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Geotechnology Publications and Related Reports: A Bibliography January Through December 1988

Christina Tolendino

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GEOTECHNOLOGY PUBLICATIONS AND RELATED REPORTS: A BIBLIOGRAPHY JANUARY THROUGH DECEMBER 1988

Christina Tolendino, Editor
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Abstract

This document is a collection of abstracts of papers prepared as part of the Sandia programs in the GeoEnergy Technology Department and other closely related research. Areas of technology represented are resource access (drilling, blasting), resource extraction (enhanced recovery) and geodiagnostics. More basic work in the Geosciences is in a separate chapter. Industry programs and Technology Transfer constitute a final section. That section also includes our geotechnical support to DOE on the Strategic Petroleum Reserve in which we work closely with the SPR site contractor.

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I. Introduction

This bibliography lists the publications discussing R&D activities performed in or for the GeoEnergy Technologies Department, 6250, at Sandia National Laboratories. All of this R&D focuses on subsurface engineering and processes. This bibliography does not include the other extensive geotechnology work at the Laboratory in fundamental research, waste repository studies or nuclear treaty verification technologies.

Copies of the publications are available from the referenced journals or conferences, or from NTIS for the Sandia reports.

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II. Resource Access

II A. Drilling

DESIGN AND EVALUATION OF LOST CIRCULATION MATERIALS FOR SEVERE ENVIRONMENTS (SAND88-1910C), G. E. Loeppke, D. A. Glowka, E. K. Wright, Sandia National Laboratories, 1988 SPE Annual Technical Conference and Exhibition, Houston, TX, October 2-5, 1988.

An independent analysis of lost circulation materials for geothermal applications has been completed using unique laboratory tools developed for the purpose. Test results of commercial materials as well as mathematical models for evaluating their performance are presented. Physical attributes that govern the performance of lost circulation materials are identified and correlated with test results.

CORING IN DEEP HARDROCK FORMATIONS (SAND88-1018), D. S. Drumheller, Sandia National Laboratories, July 1988.

The United States Department of Energy is involved in a variety of scientific and engineering feasibility studies requiring extensive drilling in hard crystalline rock. In many cases well depths extend from 6,000 to 20,000 feet in high-temperature, granitic formations. Examples of such projects are the Hot Dry Rock well system at Fenton Hill, New Mexico and the planned exploratory magma well near Mammoth Lakes, California. In addition to these programs, there is also continuing interest in supporting programs to reduce drilling costs associated with the production of geothermal energy from underground sources such as the Geysers area near San Francisco, California. The overall progression in these efforts is to drill deeper holes in higher temperature, harder formations. In conjunction with this trend is a desire to improve the capability to recover geological information. Spot coring and continuous coring are important elements in this effort. It is the purpose of this report to examine the current methods used to obtain core from deep wells and to suggest projects which will improve existing capabilities.

DRILLING PROGRAM FOR LONG VALLEY CALDERA (SAND88-0820C), J. T. Finger, Sandia National Laboratories, Annual DOE Geothermal Program Review VI, San Francisco, CA, April 19-21, 1988.

In September of this year, we will begin the first of four drilling phases in the Magma Energy Exploratory Well that is planned to reach a depth near 20,000 feet. This well will be used to verify the configuration of the magma body and to calibrate surface geophysical techniques against downhole data. It will also provide information of several kinds that is of interest to several groups: (1) We will resolve geologic uncertainties--such as the location of fractured and abnormally pressured zones, chemistry of rocks and produced fluids, and magnitude of creep in the deep basement--that affect the drilling of any subsequent well, (2) We will test drilling technology--e.g., high temperature drilling fluid, bits, coring, logging tools and tubulars--in a realistic environment, and (3) We will gain insight on the history of collapse, resurgence, and intrusion in a major young caldera.

REDUCING DRILLING AND COMPLETION COSTS--HARD ROCK PENETRATION RESEARCH (SAND88-1021A), J. C. Dunn, Sandia National Laboratories, Annual DOE Geothermal Program Review VI, San Francisco, CA, April 19-21, 1988.

