrument which can operate at frequencies of 10-40 kHz and temperatures up to 250°C. It first introduces a high-temperature circuit using Sandia's Sprytron witching tube and an over-voltage gap. Next, the high-temperature performance of a 2-V Permendur magnetostrictive transducer (for the transmitter), and a piezoelectric material (for the receiver) is described. The problems encountered and the corresponding solutions are revealed. The design of an acoustic isolator and the mechanical housing of this instrument are presented.

FIELD PATTERNS FOR ANTENNAS SITUATED IN A SIMULATED BOREHOLE (SAND83-2673A), L. D. Scott, Mission Research Corporation and H.-T. Chang, Sandia National Laboratories, 1984 International IEEE/AP-S Symposium and National Radio Science Meeting, Boston, MA, June 25-29, 1984.

The need for improved detection range and directional resolution for pulsed electromagnetic radar type downhole probes can be satisfied by the construction of simple antennas optimized to produce the narrowest beam widths and the lowest side lobes while being designed to physically fit within the confines dictated by the borehole diameter. Until now, no measurements have been reported of the field patterns for the eccentrically located dipole or monopole within a high dielectric constant media. However, Lytle and Laine have made theoretical predictions.

The reasons for selecting a high dielectric constant media within the confines of the borehole are twofold. First, the borehole is likely to be filled, at depths of primary interest, with water (high relative dielectric constant, ~80), hence to minimize the number of discontinuities traversed by the radar pulse the antenna should be immersed in a similar dielectric constant media. Secondly, a directional antenna design is enhanced by the electrical length shortening factor afforded by the antenna immersed in the media. To effectively control an antenna array pattern, separation distances on the order of element lengths are needed. The presence of water then, as the dielectric in which the array elements are immersed, permits a relatively higher gain (improved directional) antenna to be designed within the confines of a water or brine-filled borehole with minimal electrical discontinuities to scatter the radar energy.

DEVELOPMENT OF A BOREHOLE DIRECTIONAL ANTENNA AT VHF
(SAND84-0254), H.-T. Chang, Sandia National Laboratories, and
L. D. Scott, Mission Research Corp.

This report investigates the feasibility of constructing a directional VHF (30 MHz to 300 MHz) antenna to physically fit into a small borehole. The study was carried out in a test chamber containing a 15-cm-diameter borehole surrounded by sand which can be moistened with water or brine to adjust the dielectric constant and electrical conductivity. Electric field measurements were made for an eccentrically positioned monopole, a corner reflector, and a two-element array for a number of possible configurations. Using an eccentric monopole, the best beamwidth obtained was 78° and the front-to-back ratio was 3.5 db. The front-to-back ratio was increased to 8.5 db when two element arrays were arranged in such a way as to provide the optimum radiation pattern. However, the best results were achieved using a corner reflector; 60° beamwidth and 13 db front-to-back ratio. It is concluded that a directional VHF antenna can be designed for downhole application.

EVALUATION OF BOREHOLE ELECTROMAGNETIC AND SEISMIC DETECTION OF FRACTURE (SAND84-7109), S. A. Suhler, Southwest Research Institute.

The conduction of hot fluids into geothermal wells is, at least, partially dependent upon the presence of natural or artificially induced fractures in the geothermally active rock matrix. Because of the very high cost of drilling and fracturing in geothermal areas, it is economically critical that techniques for detecting natural or induced fractures be developed. A very desirable technique for detecting and locating such fractures is one which employs a borehole probe operating from within a single drill hole. In this Final Technical Report, two candidate fracture detection techniques were evaluated. Both techniques employ propagating wave energy and rely on reflections from the fractures for detection purposes.

One of the methods is a pulsed-echo electromagnetic technique in which an electromagnetic pulse is launched into the drilled formation from a borehole probe by means of a directional transmitting antenna at the depth of interest in the hole. Reflections from fractures or other geologic structures which exhibit a contrast in electromagnetic properties are detected by a receiving antenna in the same probe. The second method evaluated is a borehole seismic reflection technique in which a seismic impulse is launched into the formation and reflections from regions of contrasting elastic wave impedance are detected. With either technique, distance to the reflecting

anomaly from the probe is determined from the two-way pulse travel time between the probe and the target and the known propagation velocity of the host medium. The reflection signal waveforms provide unique information regarding the size, shape, and character of the reflector.

The reported evaluation tests were performed using probe systems developed by Southwest Research Institute for the U.S. Bureau of Mines and for the U.S. Army. These systems are basically geotechnical probes intended for use in shallow (1000 feet or less) vertical or horizontal boreholes.

To exhibit the use of these available probe systems in a minimum-cost, preliminary evaluation experiment, a test site was sought that would provide an idealized target simulating a vertical planar fracture. The test site selected for this purpose was a granite quarry near Marble Falls, Texas. After preliminary measurements of the seismic and electromagnetic properties of the granite were performed, five vertical test boreholes were drilled into the granite. Probe system output signals were recorded during the field tests in which various combinations of probe configurations and target conditions were evaluated.

FEASIBILITY OF A BOREHOLE VHF RADAR TECHNIQUE FOR FRACTURE MAPPING (SAND84-0756C), H.-T. Chang, Sandia National Laboratories, Transactions of the 1984 Annual Meeting of Geothermal Resources Council (Vol. 8, August 1984, pp. 485-488), Reno, NV, August 26-29, 1984.

Experiments were conducted to establish the feasibility of a downhole high-frequency electromagnetic technique for location of fractures in the vicinity of boreholes. An existing flame-cut slot in granite was filled with salt water to simulate a brine-filled fracture. A transmitter consisting of a phased dual-dipole array arranged to provide a directional signal toward the fracture was installed in a borehole opposite the fracture. A receiver operated at 30 Mz to 300 MHz was also located in the same borehole. The radar returns from the simulated fracture were detectable in boreholes located at distances of up to 12 meters from the fracture. These results indicate for the first time the feasibility of a downhole VHF radar for use in a single borehole for detection of fractures located away from the borehole.

DOWNHOLE VHF RADAR TECHNIQUE FOR FRACTURE MAPPING (SAND85-0250A), H.-T. Chang, Sandia National Laboratories, Society of Petroleum Engineers 60th Annual Technical Conference and Exhibition, Las Vegas, NV, September 22-25, 1985.

Based on theoretical predictions, experiments were conducted to establish the feasibility of a downhole VHF radar technique for detecting fractures away from boreholes. An existing flame-cut slot in granite was filled with salt water to simulate a brine-filled fracture. A transmitter consisting of a phased dual-dipole array arranged to provide a directional signal toward the fracture was installed in a borehole opposite the fracture. A receiver operated at 30 to 300 MHz was also located in the same borehole. The radar returns from the simulated fracture were detectable in boreholes located at distances of up to 12 meters from the fracture. These results indicate for the first time the feasibility of a downhole VHF radar for use in a single borehole for detection of fractures located away from the borehole.

Engineering design for such a system has begun. Using avalanche transistors, the transmitter is able to deliver impulses with rise-time in the order of 1-2 ns and peak power up to 50 kW. In the receiver circuit, the signals are transformed from RF to audio frequencies, using sampling bridge, so that the signals can be transmitted uphole. The beam width of a directional antenna packed in a 20-cm-diameter housing in the preliminary design is about 100°. It appears that such a radar system can be designed to fit in a borehole. A simulated fracture facility will be established to test the signal returns under various thickness and orientation of the fractures.

A GEOTHERMAL LOST CIRCULATION ZONE MAPPING TOOL (SAND85-0646C), T. J. Bauman, Sandia National Laboratories, Transactions of the Geothermal Resources Council (Vol. 9, Pt. II, August 1985, pp. 431-436), 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.

Lost circulation is an expensive and often encountered problem when drilling into geothermal formations. A method is needed to more accurately describe loss zones encountered during geothermal drilling to allow for more realistic testing since preset testing techniques are inadequate. A Lost Circulation Zone Mapping Tool (LCZMT) is being developed that will quickly locate a loss zone and then provide a visual image of this zone as it intersects the wellbore. A modified Sandia high-temperature acoustic borehole televiwer should allow modeling of geothermal loss zones, which would in turn lead to testing that can be performed to evaluate lost circulation materials under simulated downhole conditions.

GEOHERMAL INSTRUMENTATION DEVELOPMENT ACTIVITIES AT SANDIA (SAND85-0647C), C. C. Carson, Sandia National Laboratories, Transactions of the Geothermal Resources Council (Vol. 9, Pt. II, August, 1985, pp. 447-450), 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.

A major element of Sandia's Geothermal Technology Development Program is the effort directed toward development of instrumentation. This effort has two aspects, the development of high-temperature components and prototype tools and the investigation of new concepts and capabilities. The focus of these activities is the acquisition of information to make geothermal drilling and resource development more efficient. Several projects of varying nature and scope make up the instrumentation development element, and this element will expand as the program emphasis on development of an advanced geothermal drilling system and the need for improved information grow.

FEASIBILITY OF AN ACOUSTIC TECHNIQUE FOR FRACTURE DETECTION (SAND85-0652C), H.-T. Chang, Sandia National Laboratories, Transactions of the Geothermal Resources Council 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.

A field experiment was conducted at a granite quarry to determine the feasibility of an acoustic, downhole technique for location of fractures in the vicinity of boreholes. The frequency used in this test was about 5 kHz; a frequency well above the seismic frequency commonly used in reservoir evaluations. An existing flame-cut slot in the granite at the test site was filled with water to simulate a fracture. A high-energy piezoelectric transmitter was located in a borehole 8 meters from the water-filled slot, and a commercial piezoelectric transducer was used as a receiver in a borehole 4 meters from the slot. Both transducers could be rotated for maximum transmission or reception for either the compressional wave or the shear wave. During the experiment, reflections from the simulated fracture were obtained with the transducers oriented only for shear wave illumination and detection. These test results suggest that a high-frequency shear wave can be used to detect fractures located away from a borehole.

CORRELATIONS AND LIMITATIONS OF SURFACE AND BOREHOLE ELECTRICAL MEASUREMENTS (SAND85-1070A), L. C. Bartel, Sandia National Laboratories, SEG Research Symposium on Logging Accuracy and Limitations for Exploration Purposes, Washington, DC, October 7, 1985.

Results from borehole electrical logging gives information over only the region adjacent to the borehole. Surface-to-borehole and surface electrical and electromagnetic (EM) techniques yield additional information about the geoelectric section away from the borehole and in areas not covered by boreholes. Unconstrained inversions of surface electrical EM data of ten results in an interpreted geoelectric section which deviates significantly from that determined as a result of geophysical logging. The use of borehole data to constrain, for example, the layered-earth inversions can lead to a more accurate interpretation. In this paper, unconstrained and constrained inversion of simulated, layered-earth magnetotelluric (including the audio-frequency range) field data will be discussed, along with a field example by other investigators. Two- and three-dimensional structure can affect electrical/EM measurements which can lead to a significant deviation from a layered-earth picture. Borehole data is important to provide information for the 2- and 3-D models for interpreting field data in the presence of structure. The resistivity structure and the layer thicknesses and depths are important information for interpretation models. The resistivities determined through borehole logging are strongly influenced by the drilling operation itself and in some cases the true, undisturbed formation resistivity may be difficult to determine. Surface data and/or surface-to-borehole data provide a "check" on the interpretation of the undisturbed formation resistivity as obtained from logging results.

LEAST SQUARES ANALYSIS OF UNCERTAIN DATA (SAND85-0991A), P. C. Lysne, Sandia National Laboratories, New Techniques in Scientific Well Logging Symposium, Palisades, NY, May 15-16, 1985.

Geophysical data are often uncertain, inaccurate and insufficient. One is then confronted with the scenario of making the most of the situation while producing justifiable results. An attack on this problem was presented by Lanczos(1) in 1961. It is not commonly used in the evaluation of log-related data.

Lanczos considered the linear least squares problem $Ax = b$ where A is a known $m \times n$ matrix and the vectors b and x are known and unknown, respectively. In cases of interest, there are more experiments than unknowns, i.e., $m > n$. This does not insure that all components of x may be determined, but an orthogonal decomposition of A will identify the strong components of x . These components follow from those experiments which are, within experimental error, linearly independent and they are the only components of x that may be uniquely determined. Nonlinear problems may be attacked

iteratively by local linearization. To illustrate Lanczos' method, the following two problems are considered.

The thermal neutron cross sections of rock matrix material influences the interpretation of neutron logs. To measure these cross sections, specimens were placed at $n = 6$ locations in a 40 watt reactor at the Idaho National Engineering Laboratory.(2) Together, thermal and higher energy absorption and scattering properties of specimens produce a linear perturbation in the system and thereby generate the elements of A. The essence of this experiment is to calibrate the reactor by using $m = 11$ materials whose properties for high energy neutrons are similar to those of rocks and whose thermal absorption properties, b, span the region of interest. Lanczos' method was used to establish that, of the six ports in the reactor, only four are experimentally independent and that these four are sufficient to perform the desired measurement task. Over 200 specimens have been processed, and the reactor technique is now routine.

In situ stress anisotropy in ductile rocks causes boreholes to assume a smooth, elliptical shape. Evaluation of the stresses follows from an accurate determination of, among other parameters, the eccentricity and orientation of the ellipse.(3) This latter information may be deduced from caliper data obtained from a televiwer. The non-linear, least squares data inversion process involves $n = 5$ parameters: the major and minor axes of the ellipse, the orientation of the ellipse with respect to North and the location of the televiwer in the hole. In extreme cases of eccentricity and/or televiwer off centering, signals are not returned from the entire perimeter of the hole. Sometimes this poses no problem and all unknowns may be determined. In other cases, even though m may still be large compared to n , Lanczos' technique demonstrates the data are insufficient. Example bounds for acceptable experiments are presented.

- (1) Lanczos, C.; Linear Differential Operators, D. Van Nostrand Co., 1961.
- (2) Harris, J. M. et al., "Thermal Neutron Absorption from Reactivity Measurements of Selected Geologic Materials," Proc. 24th Annual SPWLA Logging Symp., Calgary, 1983.
- (3) Blanton, T. L. and Teufel, L. W., "In Situ Stress Determination from Wellbore Elongation Measurements," to be presented at the SPE/DOE Symp. on Low Permeability Reservoirs, Denver, May 1985 (SPE/DOE Number 13877).

E. Permeability Enhancement

THE MAGMA ENERGY AND GEOTHERMAL PERMEABILITY/ENHANCEMENT PROGRAMS (SAND85-0230C), J. C. Dunn, Sandia National Laboratories, Proceedings of the Geothermal Program Review, Washington, DC, September 11-12, 1985.

The Magma Energy Extraction and Permeability Enhancement programs are both U.S. Department of Energy, Geothermal Technology Division, programs managed by Sandia National Laboratories. Project funding during FY85 was \$1.4 M for magma energy and \$650 K for permeability enhancement. Accomplishments during FY85 and project plans for FY86 are described for both programs.

EFFECTS OF ARTIFICIAL FRACTURE GEOMETRY ON GEOTHERMAL WELL PRODUCTION, D. A. Glowka, Sandia National Laboratories, Transactions of the 1985 Annual Meeting of Geothermal Resources Council, Vol. 9, Part II, August 1985.

This paper examines the effects of various artificial and natural fracture systems on geothermal well productivity. Two-dimensional finite element porous flow computer models are constructed and exercised under a variety of conditions. The model is verified for a planar fracture system created with hydraulic stimulation by comparing the results with an analytical solution. It is confirmed that fractures that penetrate deeply into the formation are needed to significantly improve well productivity in low-permeability matrix formations. In high-permeability matrix or fractured formations, multiple artificial fractures of even limited length are more effective. This is particularly true for reservoirs that contain large, highly conductive natural fractures that the wellbore passes near but fails to penetrate. These results demonstrate that a stimulation technique capable of producing multiple fractures may be beneficial to geothermal well production.

GEOTHERMAL WELL STIMULATION RESEARCH REPORT, prepared for Sandia National Laboratories by Santrol Products, Inc., Houston, TX, May 1985.

The purpose of Geothermal Well Stimulation is to commercialize the wells and to keep existing geothermal wells commercially productive. In the broadest sense, any workovers that help maintain and/or increase geothermal well productivity can be considered well stimulation treatments. This report sets out to investigate and evaluate what has been done in the past, look at new and current areas of technology and recommend

possible research projects or techniques which hold promise for improved geothermal resources.

To help solve geothermal well stimulation problems or plan for new programs there are many areas of technology which could help commercialize geothermal wells. The following areas should be given priority in funding and manpower assignments. Also, the answers to many of these project areas are required before a logical geothermal field stimulation program can be formulated.

1. Geologically controlled directional drilling in combination with effective stimulation or damage removal.
2. Effective Geothermal Well Stimulation including combinations of techniques and diagnostics on what was accomplished.
3. Tests on all Materials at Downhole Conditions - High Temperature Testing.

GEOHERMAL WELL STIMULATION STATUS AND RECOMMENDATIONS FOR RESEARCH, prepared for Sandia National Laboratories by Republic Geothermal, Inc., Santa Fe Springs, CA, May 1985.

The U.S. Department of Energy-sponsored Geothermal Reservoir Well Stimulation Program (GRWSP) was conducted from February 1979 through December 1983 to research and field test stimulation methods aimed at improving the productivity of geothermal wells. The program was formulated by the Department of Energy in response to industry interest in geothermal well stimulation, and focused on extending petroleum industry stimulation technology to the geothermal environment. The principal aim was to improve geothermal development economics by developing stimulation as a viable, less expensive alternative to the normal practice of redrilling or replacing deficient wells. Republic Geothermal, Inc., and its subcontractors conducted the work in two phases. Phase I consisted of laboratory investigations, literature studies, and computer software development. This work was the predecessor to eight field experiments performed in Phase II. Candidate wells for the GRWSP field experiments fell into one or more of the three following categories:

1. Wells that failed to intersect major productive natural fractures in the reservoir;
2. Wells that suffered man-made damage during drilling, testing, or workover operations; and

3. Wells in matrix-type reservoirs that could benefit from the establishment of high-conductivity, linear-flow channels to improve flow capacity from surrounding localized regions of low-permeability formation.

Overall it was shown that both hydraulic fracturing and acidizing can, if properly applied, be effective remedies for near-wellbore formation damage and for enhancing productivity of a well penetrating a local region of low reservoir permeability. Two experiments at East Mesa and one at Beowawe were examples of successful near-wellbore type treatments. However, in three of the four hydraulic fracturing treatments at Raft River and Baca, extensive highly conductive fractures were created and propped, but failed to establish commercial productivity from the reservoir. In both Raft River and Baca the knowledge of the reservoir and geometry of the created fracture were insufficient to establish the proximity of productive natural fractures to the wellbore and whether or not the pattern of natural fractures was such that the hydraulic fracture could intercept them effectively.

F. Systems Analysis/Summaries and Reviews

A FORECAST OF DRILLING TECHNOLOGIES (SAND83-1755C), C. C. Carson, Sandia National Laboratories, IADC Drilling Technology Conference, Dallas, TX, March 19-21, 1984.

Current drilling for oil and gas resources is predominantly shallow, land drilling, as it has been throughout its history. In the near future, this will change as we are forced to exploit generally deeper and more remote reservoirs. This change in the target resources will cause a gradual change in the technologies we use to reach them. In addition, eventual exploitation of alternative resources will also introduce new drilling requirements.

An indication of the coming changes in drilling systems is provided by the current emphases in drilling research and development. These include improvements in bits and downhole motors, measurement while drilling (MWD) development, rig automation, and expanding use of computers. Introduction and continuing modification of the diamond compact bit is one of the most significant recent drilling developments. Much of the recent development and improvement of downhole motors is due to the expanded performance envelopes of PDC bits. MWD is the most active area of current research, with approximately 15 companies developing or marketing systems, and its application is expanding. Rig automation and use of computers to monitor and optimize the drilling function are also slowly growing.

By considering the future requirements for drilling systems and the current research emphases, it is possible to anticipate the changes that are likely to occur in the way we drill wells. In general, these will come in the areas of information and control. We will collect more and better information both at the surface and downhole and be better able to process it for use in controlling drilling. Improved control will focus on drilling efficiency and placement of the borehole trajectory. In addition, information will be used to improve drilling safety and formation characterization.

RESEARCH AND DEVELOPMENT ACTIVITIES IN GEOTHERMAL DRILLING, COMPLETION, AND LOGGING (SAND84-0172A), J. R. Kelsey, Sandia National Laboratories, International Symposium on Observation of the Continental Crust Through Drilling, Tarrytown, NY, May 20-25, 1984.