Hard Rock Penetration research is directed at reducing the costs associated with drilling and completing geothermal wells. The goal is to reduce these costs by about 20 percent by 1992. The program is divided into three major elements: borehole mechanics, rock penetration mechanics, and industry cost shared research. Current research topics include lost circulation control, high temperature drilling, coring technology development, drill string dynamics, fracture mapping using downhole radar, and acoustical data telemetry through drill pipe.

DESIGN AND EVALUATION OF LOST CIRCULATION MATERIALS FOR SEVERE ENVIRONMENTS (SAND87-2568A), G. E. Loeppke, Sandia National Laboratories, IADC/SPE 1988 Drilling Conference, Dallas, TX, February 28-March 2, 1988.

Sandia National Laboratories is actively involved in geothermal drilling technology development. One aspect of this work is the development and evaluation of materials and methods for the most severe and troublesome lost circulation problems. Materials have been tested in the large-scale Lost Circulation Test Facility and in a modified API RP 13I bridging materials test cell which has been modified and instrumented for computerized data collection and reduction.

Recent results from this independent analysis of commercial lost circulation materials will be presented. Test results and material attributes will be compared for several lost circulation materials, including plugging ability, compressive strength, temperature stability, resiliency, wettability and material stability. It will be shown that plugging performance can be significantly improved by controlling the particle size distribution or by combining particle shapes.

The test facilities and methods used in the evaluation process will be described. The relative merits and shortcomings of the API test as a standard for evaluating lost circulation materials will be discussed based on a large number of carefully controlled tests on numerous materials.

BOREHOLE TECHNOLOGIES FOR EXTREME ENVIRONMENTS (SAND88-2370C), R. K. Traeger, Sandia National Laboratories, Proceedings of International Symposium on Super-Deep Continental Drilling and Deep Geophysical Research, Yaroslavl, USSR, August 23-29, 1988.

Problems unique to drilling and making downhole measurements in thermal regimes will be discussed. The technologies relevant to providing research wells in the US DOE Continental Scientific Drilling Program and the planned Magma Energy well will be reviewed. Problems covered will include temperature, lost circulation, hydrogen sulfide hazards, and fractured rock. Technologies considered will include a wire line coring operations, and self contained borehole instrumentation.

THE THERMAL RESPONSE OF ROCK TO FRICTION IN THE DRAG CUTTING PROCESS (SAND88-1481C), D. A. Glowka, Sandia National Laboratories, International Conference on Friction Phenomena in Rock, Fredericton, New Brunswick, Canada, August 24-26, 1988.

Significant friction between the cutter and the rock occurs during the drag cutting process. This friction is responsible for elevating the temperature of the drag cutter and, under certain conditions, reducing cutter life. Because of this effect, friction often plays a major role in determining the economics of drilling with drill bits employing polycrystalline diamond compact (PDC) cutters. Analytical models have been developed in previous studies for predicting PDC cutter temperatures and their effects on bit wear and performance.

The current paper investigates the effects of drag cutter friction on the rock. The thermal and mechanical loading imposed during the cutting process is described, with emphasis on the rock response. Of particular interest is the thermal response of the rock to the frictional heating and convective cooling conditions imposed during drilling. The friction and thermal models developed for PDC cutters are extended and applied to quantitatively determine these conditions for the typical downhole environment. An analytical solution is then applied to determine the thermal response of the rock mass.

The results show that contact pressures and temperatures experienced by rock chips during the drag cutting process are in the range where a limited degree of metamorphism of some rock constituents is possible. It is concluded that because of the brief exposure time and shallow penetration of frictional heat, any metamorphic changes that do occur do not extend more than a fraction of a millimeter beyond the rock surface.