One of the major factors presently inhibiting the exploitation of geothermal energy is the high cost of drilling and completing geothermal wells. The cost of these wells typically ranges

from \$1 M to \$3 M, which is several times that of an oil or gas well of comparable depth. These high costs are primarily driven by the harsh environment associated with geothermal reservoirs. The high temperatures which are inherent to the resource cause rapid degradation of conventional drill bits and preclude the use of conventional drilling fluids. Geothermal formations are typically hard and highly fractured. This results in low rates of penetration, high rates of drilling fluid loss, and difficulties in obtaining competent completions. The chemical composition of the downhole geothermal fluids causes extensive scaling and, combined with high temperatures, causes corrosion of drill pipe, casing, and logging equipment.

Present research and development activities are under way to find solutions to these problems. Current activities include development of high-temperature drilling fluids, methods for plugging lost circulation zones, advanced rock-cutting techniques, and borehole instrumentation.

While these research and development activities are aimed at solving geothermal well problems, the technology has direct application to deep oil and gas operations, as well as drilling activities for scientific purposes.

RESEARCH AND DEVELOPMENT ACTIVITIES IN GEOTHERMAL DRILLING, COMPLETION AND LOGGING (SAND84-0172C), J. T. Finger, Sandia National Laboratories, Proceedings of International Symposium on Observation of the Continental Crust through Drilling.

Sandia National Laboratories manages the Geothermal Drilling and completion Program for the U.S. Department of Energy. The primary purpose of this program is to expand access to the geothermal resource by reducing the cost of drilling and completing geothermal wells. This cost is typically two to five times that for an oil well of comparable depth, and well cost is usually about half the total capital investment for a geothermally powered plant to generate electricity.

Geothermal drilling is plagued by a combination of problems not shared by the rest of the drilling industry. Formations are hard, abrasive, fractured, and frequently underpressured, which results in slow drilling and lost circulation. The fluids produced are often corrosive and high in dissolved solids. Completions are difficult, with casing failure a major cost in many geothermal wells. Aggravating this catalog of complications is the fact that the geothermal industry is so small compared to the oil and gas industry that oil tool manufacturers and service companies have little incentive to do

C. Energy Extraction

PRELIMINARY CONSIDERATIONS FOR EXTRACTION OF THERMAL ENERGY FROM MAGMA (SAND85-0650C), C. E. Hickox and J. C. Dunn, Sandia National Laboratories, GRC Transactions, 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.

Simplified mathematical models are developed to describe the extraction of thermal energy from magma based on the concept of a counterflow heat exchange, inserted into the magma body. Analytical solutions are used to investigate influence of the basic variables on electric power production. Calculations confirm that the proper heat exchanger flow path is down the annulus with hot fluid returning to the surface through the central core. The core must be insulated from the annulus to achieve acceptable well-head temperatures, but this insulation thickness can be quite small. The insulation is effective in maintaining the colder annular flow below expected formation temperatures so that a net heat gain from the formation above a magma body is predicted. The analyses show that optimum flow rates exist that maximize electric power production. These optimum flow rates are functions of the heat transfer coefficients that describe magma energy extraction.

A NUMERICAL STUDY OF THE APPLICABILITY OF THE BOUSSINESQ APPROXIMATION FOR A FLUID-SATURATED POROUS MEDIUM (SAND85-0368A), C. E. Hickox and D. K. Gartling, Sandia National Laboratories, Symposium on Fluid Mechanics Honoring Professor Chia-Shun Yih, University of Michigan, Ann Arbor, Michigan, July 22-24, 1985.

The regions of applicability of the Oberbeck-Boussinesq (OB) approximation are investigated for natural convection in a fluid-saturated porous medium. A perturbation method is utilized to assess the relative importance of individual terms in the differential equations which describe the natural convection process. Specific limits to the validity of the OB approximation are identified for water and air. For water, it is shown that the restrictions imposed by the classical OB approximation can be relaxed by allowing for the variation of thermophysical properties with temperature while still retaining the incompressible form of the continuity relation. This is referred to as the extended OB approximation. Results of the analysis are verified through numerical calculations performed for steady natural convection in a water-saturated porous medium, confined within a planar enclosure of unity aspect ratio, and subjected to a constant temperature difference imposed between the vertical boundaries. The following

three equation systems are studied: (1) the classical OB system, (2) the extended OB system, and (3) the exact or complete system. For the various equation systems studied, computed results are presented for the heat transfer rate across the enclosure as well as for the thermal and flow fields, all as functions of the Rayleigh number. Differences between the equation systems studied are quantified through calculation of the discrete 2 norm for the velocity fields and boundary heat fluxes. Estimates are deduced for the maximum temperature differences that are compatible with the strict and extended OB approximations.

D. Systems Analysis/Summaries and Reviews

A PROGRAM TO INVESTIGATE THE ENGINEERING FEASIBILITY OF EXTRACTING ENERGY FROM SHALLOW MAGMA BODIES (SAND84-0759C), C. C. Carson, Sandia National Laboratories and A. D. Allen, U. S. Department of Energy, Transactions of Geothermal Resources Council Annual Mtg., August 26-29, 1984.

A new program, sponsored by the Department of Energy's Geothermal & Hydropower Technologies Division, has begun to investigate the engineering feasibility of extracting energy from shallow magma bodies. This program follows a previous investigation of the scientific feasibility of using magma and differs from it in focus. The current program is directed toward determining whether magma energy can be extracted economically. In the first year of the program, the three most promising sites for a long-term experiment will be characterized; the research and development tasks that will be required will be identified; and a program plan outlining the entire feasibility study will be compiled.

THE ENGINEERING FEASIBILITY OF MAGMA ENERGY (SAND84-1203A), J. C. Dunn and H. C. Hardee, Sandia National Laboratories, AGU Fall Meeting, San Francisco, CA, December 3-7, 1984.

A new program, sponsored by the Geothermal and Hydropower Technologies Division of the Department of Energy, has been initiated to determine the engineering feasibility of magma energy. This program builds on the previous investigation of scientific feasibility which was funded by the Office of Basic Energy Sciences and completed in 1982. The current program will include the development of techniques and hardware necessary to build a magma energy plant. In addition, the important questions of economic viability will be addressed. A major milestone will be the completion of a long-term experiment that includes drilling into an actual crustal magma body and emplacing energy extraction hardware.

Potential U.S. sites for magma energy experiments are being reviewed with the criteria of not only scientific evidence for shallow magma but also favorable physical and institutional factors that would influence completion of a long-term field experiment. To focus engineering development, magma sites will be reduced to a maximum of three by the end of October, 1984. These sites will then be studied in more detail to identify acceptable drilling targets. The complete list of potential magma sites and results of the site selection process will be discussed. In addition, the nature of research and development required to support the engineering feasibility study will be

described in terms of the major project areas: geophysics, geochemistry/materials, energy extraction, and drilling.

THE MAGMA ENERGY AND GEOTHERMAL PERMEABILITY/ENHANCEMENT PROGRAMS (SAND85-0230C), J. C. Dunn, Sandia National Laboratories, Proceedings of the Geothermal Program Review, Washington, DC, September 11-12, 1985.

The Magma Energy Extraction and Permeability Enhancement programs are both U.S. Department of Energy, Geothermal Technology Division, programs managed by Sandia National Laboratories. Project funding during FY '85 was \$1.4 M for magma energy and \$650 K for permeability enhancement. Accomplishments during FY '85 and project plans for FY86 are described for both programs.

THE ECONOMICS OF MAGMA POWER GENERATION (SAND85-0648C), C. C. Carson, Sandia National Laboratories; J. Haraden, Well Production Testing, Inc., GRC Transactions 9, p. 171, August 1985.

An analysis of the economics of generating electricity using magma reservoirs as the energy source indicates that magma-based energy could be roughly competitive with existing sources of electricity. The conclusion seems justified even though the analysis requires many assumptions that may or may not prove to be realistic as technology advances. Another important result of this analysis that is not dependent on the state of technology is the identification of the parameters that have the largest effect on the economics of magma energy. These include the initial cost and the lifetime of the wells that are drilled to each the magma reservoir and the rate at which energy can be extracted from each well--the same parameters that control the economics of hydrothermal resources. The technological improvements that affect these parameters will be the focus of the continuing magma energy extraction program.

MAGMA ENERGY (SAND85-1740A), H. C. Hardee, Sandia National Laboratories, 7th Miami International Conference, Miami, FL, December 9-11, 1985.

Evidence accumulated over the past ten years has established that it is scientifically feasible to extract energy from extensive sources of shallow molten magma deposits in the earth's crust. The USGS estimates the amount of the magma resource in the upper 10 km of the crust in the western continental United States to be of a quantity equal to 5×10^{23}

J or about 7000 times the annual United States total energy consumption. The worldwide magma resource is estimated to be 1.5×10^{25} J. Recent studies conclude that the magma resource in the crust is replenished or renewed at a significant rate. Theoretical studies, and laboratory and field experiments indicate that it is scientifically feasible to drill into a magma body and extract useful heat. Field experiments conducted at volcanic eruption sites and in lava lakes have examined the geophysical state of molten rock, methods of drilling molten rock and heat extraction techniques.

The Magma Energy Program has recently moved into the engineering feasibility stage. This program, sponsored by the Geothermal Hydropower Technologies Division of the Department of Energy, will investigate the development of techniques and hardware necessary to build a magma energy plant. Within the next few years a hole will be drilled into a shallow magma body in the western United States for the purpose of evaluating the engineering feasibility of magma energy.

III. Continental Scientific Drilling Program (CSDP)

Advanced drilling and instrumentation technology is being applied to the geoscience research driven CSDP. Sandia also maintains a Geoscience Research Drilling Office that provides field support and logistics to scientists involved in the thermal regimes research of CSDP.

A. Field Research and Support

CONTINENTAL SCIENTIFIC DRILLING AT INYO DOMES LONG VALLEY CALDERA, CA (SAND84-1900A), J. C. Eichelberger, P. C. Lysne, L. W. Younker, Sandia National Laboratories, AGU 1984 Fall Meeting, December 3-7, 1984, San Francisco, CA

On September 6, 1984, a core hole, sited just outside the vent area of Obsidian Dome and dipping 60° toward the vent, intersected the conduit of the 600-year-old volcano at a slant depth of 485 m. Drilling continued through the far wall of the conduit at 597 m and terminated in Sierran granite at 624 m. Zones encountered included an outermost zone of fracturing and hydrothermal mineral deposition, a zone of intense fracturing and injection of pyroclastic debris, a vent breccia with wallrocks dropped down from above, and an innermost zone of pure rhyolite intrusive. The hole is the second in a program of research drilling, the goal of which is to describe the thermal, chemical and mechanical behavior of magma as it intrudes the upper continental crust. Results will encompass definition of the residual thermal anomaly from the intrusive event, fluid and vapor phase mineral deposition as a function of distance from the conduit, and degassing and crystallization behavior of the magma as a function of depth. A third hole will be started on September 17 and is planned to intersect the dike postulated to underlie the Inyo chain.

The Inyo Drilling Program is funded by the Office of Basic Energy Sciences of the U.S. Department of Energy as part of the national CSDP effort. Participants include four DOE laboratories, five universities, and the U.S. Geological Survey.

RESEARCH DRILLING AT INYO DOMES, LONG VALLEY CALDERA, CALIFORNIA, J. C. Eichelberger and P. C. Lysne, Sandia National Laboratories, and L. W. Younker, Lawrence Livermore National Laboratory, EOS 65, No. 39, p. 721-725, 9/25/84.

A program of research drilling has begun at the Inyo Domes volcanic chain which cuts north-south across the northwest rim of Long Valley Caldera. The youngest features of this chain (four magmatic vents, at least six phreatic vents, and

associated normal faults) are believed to be the surface expression of a dike or system of dikes which is at least 8 km long and was emplaced approximately 600 years ago. During October 1983, a vertical 150-m hole was cored through Obsidian Dome, northernmost of the young magmatic vents. Work is now underway on a 600-m slant core hole to intersect the conduit which fed Obsidian Dome and a 1000-m slant core hole to intersect the Inyo Dike between Obsidian Dome and the Glass Creek Flow. Additional holes, both inside and outside the caldera, have been proposed for subsequent years.

Both the drilling and supporting research are funded by the Office of Basic Energy Sciences of the U.S. Department of Energy (DOE). As an investigation of processes of heat and mass transport in an anomalously hot region of the earth's crust, this effort represents part of the national Continental Scientific Drilling Program (CSDP).

RESEARCH DRILLING AT INYO DOMES, CALIFORNIA: 1984 RESULTS, J. C. Eichelberger, P. C. Lysne, C. D. Miller, and L. W. Younker, EOS 66, No. 17, p/186-187, 4/23/85.

During the 1984 field season, two research holes were cored into the Inyo chain of young rhyolite domes, which cuts across the northwest margin of Long Valley Caldera, California. One hole slanted under the vent of Obsidian Dome and completely penetrated the conduit of the volcano. It was spudded on August 16 and reached its final depth on September 9. The second hole was sited along Glass Creek between Obsidian Dome and the next dome to the south; it intersected the rhyolite dike which underlies the chain. It was spudded on September 18 and reached final depth on October 28.

Both holes are part of the Inyo Drilling Program, whose goal is to determine the thermal, chemical, and mechanical behavior of silicic magma in the upper crust. Such data are essential for understanding the causes of explosive volcanism and the development of hydrothermal systems. On the basis of surface geologic evidence, an intrusion beneath the northern portion of the Inyo Chain was selected for study. This intrusion is sufficiently young to be neither thermally nor chemically equilibrated with its environment and was emplaced in the relatively simple geologic setting of Sierra Nevada basement. Choice of a site where the crust was initially cold and where the only local eruptive event in the last 3 My is the 600-y event of interest greatly facilitates interpretation of the thermal effects of the intrusion.

1984 DRILLING RESULTS AT INYO DOMES, CALIFORNIA (SAND85-0504A), J. C. Eichelberger and P.C. Lysne, Sandia National Laboratories, C. D. Miller, U.S. Geological Survey, Denver, CO, L. W. Younker, Lawrence Livermore National Lab, Livermore, CA

Two holes cored into the Inyo Domes chain provided continuous samples through the conduit of Obsidian Dome and the rhyolite dike which underlies the northern portion of the chain. The first hole was sited on the Dome just outside the elevated vent region and slanted inward at an initial dip of 55°. The hole passed through 64 m of the Dome into Inyo airfall tephra, moraine, and a thick section of precaldera basalts. At 484 m, it entered the conduit beneath the central depression in the vent region. The hole traversed xenolith-free crystalline rhyolite until 564 m where it entered a complex zone of granite screens, rhyolite fingers, and breccia. The last rhyolite was encountered at 596 m in Sierran basement. The intruded section is 51 m wide.

The second hole was sited between Obsidian Dome and the Glass Creek Flow with an initial dip to the west of 54°. The hole passed through Inyo tephra, moraine, precaldera basalts, and reached basement at 297 m. Numerous fractures containing juvenile Inyo pyroclasts were encountered in the basement, beginning at 329 m. The hole also intersected two basaltic dikes presumably related to the precaldera flows. From 690-716 m, the hole passed through a rhyolite intrusion with glassy margins and a crystalline core. The intersected body lies beneath a line defined by a phreatic crater south of Glass Creek and structures within the vent region of Obsidian Dome, indicating that the intrusion is a vertical dike 7.3 m thick.

SEISMIC IMAGING IN LONG VALLEY, CALIFORNIA, BY SURFACE AND BOREHOLE TECHNIQUES: AN INVESTIGATION OF ACTIVE TECTONICS (SAND85-0517J), John B. Rundle, Greg J. Elbring, Richard P. Striker, John T. Finger, Charles C. Carson, Marianne C. Walck, Sandia National Laboratories; William L. Ellsworth, David P. Hill, U.S. Geological Survey, Menlo Park, CA; Peter Malin, Enrique Tono, Michelle Robertson, Steve Kuhlman, University of California, Santa Barbara; Tom McEvelly, Richard Clymer, Lawrence Berkeley Laboratory, Berkeley, CA; Scott B. Smithson, Sharon Deemer, Roy Johnson, University of Wyoming, Laramie; Tom Henyey, Egill Hauksson, Peter Leary, John McCraney, University of Southern California, Los Angeles; Edi Kissling, Eidgenossische Technische Hochschule (ETH), Zurich, EOS 66, p. 194-200, April 30, 1985.

The search for silicic magma in the upper crust is converging on the Long Valley Caldera of eastern California, where several

lines of geophysical evidence show that an active magma chamber exists at mid-to-lower-crustal depths. There are also other strong indications that magma may be present at depths no greater than about 5 km below the surface. In this paper, we review the history of the search for magma at Long Valley. We also present the preliminary results from a coordinated suite of seismic experiments, conducted by a consortium of institutions in the summer and fall of 1984, that were designed to refine our knowledge of the upper extent of the magma chamber. Major funding for the experiments was provided by the Geothermal Research Program of the U.S. Geological Survey (USGS) and by the Magma Energy Technology Program of the U.S. Department of Energy (DOE), a program to develop the technology necessary to extract energy directly from crustal magma. Additional funding came from the Department of Energy Office of Basic Energy Sciences and the National Science Foundation (NSF). Also, because extensive use was made of a 0.9-km-deep well lent to us by Santa Fe Geothermal, Inc., the project was conducted partly under the auspices of the Continental Scientific Drilling Program (CSDP). As an integrated seismic study of the crust within the caldera that involved the close cooperation of a large number of institutions, the project was moreover viewed as a prototype for future scientific experiments to be conducted under the Program for Array Seismic Studies of the Continental Lithosphere (PASSCAL). The experiment thus represented a unique blend of CSDP and PASSCAL methods and achieved goals consistent with both programs.

RESULTS OF LIMITED CSAMT SURVEY ACROSS THE INYO CHAIN DIKE NEAR GLASS CREEK (SAND85-0612A), L. C. Bartel, Sandia National Laboratories, American Geophysical Union 1985 Spring Meeting, Baltimore, Maryland, May 27-31, 1985.

One of the objectives of the drilling program during the fall of 1984 was to intersect the rhyolite dike intrusion, which is believed to connect Obsidian Dome and the Glass Creek Flow. Prior to the actual intersection of the dike by the corehole, a limited controlled source audio-frequency magnetotelluric (CSAMT) survey was performed across the dike in an area between Obsidian Dome and Glass Creek. The purpose of the CSAMT survey was to evaluate the technique for detecting and delineating dike intrusions in the Inyo setting and obtain an estimate of the geoelectric parameters for initial modeling work. With respect to the dike, both TE and TM modes were measured, as well as the vertical component of the magnetic field. Although the survey was limited in extent, the experimental results indicate that the fracture system associated with the dike intrusion can be detected by the TE mode. Depending upon the depth to the top of the conductor, the TM mode may or may not

detect the intrusion or the fracture system associated with the intrusion. The far-field (plane-wave) regime data were used to obtain preliminary estimates of the geoelectric section using a two-layer inversion. The results of the inversion show that the surface layer, ~20 m thick, has a resistivity of ~10k ohm-m, and the surface layer is over a competent basal layer of country rock/intrusive material with a resistivity of ~200 ohm-m or is over a fractured country rock/intrusive material with a resistivity of ~80-90 ohm-m. These estimates provide initial parameters for 2-D finite difference calculations, in progress, to determine the geometry of the dike intrusion. The results of these calculations, an estimate of the width of the fractured region and an estimate of the depth to the top of the dike, will be discussed.

CORRELATIONS AND LIMITATIONS OF SURFACE AND BOREHOLE ELECTRICAL MEASUREMENTS (INVITED), L. C. Bartel, Sandia National Laboratories, 55th Annual Meeting and Exposition of the Society of Exploration Geophysicists, Washington, DC, October 6-10, 1985.

Results from borehole electrical logging gives information over only the region adjacent to the borehole. Surface-to-borehole and surface electrical and electromagnetic (EM) techniques yield additional information about the geoelectric section away from the borehole and in areas not covered by boreholes. Unconstrained inversions of surface electrical/EM data often results in an interpreted geoelectric section which deviates significantly from that determined as a result of geophysical logging. The use of borehole data to constrain, for example, the layered-earth inversions can lead to a more accurate interpretation. In this paper, unconstrained and constrained inversions of simulated, layered-earth magnetotelluric (including the audio-frequency range) field data will be discussed, along with a field example by other investigators. Two- and three-dimensional structure can affect electrical/EM measurements which can lead to a significant deviation from a layered-earth picture. Borehole data is important to provide information for the 2- and 3-D models for interpreting field data in the presence of structure. The resistivity structure and the layer thicknesses and depths are important information for interpretation models. The resistivities determined through borehole logging are strongly influenced by the drilling operation itself and in some cases the true, undisturbed formation resistivity may be difficult to determine. Surface data and/or surface-to-borehole data provide a "check" on the interpretation of the undisturbed formation resistivity as obtained from logging results.