SIGNIFICANCE OF DRILLING- AND CORING-INDUCED FRACTURES IN MESAVERDE CORE, NORTHWESTERN COLORADO (SAND87-1111), J. C. Lorenz and S. J. Finley, Sandia National Laboratories, June 1988

Several types of mechanically induced fractures occur in Mesaverde core from the US Department of Energy's Multiwell Experiment wells. Two types of fractures have significance to the determination of in situ stresses. (1) Scribe-line fractures originate at orientation grooves on the surface of the core and are initiated by scribing knives in the core barrel minutes after the core is cut free from the surrounding rock. In sandstone, they strike parallel to the maximum in situ horizontal stress direction that has been determined in these wells by anelastic strain recovery measurements. (2) Drilling- or coring-induced petal and petal-centerline fractures form just below the advancing core bit. Their strike is controlled primarily by the in situ stress, but locally may be influenced by shear stress created by bit rotation. Large shear stress may reorient petal fracture strikes in the direction of bit rotation, oblique to the maximum in situ horizontal stress direction. In most situations, however, orientations of these two types of fractures may be used to determine the orientation of the in situ stresses relative to natural fractures, and ultimately whether a stimulation fracture will parallel or intersect natural fracture permeability systems in a reservoir.

II B. Blasting

DESIGN AND PRETEST NUMERICAL SIMULATIONS OF BENCH-SCALE BLASTING EXPERIMENTS IN GRANITE (SAND88-2729A), D. S. Preece and P. M. Drozda, Sandia National Laboratories, 30th US Symposium on Rock Mechanics, University of West Virginia, Morgantown, WV, June 19-21, 1989.

A series of bench-scale experiments has been designed to provide further validation of the current methods used for numerical simulation of the blasting process. In bench-scale experiments there is a higher degree of control over critical variables than there is in field cratering tests. For example, geometric tolerances are tighter, explosive weights more accurate and the experimental core can be selected to be free from natural joints and fractures. The bench-scale experiments also represent a totally different scale than the field experiments which is an important test of the physics involved in the simulation.

The proposed experimental design presented here is the result of numerous computer simulations using PRONTO2D. The design parameters to be adjusted included experiment geometry (height, diameter and charge location) and charge size. This paper contains pretest numerical simulations of the final experimental configurations and will be compared with experimental data in the following areas: 1) initial surface velocities, 2) fragment size distributions, and 3) crater geometry. The actual experiments will be performed over the next few months and the results will be published in a separate paper. Publication of numerical predictions prior to the experiments is deemed to be good scientific practice.

A SPHERICAL ELEMENT MESH GENERATOR USING A SCAN-LINE TECHNIQUE (SAND88-1897A), D. S. Preece, 8th CUBE Symposium, Sandia National Laboratories, November 16-18, 1988.

Conventional rock blasting has traditionally been modeled with a shock wave propagation and fragmentation phase followed by a rock motion phase. Because the nature of the two phases of this problem are so different, two different means of computation are applied to each. A finite element approach is used to calculate the shock wave propagation during the first phase and a discrete element approach is used to calculate the motion of rock material during the second phase. Transfer of data in the form of calculated fragment sizes and shock induced residual velocities has been done manually in the past. In order to automate the process, a spherical mesh generator has been written.

The spherical mesh generator requires as input a closed boundary defined by nodes and straight lines. The sphere diameter is used to determine the spacing of a series of horizontal scan-lines through the region. The intersections of each scan-line with the boundary is used to determine how the scan-line will be filled with spheres. The horizontal positions of the spheres on alternate rows are adjusted to result in close-packing.

After the wave propagation phase, groups of fragmented finite elements can be defined around which boundaries can be traced. These boundaries are then used by the spherical mesh generator to fill the fragmented regions with spheres. Interpolation of velocities from the finite element model to the spherical element model is then performed automatically and the information transferred to the discrete element code.

The presentation will cover the scan-line mesh generation algorithm as well as applications of the mesh generation capability to several blasting simulations.

III. Resource Extraction

III A. Magma

THERMAL CONVECTION WITH LARGE VISCOSITY VARIATION IN AN ENCLOSURE WITH LOCALIZED HEATING (SAND88-2122A), C. E. Hickox and T. Y. Chu, Sandia National Laboratories, 8th Biennial CUBE Symposium, Albuquerque, NM, November 16-18, 1988.