B. Reviews and Summaries

STATE-OF-THE-ART: HIGH TEMPERATURE LOGGING (SAND83-2412A),
R. K. Traeger, Sandia National Laboratories, Borehole
Measurements and Interpretation in Scientific Drilling
Workshop, Albuquerque, NM, November 15-17, 1983

High-temperature electronic systems are needed for downhole logging to characterize the earth's crust via borehole measurements. Specific areas of need include geothermal systems, deep gas wells, volcanic regions including the oceanic ridges, and deep crustal observatory wells.

Current commercial logging systems are nominally capable of 100°C with a limited number of systems capable of 225°C to 250°C. Current technology is capable of providing, in some cases, downhole instrumentation useable at 300°C for extended times. Developments for higher temperatures will probably be experiment specific depending on sensor, power, data rate, sensitivity and other needs.

A borehole logging system generally includes surface mechanical and electrical hardware and software plus downhole components of:

- A. Cables for mechanical and electrical communication to the surface from instruments at depths of 3 km to 10 km.
- B. Cableheads which interconnect the cable and the electronic package providing a mechanical, electrical and environmental seal.
- C. Logging tool housing which contains the sensors, electronics, and mechanical systems. The housing may also include external devices as centralizers and sidewall clamping devices which require operation in the downhole environment. For some logging applications, this housing may also be a dewared system for thermal isolation of electronics.
- D. Transducers and sensors.
- E. Electrical systems for signal generation, data gathering and processing, power boosting and data transmission.

Capabilities and limitations of each of these areas will be reviewed.

Cables: Commercial, TFE insulated, multiconductor logging cables are available for use to 300°C. This cable capability is currently the temperature limiting item in many of the downhole sampling and measuring techniques. Very high temperature, two and four conductor, magnesium oxide insulated and stainless steel sheathed cables are available for use to 500°C - 700°C. They have not been sufficiently used in the field to understand handling problems with 7 km lengths, to develop reliable cable heads, and to appreciate power and signal transmission limitations (MgO has a high capacitance). Another possibility for using existing cables in higher temperature environments is to operate through a drill string with a continuous flow of mud or water to maintain low temperatures.

Cablehead: Connection from the cable to the logging tool is made through the cable head; the operation is done at the wellsite, usually in adverse conditions. Maintaining appropriate environmental and electrical seals is always a problem. Current designs can provide satisfactory connection but most of those designs are not compatible with normal field operations. Thus special facilities are needed as well as a rapid test to assure electrical and environmental isolation.

Housing: Structural, mechanical and electrical pass throughs, and material selection do not generally present limitations. However, mechanical systems as springs and latches that are needed for centralizers, side wall loading, clamps, etc., can present problems. Appropriate materials are available for use to 500°C but material selection and mechanical detail are most important design needs.

Dewared or insulated housing is widely used in commercial logging. Recent advances have been made by Dennis at the Los Alamos National Laboratory in dewar design combined with the use of phase change heat sinks and heat pipes.

Transducers and Sensor: Electric, magnetic, acoustic, temperature, pressure, flow, etc., are measurements of interest. Limitations of transducers and sensors obviously have to be evaluated based on experimental sensitivity and accuracy needs. Details will not be discussed in this review.

Electronics: Use of thick film microcircuitry on ceramics combined with welding or brazing plus careful selection of detailed active and passive discrete devices has led to semicommercial availability of circuits that operate to 250°C - 300°C. Current major limitations include a stable, non-leaky diode and power switching. In general circuit design can bypass the diode problem. Current work by Chang at Sandia on switching tubes and magnetostrictive materials offers potential solutions for power systems.

Electronic limitations in the 300°C - 500°C range have not been studied in any detail. Thick film microcircuit elements as conductors, resistors and capacitors would probably function at those temperatures but would require special designs and/or calibrations. Discrete devices as capacitors, resistors, transistors are not available for use in that range. Silicon or gallium arsenide based semiconductor circuits will not be available above 300°C. Research at Sandia on temperature- and radiation-hardened semiconductors has lead to successful construction and testing of gallium phosphide/aluminum gallium phosphide transistors and thyristors that operate at 500°C with useable characteristics over 700°C. Future circuits combining thick film interconnections and heterojunction devices could probably operate successfully at 500°C but needed extensive research, development and testing is not being pursued nor are any of the more pragmatic packaging problems being addressed.

In summary, commercial logging systems are available that operate at 200°C - 250°C and a field capability to 300°C has been demonstrated. Logging at higher temperatures will be limited by availability of appropriate sensors and electronics. No current research appears capable of providing a field useable, 300°C - 500°C logging system in the next 5-10 years. Options for high-temperature logging needs may be met (1) by the use of simple, temperature-resistant systems as sheathed, MgO-insulated thermocouples for temperature measurements; (2) by fast round trips in a precooled well; or (3) by circulating coolant around the cable and electronics. Decisions on options can only be made when experimental needs are defined and the required cable-cablehead-housing-sensor-electronic system is evaluated.

GEOSCIENCE EXPERIMENTS IN BOREHOLES: INSTRUMENTATION
(SAND83-2413C), R. K. Traeger, Sandia National Laboratories,
International Symposium on Observation of the Continental Crust
Through Drilling, Tarrytown, NY, May 21-25, 1984.

Drilling is the only method available to obtain unambiguous information on processes occurring in the earth's crust. When core and virgin formation fluid samples are available, the geological state of the formation may be defined in that vicinity of the borehole with little ambiguity. Unfortunately, core recovery is expensive and often not complete, and drilling muds contaminate formation fluids. Thus, investigations turn to downhole instrumentation systems to evaluate in situ

formation parameters. Some such instruments and the associated interpretative techniques are well developed, especially if they find usage in the evaluation of hydrocarbon reservoirs. Other systems, particularly those that yield geochemical information are, at best, shallow-hole devices, but they could be engineered for deep-hole applications. Interpretations of logs obtained in igneous and metamorphic systems are not well developed. Finally, measurements away from the immediate vicinity of the borehole are possible but the technology is primitive.

In situ instrumentation capabilities and needs for research in boreholes will be reviewed; the review will include details from recent U.S. and European discussions of instrumentation needs. The capability and availability of slim hole logging tools will be summarized. Temperature limitations of the overall logging system will be discussed (current limits are 300°C) and options for measurements to 500°C will be described.

PROCEEDINGS OF THE WORKSHOP ON BOREHOLE MEASUREMENTS AND INTERPRETATION IN SCIENTIFIC DRILLING: IDENTIFICATION OF PROBLEMS AND PROPOSALS FOR THEIR SOLUTION (SAND84-0288), D. L. Cooper and R. K. Traeger, Sandia National Laboratories,

Critical instrumentation needs for borehole-oriented, geoscience research were identified in a program consisting of formal presentations, poster sessions and a workshop. The proceedings include results of the workshops, abstracts of the papers and poster sessions, and the attendance list. Details of any of the presentations should be obtained from the individual authors.

In general, conventional logging and sampling capabilities can meet the majority of borehole research needs for temperatures to 200°C, possibly 300°C. However, theoretical and experimental studies and calibration facilities are needed for the interpretation of logs obtained from non-petroleum environments. Specific hardware requiring improvements include borehole televiewers, calipers, side-wall coring, downhole gravimeter and high-resolution sonic and resistivity system. Theoretical developments are needed on in situ stress models, hydraulic fracturing data interpretation, improved models of in situ deformation processes, and mechanisms of electric and seismic signal propagation through complex geologic structures.

TECHNOLOGIES FOR SCIENTIFIC DRILLING AND BOREHOLE RESEARCH (INVITED) (SAND85-1830C), R. K. Traeger, Sandia National Laboratories, Proceedings Second International Symposium on Observation of the Continental Crust through Drilling, Seeheim, West Germany, October 4-6, 1985.

Use of the drill bit to access the third dimension of the earth's crust provides an exciting opportunity for

geoscientists to evaluate hypotheses on the structure and processes occurring in the crust. The Continental Scientific Drilling Programs (CSDP) being initiated in many places can provide this opportunity but scientific enthusiasm is dampened by a perceived technology limitation to provide the needed research facility (drillhole) and instrumentation. This paper discusses the borehole as a research facility using currently active research drilling to illustrate technological solutions. Subsequent discussion summarizes the status of drilling technologies and borehole instrumentation capabilities.

SANDIA GEOTHERMAL TECHNOLOGY PROGRAMS: INTERACTIONS WITH OTHER DOE RESEARCH AND CSDP (SAND85-1871C), R. K. Traeger, Sandia National Laboratories, DOE/Geothermal Program Review, Washington, DC, September 11-12, 1985.

When the energy programs were initiated in the mid-70s, Sandia management made a conscious decision to apply existing Engineering expertise and capabilities in support of industry, government and university needs. A decision was made not to expend resources independently developing a panacea for the U.S. energy ills. Consequently, exchange of information and technology with others occurred from the start prior to the "Tech Transfer" buzz words of the 1980s.

The purpose of this paper is to briefly outline the Geothermal Technology Development (GTD)-supported Sandia programs; details will be given in subsequent papers by J. Kelsey and J. Dunn. Then, I will show how these programs interact with other energy programs at Sandia. Finally, I will discuss the overall Continental Scientific Drilling Program, its status (except for details on the GTD-run Salton Sea Experiment which is discussed elsewhere), and Sandia GTD interactions with CSDP.

IV. Past Bibliographies

GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS: A BIBLIOGRAPHY, January 1977-December 1980, Sandra R. Hudson, Ed., SAND81-0662, Printed April 1981.

GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS: A BIBLIOGRAPHY, January through December 1981, Sandra R. Hudson, Ed., SAND82-0993, Printed May 1982.

GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS: A BIBLIOGRAPHY, January through December 1982, Sandra R. Hudson, Ed., SAND83-0492, Printed March 1983

GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS: A BIBLIOGRAPHY, January through December 1983, Dana L. Cooper, Ed., SAND84-1767, Printed September 1984

V. AUTHOR LISTING

- Baird, J. A., Jordan, Apostol, Ritter Assoc., Inc. and B. C. Caskey, ANALYZING THE DYNAMIC BEHAVIOR OF DOWNHOLE EQUIPMENT DURING DRILLING (SAND84-0758C), Sandia National Laboratories, Transactions of 1984 Annual Meeting of Geothermal Resources Council (Vol. 8, August 1984, pp. 243-247), Reno, NV, August 26-29, 1984.
- Baird, J. A., Jordan Apostol, Ritter Assoc., B. C. Caskey, GEODYN2: A BOTTOM HOLE ASSEMBLY - GEOLOGICAL FORMATION DYNAMIC INTERACTION COMPUTER PROGRAM (SAND85-1604C), Sandia National Laboratories, D. N. Wormley, Massachusetts Institute of Technology, and C. M. Stone, Sandia National Laboratories, Society of Petroleum Engineers Annual Technical Conference and Exhibition, Las Vegas, NV, September 22-25, 1985.
- Bartel L. C. and R. D. Jacobson, RESULTS OF A CSAMT SURVEY AT THE PUHIMAU THERMAL AREA KILAUEA VOLCANO, HAWAII (SAND84-0987J), Sandia National Laboratories, Geophysics.
- Bartel L. C., CORRELATIONS AND LIMITATIONS OF SURFACE AND BOREHOLE ELECTRICAL MEASUREMENTS (SAND85-1070A), Sandia National Laboratories, SEG Research Symposium on Logging Accuracy and Limitation for Exploration Purposes, Washington, DC, October 7, 1985
- Bauman, T. J., A GEOTHERMAL LOST CIRCULATION ZONE MAPPING TOOL (SAND85-0646C), Sandia National Laboratories, Transactions of the Geothermal Resources Council (Vol. 9, Pt. II, August 1985, pp. 431-436), 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.
- Captain, K. M. and A. C. Harvey, Foster-Miller, Inc., and B. C. Caskey, DEVELOPMENT OF SEALS FOR A GEOTHERMAL DOWNHOLE INTENSIFIER--A PROGRESS REPORT (SAND85-0849C), Sandia National Laboratories, GRC Transactions, 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.
- Carson, C. C., A FORECAST OF DRILLING TECHNOLOGIES (SAND83-1755C), Sandia National Laboratories, IADC Drilling Technology Conference, Dallas, TX, March 19-21, 1984.
- Carson C. C., SUGGESTED DRILLING RESEARCH TASKS FOR THE FEDERAL GOVERNMENT (SAND84-0436), Sandia National Laboratories.
- Carson, C. C., TRENDS IN DRILLING TECHNOLOGIES (SAND84-0492J), Sandia National Laboratories, in "American Oil and Gas Reporter."

- Carson, C. C., A PROGRAM TO INVESTIGATE THE ENGINEERING FEASIBILITY OF EXTRACTING ENERGY FROM SHALLOW MAGMA BODIES (SAND84-0759C), Sandia National Laboratories and A. D. Allen, U. S. Department of Energy, Transactions of Geothermal Resources Council Annual Mtg., August 26-29, 1984.
- Carson, C. C., SELECTION OF PROMISING SITES FOR MAGMA ENERGY EXPERIMENTS (SAND84-2171), Sandia National Laboratories.
- Carson, C. C., GEOTHERMAL INSTRUMENTATION DEVELOPMENT ACTIVITIES AT SANDIA (SAND85-0647C), Sandia National Laboratories, Transactions of the Geothermal Resources Council (Vol. 9, Pt. II, August, 1985, pp. 447-450), 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.
- Carson, C. C., and J. Haraden, Well Production Testing, Inc., THE ECONOMICS OF MAGMA POWER GENERATION (SAND85-0648C), Sandia National Laboratories; GRC Transactions 9, p. 171, August 1985.
- Caskey, B. C. and C. M. Stone, GEODYN - A GEOLOGICAL FORMATION/ DRILL STRING DYNAMICS COMPUTER PROGRAM (SAND84-0314C), Sandia National Laboratories, Proceedings Society of Petroleum Engineers 59th Annual Technical Conference & Exhibit, Houston, TX, September 16-19, 1984.
- Caskey, B. C., LOST CIRCULATION TECHNOLOGY WORKSHOP (SAND85-0109), Sandia National Laboratories, October 9-10, 1984.
- Caskey, B. C., LOST CIRCULATION IN GEOTHERMAL WELLS: RESEARCH AND DEVELOPMENT STATUS (SAND85-0783C), Sandia National Laboratories and J. V. Satrape, Meridian Corporation, Transactions of the Geothermal Resources Council 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.
- Chahine, G. L., P. F. Genoux, V. E. Johnson, Jr., and G. S. Frederick, ANALYTICAL AND EXPERIMENTAL STUDY OF THE ACOUSTICS AND THE FLOW FIELD CHARACTERISTICS OF CAVITATING SELF-RESONATING WATER JETS (SAND84-7142), Tracor Hydro-nautics under contract to Sandia National Laboratories.
- Chang, H. T., A HIGH-TEMPERATURE PROTOTYPE INSTRUMENT FOR DOWNHOLE ACOUSTIC SENSING (SAND-82-2893J), Sandia National Laboratories.
- Chang, H.-T., DEVELOPMENT OF A BOREHOLE DIRECTIONAL ANTENNA AT VHF (SAND84-0254), Sandia National Laboratories, and L. D. Scott, Mission Research Corp.

- Chang, H.-T., FEASIBILITY OF A BOREHOLE VHF RADAR TECHNIQUE FOR FRACTURE MAPPING (SAND84-0756C), Sandia National Laboratories, Transactions of the 1984 Annual Meeting of Geothermal Resources Council (Vol. 8, August 1984, pp. 485-488), Reno, NV, August 26-29, 1984.
- Chang, H.-T., DOWNHOLE VHF RADAR TECHNIQUE FOR FRACTURE MAPPING (SAND85-0250A), Sandia National Laboratories, Society of Petroleum Engineers 60th Annual Technical Conference and Exhibition, Las Vegas, NV, September 22-25, 1985.
- Chang, H.-T., FEASIBILITY OF AN ACOUSTIC TECHNIQUE FOR FRACTURE DETECTION (SAND85-0652C), Sandia National Laboratories, Transactions of the Geothermal Resources Council 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.
- Cooper, D. L. and R. K. Traeger, PROCEEDINGS OF THE WORKSHOP ON BOREHOLE MEASUREMENTS AND INTERPRETATION IN SCIENTIFIC DRILLING: IDENTIFICATION OF PROBLEMS AND PROPOSALS FOR THEIR SOLUTION (SAND84-0288), Sandia National Laboratories.
- Cutler, R. A., THE EFFECTS OF BINDER THICKNESS AND RESIDUAL STRESSES ON THE FRACTURE TOUGHNESS OF CEMENTED CARBIDES (SAND84-7127C), Terra Tek under contract to Sandia National Laboratories, American Ceramic Society, Annual Mtg., Pittsburgh, PA, May 2, 1984.
- Duda, L. E., COMPUTER SIMULATION OF THE COOLING EFFECT DUE TO CIRCULATION (SAND84-1589), Sandia National Laboratories.
- Duda, L. E., COMPUTER SIMULATION OF WELLBORE COOLING BY CIRCULATION AND INJECTION (SAND84-1922C), Sandia National Laboratories, Proceedings of the Tenth Annual Workshop Geothermal Reservoir Engineering, Stanford, CA, January 22-25, 1985.
- Duda, L. E., COMPUTER SIMULATION OF THE COOLING EFFECT DUE TO CIRCULATION IN SOME SELECTED GEOTHERMAL WELLS (SAND84-2211a), Sandia National Laboratories.
- Duda, L. E., INVESTIGATION OF WELLBORE COOLING BY CIRCULATION AND FLUID PENETRATION INTO THE FORMATION USING A WELLBORE THERMAL SIMULATOR COMPUTER CODE (SAND85-0651C), Sandia National Laboratories, Transactions of the Geothermal Resources Council 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.
- Dunn, J. C. and H. C. Hardee, SURFACE HEAT FLOW MEASUREMENTS AT THE PUHIMAU HOT SPOT (SAND84-0456J), Sandia National Laboratories, Geophysics 50, July 1985, p. 1108-1112.

- Dunn, J. C. and H. C. Hardee, THE ENGINEERING FEASIBILITY OF MAGMA ENERGY (SAND84-1203A), Sandia National Laboratories, AGU Fall Meeting, San Francisco, CA, December 3-7, 1984.
- Dunn, J. C., THE MAGMA ENERGY AND GEOTHERMAL PERMEABILITY/ ENHANCEMENT PROGRAMS (SAND85-0230C), Sandia National Laboratories, Proceedings of the Geothermal Program Review, Washington, DC, September 11-12, 1985.
- Eichelberger, J. C., P. C. Lysne, Sandia National Laboratories, L. W. Younker, Lawrence Livermore National Lab, Livermore, CONTINENTAL SCIENTIFIC DRILLING AT INYO DOMES LONG VALLEY CALDERA, CA (SAND84-1900A), AGU 1984 Fall Meeting, December 3-7, 1984, San Francisco, CA
- Eichelberger, J. C. and P.C. Lysne, Sandia National Laboratories, C. D. Miller U.S. Geological Survey, Denver, L. W. Younker, Lawrence Livermore National Lab, Livermore, CA, 1984 DRILLING RESULTS AT INYO DOMES, CALIFORNIA (SAND85-0504A),
- Finger, J. T., PROGRAM FOR THE IMPROVEMENT OF DOWNHOLE DRILLING MOTORS (SAND83-0130), Sandia National Laboratories.
- Finger, J. T., INVESTIGATION OF PERCUSSION DRILLS FOR GEOTHERMAL APPLICATIONS (SAND83-2610J), Sandia National Laboratories, Journal of Petroleum Technology.
- Finger, J. T., RESEARCH AND DEVELOPMENT ACTIVITIES IN GEOTHERMAL DRILLING, COMPLETION AND LOGGING (SAND84-0172C), Sandia National Laboratories, Proceedings of International Symposium on Observation of the Continental Crust through Drilling.
- Givler, R. D., PLUGGING MECHANISMS IN A LOST CIRCULATION MODEL (SAND85-0316C), Sandia National Laboratories, Transactions, Vol. 9, Part 1, August 1985.
- Glowka, D. A. and C. M. Stone, THERMAL RESPONSE OF POLYCRYSTALLINE DIAMOND COMPACT CUTTERS UNDER SIMULATED DOWNHOLE CONDITIONS (SAND83-0489), Sandia National Laboratories, APE Journal 4/85 pp. 143-156.
- Glowka, D. A. and C. M. Stone, EFFECTS OF THERMAL AND MECHANICAL LOADING ON PDC BIT LIFE (SAND84-0316C), Sandia National Laboratories, Society of Petroleum Engineers Annual Meeting, Houston, TX, September 16-19, 1984.