The present study is undertaken in order to gain an understanding of convective transport in a magma chamber, and is being pursued in support of the Magma Energy Extraction Program at Sandia National Laboratories. Our approach is to first characterize convection in a magma chamber and then to examine the convective heat transfer to an inserted energy extraction device. Typically, a magma chamber is periodically replenished at a discrete location. Hence, we represent the magma chamber as an enclosure with localized heating from below. We describe initial results obtained from numerical simulations of a laboratory-scale experiment that is being used to investigate several aspects of natural convection in a magma chamber.

The experimental apparatus consists of a transparent enclosure with a square planform. An electrically heated strip, with a width equal to one-fourth the length of a side of the enclosure, is centered on the lower inside surface of the enclosure. The large viscosity variation characteristic of magma convection is simulated by using corn syrup as the working fluid. The top of the fluid layer is maintained at a constant temperature and the depth of the layer is equal to the width of the heated strip.

The experiment is numerically simulated through use of a finite element computer program based on the Galerkin formulation of the finite element method. The flow field is assumed steady, planar, and incompressible, the fluid is assumed Newtonian, and the Boussinesq approximation is invoked. A discontinuous pressure discretization is used and a consistent penalty function approach is adopted to enforce the incompressibility constraint. Steady-state simulations are obtained iteratively through use of successive substitution followed by Newton-Raphson iteration. The iteration procedure is typically initiated from a previously converged solution.

Numerically predicted streamlines, isotherms, and velocity distributions are presented for selected values of Rayleigh number, Prandtl number, and overall viscosity contrast. Good agreement is demonstrated between numerical predictions and experimental results.

THERMAL CONVECTION WITH LARGE VISCOSITY VARIATION IN AN ENCLOSURE WITH LOCALIZED HEATING (SAND88-0271C), T. Y. Chu and C. E. Hickox, Sandia National Laboratories, ASME Winter Meeting, Chicago, IL, November 28-December 2, 1988.

The present study is undertaken in order to gain an understanding of convective transport in a magma chamber and is being pursued in support of the Magma Energy Extraction Program at Sandia National Laboratories. The approach taken in our studies is to first characterize the convection in the magma chamber and then to examine the convective heat transfer to an energy extraction device inserted into the magma chamber. Typically, a magma chamber is periodically recharged at a discrete location. Hence, we elect to represent the magma chamber as an enclosure with localized heating from below. Specifically, the enclosure chosen for study has a square planform with a heated strip centered on the lower inside surface of the enclosure. The large viscosity variation characteristic of magma convection is simulated by using corn syrup as a working fluid. Results from laboratory experiments and computer modeling are presented.

Thermal convection is of continuing interest because of its application in the modeling of flow and energy transfer in geophysics, meteorology, and astrophysics as well as in numerous applications to engineering systems. The numerical modeling of Torrance of Turcotte, which treats thermal convection between horizontal free boundaries, appears to be the first such study to consider large viscosity variations. For a Rayleigh number of 3600, the viscosity variation was found to exert a significant influence on the flow field. Richter, et al, and Brooker experimental investigated thermal convection with large viscosity variations in a horizontal fluid layer using a variety of working fluids including a golden syrup. In addition, Richter, et al., also measured horizontally-averaged temperatures in the fluid layer. Their results indicate that the Nusselt number Nu for the variable viscosity cases can be approximated by the constant viscosity results if the correlation is cast in a form where the Rayleigh number Ra is normalized with the Rayleigh number at the onset of convection, i.e., $Nu = C(Ra/Ra_c)^n$, where C is a constant and the c-subscript indicates a critical value. Furthermore, temperature measurements showed the existence of a stagnant conduction zone above the actively convecting part of the layer.