- Glowka, D. A., THERMAL LIMITATIONS ON THE USE OF PDC BITS IN GEOTHERMAL DRILLING (SAND84-0757C), Sandia National Laboratories, Transactions the 1984 Annual Meeting of the of the Geothermal Resources Council (Vol. 8. August 1984, pp. 261-266), Reno, NV, August 26-29, 1984.
- Glowka, D. A., IMPLICATIONS OF THERMAL WEAR PHENOMENA FOR PDC BIT DESIGN AND OPERATION (SAND85-0389C), Sandia National Laboratories, Society of Petroleum Engineers 60th Annual Technical Conference and Exhibition, Las Vegas, NV, September 22-25, 1985.
- Glowka, D. A., EFFECTS OF ARTIFICIAL FRACTURE GEOMETRY ON GEOTHERMAL WELL PRODUCTION (SAND85-0571C), Sandia National Laboratories, Geothermal Resources Council Annual Meeting, August 26-30, 1985, Kailua-Kona, Hawaii.
- Glowka, D. A., DESIGN CONSIDERATIONS FOR A HARD-ROCK PDC DRILL BIT (SAND85-0666C), Sandia National Laboratories, Transactions of 1985 Annual meeting of Geothermal Resources Council, Vol. 9, Part I, August 1985.
- Guven, N., L. L. Garney, F. Malekahmadi, and L. J. Lee, FACTORS AFFECTING THE BEHAVIOR OF BENTONITE FLUIDS AND THEIR IN-SITU CONVERSION INTO CEMENT (SAND84-7170), Texas Tech University.
- Hardee, H. C., SHALLOW MAGMA TARGETS IN THE WESTERN U.S. (SAND83-1361), Sandia National Laboratories.
- Hardee, H. C., MAGMA ENERGY (SAND85-1740A), Sandia National Laboratories, 7th Miami International Conference, Miami, FL, December 9-11, 1985.
- Hickox, C. E. and D. K. Gartling, A NUMERICAL STUDY OF THE APPLICABILITY OF THE BOUSSINESQ APPROXIMATION FOR A FLUID-SATURATED POROUS MEDIUM (SAND85-0368A), Sandia National Laboratories, Symposium on Fluid Mechanics Honoring Professor Chia-Shun Yih, University of Michigan, Ann Arbor, Michigan, July 22-24, 1985.
- Hickox, C. E. and J. C. Dunn, PRELIMINARY CONSIDERATIONS FOR EXTRACTION OF THERMAL ENERGY FROM MAGMA (SAND85-0650C), Sandia National Laboratories, GRC Transactions, 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.
- Kelsey, J. R., RESEARCH AND DEVELOPMENT ACTIVITIES IN GEOTHERMAL DRILLING, COMPLETION, AND LOGGING (SAND84-0172A), Sandia National Laboratories, International Symposium on Observation of the Continental Crust Through Drilling, Tarrytown, NY, May 20-25, 1984.

- Kelsey, J. R. and C. C. Carson, GEOTHERMAL DRILLING (SAND84-1024J), Sandia National Laboratories, in Geothermal Energy.
- Kelsey, J. R., GEOTHERMAL TECHNOLOGY DEVELOPMENT PROGRAM ANNUAL PROGRESS REPORT, 10/82-9/83 (SAND84-1028), Sandia National Laboratories.
- Kelsey, J. R., GEOTHERMAL TECHNOLOGY DEVELOPMENT PROGRAM ANNUAL PROGRESS REPORT, (SAND85-1138), Sandia National Laboratories, October 1983 - September 1984.
- Kelsey, J. R., DRILLING TECHNOLOGY/GDO (SAND85-1866C), Sandia National Laboratories, Proceedings of the Geothermal Program Review, Washington, DC, September 11-12, 1985.
- Kraynik, A. M., FOAM DRAINAGE (SAND84-0844), Sandia National Laboratories
- Loeppke, G. E. and B. C. Caskey, DESIGN AND EVALUATION OF LOST CIRCULATION MATERIALS FOR HIGH TEMPERATURE APPLICATIONS (SAND85-1485A), Sandia National Laboratories, IADC/SPE 1986 Drilling Conference, Dallas, TX, February 10-12, 1985.
- Lysne, Peter L., LEAST SQUARES ANALYSIS OF UNCERTAIN DATA (SAND85-0991A), Sandia National Laboratories, Presentation at "New Techniques in Scientific Well Logging Symposium," May 15-16, 1985, Palisades, New York
- Mondy, L. A. and L. E. Duda, ADVANCED WELLBORE THERMAL SIMULATOR GEOTEMP2 USER MANUAL, (SAND84-0857), Sandia National Laboratories.
- Polk, G., NL Baroid/NL Industries, K. Baughman, Poly Plug, Inc., and G. E. Loeppke, SELF-CONTAINED RIGID-FOAM PLACEMENT TOOL FOR PLUGGING LOST-CIRCULATION ZONES (SAND85-0937C), Sandia National Laboratories, Transactions of the Geothermal Resources Council 1985 International Symposium on Geothermal Energy (Vol. 9, Pt. I, August 1985, pp. 141-145), Kona, Hawaii, August 26-30, 1985.
- Rundle, J. B., C. R. Carrigan, H. C. Hardee, W. C. Luth, ASSESSMENT OF LONG VALLEY AS A SITE FOR DRILLING TO THE MAGMATIC ENVIRONMENT (SAND85-2356), Sandia National Laboratories.

Rundle, John B., Greg J. Elbring, Richard P. Striker, John T. Finger, Charles C. Carson, Marianne C. Walck, Sandia National Laboratories; William L. Ellsworth, David P. Hill, U.S. Geological Survey, Menlo Park, CA; Peter Malin, Enrique Tono, Michelle Robertson, Steve Kuhlman, University of California, Santa Barbara; Tom McEvelly, Richard Clymer, Lawrence Berkeley Laboratory, Berkeley, CA; Scott B. Smithson, Sharon Deemer, Roy Johnson, University of Wyoming, Laramie; Tom Henyey, Egill Hauksson, Peter Leary, John McCraney, University of Southern California, Los Angeles; Edi Kissling, Eidgenossische Technische Hochschule (ETH), Zurich, SEISMIC IMAGING IN LONG VALLEY, CALIFORNIA, BY SURFACE AND BOREHOLE TECHNIQUES: AN INVESTIGATION OF ACTIVE TECTONICS (SAND85-0517J), EOS 66, p. 194-200, April 30, 1985.

Scott, L. D., Mission Research Corporation and H.-T. Chang, FIELD PATTERNS FOR ANTENNAS SITUATED IN A SIMULATED BOREHOLE (SAND83-2673A), Sandia National Laboratories, 1984 International IEEE/AP-S Symposium and National Radio Science Meeting, Boston, MA, June 25-29, 1984.

Stone, C. M., T. G. Carne, and B. C. Caskey, QUALIFICATION OF A COMPUTER PROGRAM FOR DRILL STRING DYNAMICS, (SAND85-0633C), Sandia National Laboratories, Transactions of the Geothermal Resources Council 1985 International Symposium on Geothermal Energy, Kona, Hawaii, August 26-30, 1985.

Suhler, S. A., EVALUATION OF BOREHOLE ELECTROMAGNETIC AND SEISMIC DETECTION OF FRACTURE (SAND84-7109), Southwest Research Institute.

Traeger, R. K., STATE-OF THE ART: HIGH TEMPERATURE LOGGING (SAND83-2412A), Sandia National Laboratories, Borehole Measurements and Interpretation in Scientific Drilling Workshop, November 15-17, 1983

Traeger R. K., GEOSCIENCE EXPERIMENTS IN BOREHOLES: INSTRUMENTATION (SAND83-2413C), Sandia National Laboratories, International Symposium on Observation of the Continental Crust Through Drilling, May 21-25, 1984, Tarrytown, NY

Traeger R. K., TECHNOLOGIES FOR SCIENTIFIC DRILLING AND BOREHOLE RESEARCH (SAND85-1830C), Sandia National Laboratories, Albuquerque, NM

Traeger R. K., SANDIA GEOTHERMAL TECHNOLOGY PROGRAMS: INTERACTIONS WITH OTHER DOE RESEARCH AND CSDP, (SAND85-1871C), Sandia National Laboratories,

Walck, M. C., P-WAVE VELOCITY VARIATIONS IN THE COSO REGION, CALIFORNIA, DERIVED FROM LOCAL EARTHQUAKE TRAVEL TIMES, (SAND85-2661), Sandia National Laboratories; R. W. Clayton, California Institute of Technology.

Zeuch, D. H. and J. T. Finger, ROCK BREAKAGE MECHANISMS WITH A PDC CUTTER (SAND85-0443A), Sandia National Laboratories, Society of Petroleum Engineers 60th Annual Technical Conference and Exhibition, Las Vegas, NV, September 22-25, 1985.

Zeuch, D. H. and J. T. Finger, ROCK BREAKAGE MECHANISMS WITH A PDC CUTTER (SAND85-1439C), Sandia National Laboratories, Society of Petroleum Engineers Annual Technical Conference, Las Vegas, NV, September 22-25, 1985.

Distribution:

DOE/TIC-4500-UC-66 (212)

S. Adam
Brinkerhoff Signal
2 Houston Center, Suite 1010
Houston, TX 77010-1005

D. Allen
6411 Earham Drive
Bethesda, MD 20817

W. C. Allen
Union Oil Co. of Calif.
Research Dept.
P. O. Box 76
Brea, CA 92621

D. N. Anderson
Geothermal Resources Council
P. O. Box 1350
Davis, CA 95617

Roger N. Anderson
Lamont-Doherty Geological
Observatory
Palisades, NY 10964

T. Anderson
Drilling Fluid Consultants
17726 S. W. Overlook Ln.
Lake Oswego, OR 97034

Chuji Araki
Geothermal Energy Research
and Development Co., Ltd.
11-7, Kabuto-Cho
Nihonbashi, Chuo-Ku
Tokyo 103
Japan

J. F. Arestad
Santa Fe Geothermal, Inc.
3333 Lee Parkway
Dallas, TX 75219

Dr. C. Austin
Code 266
Geothermal Utilization Div.
Daval Weapons Center
China Lake, CA 93555

G. A. Barber
DOSECC
Room 316
2100 Pennsylvania Ave, NW
Washington, DC 20037

E. Bingman
Shell Oil Company
Two Shell Plaza
P. O. Box 2099
Houston, TX 77001

B. Bradford
Dowell
P. O. Box 2710
Tulsa, OK 74102

J. Bresee
U. S. Department of Energy
Geothermal Technologies Div.
Forrestal Bldg., CE 324
1000 Independence Ave., SW
Washington, DC 20585

A. Cassiano
Daily Directional Serv., Inc.
2018 W. Chandler
Santa Ana, CA 92704

B. Coats
Eastman Whipstock
P. O. Box 6923
Ventura, CA 93003

J. L. Colp, Vice President
Island Science, Inc.
1023 Washington, SE
Albuquerque, NM 87108

M. D. Clark
Mammoth Ranger District
Inyo National Forest
P. O. Box 148
Mammoth Lakes, CA 93546

J. Combs
Geothermal Resources Intl.,
Inc.
1825 S. Grant, Suite 900
San Mateo, CA 94402

O. L. Day
Geothermal Consulting Services
316 California Ave., No. 418
Reno, NV 89509

L. Diamond
Dyna-Drill
P. O. Box C-19576
Irvine, CA 92713

W. M. Dolan
Steam Reserve Corp.
1707 Cole Blvd.
Golden, CO 80401

T. Downey
Vetco Gray
Combustion Engineering, Inc.
250 W. Stanley Avenue
Ventura, CA 93001

Al Duba
Lawrence Livermore Natl. Lab.
University of California
P. O. Box 808
Livermore, CA 94550

T. Ecox
Dresser Industries
Magcobar Division
10201 Westheimer 1A
Houston, TX 77042

W. Elders
IGPP
University of California
Riverside, CA 92521

B. Ellsworth
U. S. Geological Survey
345 Middlefield Rd.
Menlo Park, CA 94025

J. R. Evans
Office of Earthquake Studies
Branch of Seismology
MS 77
U. S. Geological Survey
345 Middlefield Rd.
Menlo Park, CA 94025

J. E. Fontenot
NL, MWD
P. O. Box 60070
Houston, TX 77205

M. Friedman
Dean, Geosciences
Texas A&M University
College Station, TX 77843

R. Gardner
Dresser Industries
10920 Wilshire Blvd.
Suite 1100
Los Angeles, CA 90024

F. Goff
Los Alamos National Labs.
Los Alamos, NM 87545

N. E. Goldstein
Lawrence Berkeley Laboratory
B50A-1140
Berkeley, CA 94720

Barry W. Harding
Manager of Engineering
and Drilling Operations
Ocean Drilling Program
Texas A&M University
College Station, TX
77843-3469

C. A. Harper
Bechtel Group, Inc.
50 Beale Street
P. O. Box 3965
San Francisco, CA 94119

T. Henyey
Dept. of Geological Sciences
Univ. of Southern California
Los Angeles, CA 90007

J. F. Hermance
Dept. of Geological Sciences
Brown University
Providence, RI 02912

R. T. Hickethier
Hickethier & Associates
2828 Walnut Bend Lane
Houston, TX 77042

D. P. Hill
U. S. Geological Survey
345 Middlefield Road
MS 977
Menlo Park, CA 94025

T. Hiratsuka
Sunshine Project
Agency of Industrial Science
& Technology
Ministry of Intl. Trade &
Industry
1.3.1 Kasumigaseki
Chiyoda.Ku
Tokyo, Japan

A. S. Johnson
DOSECC
7805 Windfont Row
Parker, CO 80134

H. Kanamori
Seismological Laboratory
252-21
California Institute of
Technology
Pasadena, CA 91125

P. Kasameyer
Lawrence Livermore Labs.
P. O. Box 808
Livermore, CA 94550

D. W. Klick
U. S. Geological Survey
12001 Sunrise Valley Drive
MS 905
Reston, VA 22092

S. Knabe
Penzoil
Box 2967
Houston, TX 77252-2967

J. Knowlton
Smith International
P. O. Box 1860
Newport Beach, CA 92660

G. A. Kolstad
GPN Bldg., G-226
U. S. Department of Energy
Office of Basic Energy
Sciences
Washington, DC 20545

F. L. Kowatschitsch
TG-Exploration und Produktion
OMB Aktiengesellschaft
Otto-Wagner-Platz 5
A-1090 Wien
Federal Republic of Germany

L. E. Kukacka
Brookhaven National Laboratory
Associated Universities, Inc.
Upton, L.I., NY 11973

J. W. Langford
Security Division
Dresser Industries, Inc.
P. O. Box 24647
Dallas, TX 75224

T. K. Linscott
Santa Fe Geothermal, Inc.
3333 Lee Parkway
Dallas, TX 75219

B. J. Livesay
2616 Angell Ave.
San Diego, CA 92122

W. C. Lyons
Rift Engineering & Drilling
Co.
P. O. Box 2457
Santa Fe, NM 87504-2457

H. E. Mallory
P. O. Box 54696
Tulsa, OK 74144

E. Martin
Mobil Research &
Development Corp.
Dallas Research Laboratory
13777 Midway Road
Dallas, TX 75224

Claus Marx
Institute of Petroleum Engr.
Technical U. of Clausthal
D 3392 Clausthal-Zellerfeld
West Germany

Larry Matson
Stratabit
600 Kenrick, Suite A1
Houston, TX 77060

T. McEvilly
Lawrence Berkeley Laboratory
Bldg. 90, Rm. 1106
Berkeley, CA 94720

J. L. Moore
California Energy Company
3333 Mendocino Avenue
Santa Rosa, CA 95401

L. J. P. Muffler
U. S. Geological Survey
345 Middlefield Rd.
Menlo Park, CA 94025

Fred Ng
2300 W. Plano Pkwy.
Plano, TX 75075

J. Olsen
NL Industries
200 N. Berry Street
Brea, CA 92621

B. J. Perry
Mono Power Company
2244 Walnut Grove Ave.
Rosemead, CA 91170

G. F. Polk
NL Baroid
P. O. Box 280
Sandia Park, NM 87047

R. A. Pryde
California Energy Company
3333 Mendocino Ave.
Suite 100
Santa Rosa, CA 95401

Steve Pye
Union Geothermal Division
Union Oil Co. of California
Union Oil Center
Los Angeles, CA 90017

M. J. Reed
Geothermal & Hydropower
Technologies
U. S. Department of Energy
CE-324
Forrestal Building
Washington, DC 20585

Roger Renaldi
Resource Technology Inc
4555 S. Howard
Tulsa, OK 74135

D. A. Rennels
Foamair, Div. of Pool Co.
P. O. Box 4207
Grand Junction, CO 81502

J. C. Rowley
Los Alamos National Labs.
MS 570
Los Alamos, NM 87545

H. Rushing
H&H Oil Tool Co., Inc.
201 S. Hallock Drive
Santa Paul, CA 93060

M. P. Ryan
U. S. Dept. of the Interior
Geological Survey
Reston, VA 22092

D. G. Santti
Chevron Resources Co.
595 Market Street
San Francisco, CA 94120

John Sass
US Geologic Survey
2255 N. Gemini Dr.
Flagstaff, AZ 86001

Stan Serocki
Ocean Drilling Program
Texas A&M University
MS 3469
College Station, TX 77843

Wayne Simmons
Exxon Production Research
Box 2189
Houston, TX 77001

Morris Skalka
Geothermal Technologies
Division
U. S. Department of Energy
CE-324
Forrestal Building
Washington, DC 20585

B. Smith
Exlog-Smith
3740 Industry Ave., #303
Lakewood, CA 90712

D. Smith
Halliburton
Drawer 1431
Duncan, OK 73533

M. Sorey
U. S. Geological Survey
345 Middlefield Rd., MS 439
Menlo Park, CA 94025

Hermann F. Spoerker
OMV Otto-Wagner-Platz 5
A-1090 Vienna
Austria

S. Sugine, Jr.
L. A. Dept. of Water and Power
Room 1149
P. O. Box 111
Los Angeles, CA 90051

Shoichi Tanaka
The University of Tokyo
7.3.1 Hongo Bunkyo Ku
Tokyo 113
Japan

R. Toms
U. S. Department of Energy
Geothermal Technologies Div.
Forrestal Bldg., CE 324
1000 Independence Ave., SW
Washington, DC 20585

H. Waff
Department of Geology
University of Oregon
Eugene, OR 97403

T. Warren
Amoco Production Company
Research Center
P. O. Box 591
Tulsa, OK 74102

D. F. Weill
National Science Foundation
Earth Sciences Division
1800 G Street NW
Washington, DC 20550

H. Wollenberg
Earth Sciences Div. MS-50E
Lawrence Berkeley Laboratory
Berkeley, CA 94720

M. M. Wright
Earth Science Laboratory
Univ. of Utah Research Inst.
391 Chipeta Way, Suite A
Salt Lake City, UT 84108

L. Younker
Lawrence Livermore Labs.
Mail Code L-209
P. O. Box 808
Livermore, CA 94550

DOE/ALO G. P. Tennyson
DOE/ALO W. P. Grace

1511 G. G. Weigand
1511 D. K. Gartling
1513 D. W. Larson
1513 C. E. Hickox
1524 D. B. Longcope
1540 W. C. Luth
1541 H. C. Hardee
1541 C. R. Carrigan
1541 G. J. Elbring
1541 J. B. Rundie
1541 M. C. Walck
1543 T. M. Gerlach
1543 R. T. Cygan
1543 J. C. Eichelberger
1543 H. R. Westrich
1543 H. R. Stockman
1543 J. L. Krumhansl
1830 M. J. Davis
1841 R. B. Diegle
1841 L. J. Weirick
3141 S. A. Landenberger (5)
3151 W. L. Garner (3)
3161 N. S. Hey
6000 E. H. Beckner
6200 V. L. Dugan
6240 R. K. Traeger (10)
6240 D. L. Cooper (10)
6242 J. C. Dunn (20)
6246 B. Granoff
6250 B. W. Marshall
6330 W. D. Weart
8024 P. W. Dean