RESEARCH TO TAP THE CRUSTAL MAGMA SOURCE (SAND88-1020A), J. C. Dunn, Sandia National Laboratories, Annual DOE Geothermal Program Review VI, San Francisco, CA, April 19-21, 1988.

Thermal energy contained in magmatic systems represents a huge potential resource. In the US, useful energy contained in molten and partially-molten magma within the upper 10 km of the crust has been estimated at 50,000 to 500,000 Quads. The goal of the Magma Energy Extraction Program is to determine the engineering feasibility of locating, accessing, and utilizing magma as a viable energy resource. The stated Level I objective is to develop technology that would enable magma generated power to be produced in the cost range of 10 to 20 cents/kWh by the year 2000. Realization of this objective will require progress in four critical areas. (1) Magma location and definition - crustal magma bodies must be located and defined in enough detail to locate the drill. (2) Drilling - high temperature drilling and completion technology require development for entry into magma. (3) Materials - engineering materials need to be selected and tested for compatibility with the magmatic environment. (4) Energy extraction - heat extraction technology needs to be developed to produce energy extraction rates sufficient to justify the cost of drilling magma wells.

MAGMA ENERGY (SAND83-1842J), H. C. Hardee, Sandia National Laboratories, Geothermal Science & Technology, Vol 1, No. 2, pp. 165-224, 1988.

A program to investigate the feasibility of magma energy was initiated at Sandia National Laboratories in 1975 under the sponsorship of the DOE Office of Basic Energy Sciences. Evidence accumulated over seven years of Magma Energy Research Program established that it is scientifically feasible to extract energy from extensive sources of shallow molten magma deposits in the crust. The USGS estimates the amount of the magma resource in the upper 10 km of the crust of the continental western United States to be of a quantity equal to 800 to 8000 times the total annual United States energy consumption. Theoretical studies coupled with laboratory and field experiments indicate that it is scientifically feasible to drill into a magma body and extract large amounts of useful heat. Field experiments have been conducted at volcanic eruption sites and in lava lakes. These experiments have examined: the geophysical state of molten rock, methods of drilling molten rock and heat extraction techniques. An advanced heat exchanger, tested in the molten lava of Kilauea Iki Lava Lake in 1981, produced steady heat extraction rates of 180 kW/m^2 and transient extraction rates as high as 1 kW/m^2. These high heat extraction rates combined with the enormous magnitude of the magma resource will make magma a major energy source of the future.

The Magma Energy Program moved into the engineering feasibility stage in 1983. This program, sponsored by the Geothermal Technology Division of

DOE, concentrates on the development of technology and hardware necessary to build a magma energy plant. A major milestone will be the completion of a long-term experiment that includes drilling into an actual crustal magma body in the western United States and emplacing energy extraction hardware.

THE BIOT NUMBER AND THE "THERMOS BOTTLE" EFFECT: IMPLICATIONS FOR MAGMA CHAMBER CONVECTION (SAND87-0659J), C. R. Carrigan, Sandia National Laboratories, Geology, Vol. 16, No. 9, pp. 771-774, September 1988.

Thermal boundary conditions applied at the margin of a convecting magmatic body represent, implicitly, the thermal coupling between the host and intrusion. Such conditions are often required for geologic models involving thermal histories, temperature dependent processes such as crystallization and processes involving magmatic convection. Usually, investigations of magmatic systems have tended to emphasize modelling the interior convective regime relative to treatment of the thermal coupling. Yet it is found that thermal nature of an intrusion is likely to be influenced more by its coupling to the host than by the details of internal convective flows. Evaluation of a parameter having the form of a Biot number provides a basis for estimating which boundary conditions are most appropriate. It is found that $Bi \leq .1$ (constant heat flux limit) for models of several caldera systems. In this limit of the Biot number, the host regime behaves something like a "thermos" by limiting the flow of heat from the intrusion in a manner that is somewhat independent of the state of magmatic convection.

DEGASSING OF RHYOLITIC MAGMA DURING ASCENT AND EMPLACEMENT (SAND87-1419J), H. R. Westrich, H. W. Stockman and J. C. Eichelberger, Sandia National Laboratories, J. Geophysical Research, Vol. 93, No. B6, pp. 6503-6511, 1988.

The degassing history of a rhyolitic igneous system was documented from analyses of drill-core samples through the extrusive and intrusive portions of Obsidian Dome and of surface samples of associated tephra. The initial volatile composition of the Inyo magma was estimated to be 4.0 wt percent H_2O, 500 ppm F, 800 ppm C1, and 80 ppm S. Retained volatile contents of glassy and crystalline samples reflect the effects of decompression and second boiling. Decompression is rapid, and involves loss of water-rich fluid until a close approach to lithostatic equilibrium is achieved. Second boiling is a slower process and produces a chlorine-rich fluid, some of which can be trapped during development of extremely fine crystallization textures. Nearly complete dewatering during decompression of surface-extruded magma strongly undercools the system ($\Delta T \approx 175°C$), suppressing crystallization and yielding glassy rhyolitic lava. partial degassing of shallowly intruded magma permits pervasive crystallization even at high cooling rates. The subvolcanic intrusive regime is the zone of maximum volatile release, because second boiling is incomplete in extrusives, and volatile-bearing crystalline phases are stable in magma crystallized at greater depth.

RECENT ADVANCES IN MAGMA ENERGY EXTRACTION (SAND88-0876A), T. Y. Chu, Sandia National Laboratories, Annual DOE Geothermal Program Review VI, San Francisco, CA, April 19-21, 1988.

Research in Magma Energy Extraction is aimed at developing engineering capability to extract energy directly from crustal magma bodies. It is envisioned that energy will be extracted by direct-contact heat transfer where a working fluid is circulated through a mass of solidified and fractured magma, first established during drilling, surrounded by a convecting magma body. The paper presents results of recent research in four areas: (1) thermal stress fracturing during solidification, (2) laboratory demonstration of drilling into a molten body, (3) experimental and numerical simulation of convection in magma, and (4) thermodynamic system analysis of energy conversion in a magma power plant. Experiments using a low temperature simulant showed that a magma-like material during solidification will produce a regular three-dimensional network of interconnecting fractures. We have also demonstrated experimentally, in the laboratory, for the first time the solidifying while drilling technique proposed for drilling into molten magma.

III B. Tight Gas

INSIGHTS INTO NATURAL GAS PRODUCTION FROM LOW PERMEABILITY RESERVOIRS (SAND87-3057C), D. A. Northrop, Sandia National Laboratories, Proceedings of the 1988 SPE Gas Technology Symposium, Dallas, TX, June 13-15, 1988.

Insights have been gained into natural gas production from low permeability sandstone reservoirs in the western United States as a result of the US Department of Energy's Multiwell Experiment (MWX). Three wells, between 110 and 215 ft (34-66 m) apart at depth, have been drilled at a site southwest of Rifle, Colorado, in the Piceance Basin, where the Cretaceous-age Mesaverde lies at a depth of 4,000 to 8,250 ft (1220-2520 m). Activities have been conducted in the lowermost Corcoran-Cozzette marine sandstones and in the overlying paludal, coastal, and fluvial nonmarine intervals. Insights include: (1) the depositional environment controls reservoir morphology, size, internal structure, and natural fracturing; thus, it must be discerned in order to optimize completions and interpret reservoir performance, (2) natural fractures, even if small and mineralized, are the dominant production mechanism in these, and probably most other, very tight reservoirs; (3) breakdowns and extended cleanup and test times are required for accurate reservoir assessment; (4) effectiveness of hydraulic fracturing appears limited by an anisotropic natural fracture system, high fracturing pressures, accelerated leakoff, and damage to the natural fracture system; and (5) in situ stress behavior varies with depth and lithology, is complex, and significantly affects stimulation and gas production.

PERMEABILITY DAMAGE TO NATURAL FRACTURES CAUSED BY FRACTURING FLUID POLYMERS (SAND87-2514C), B. L. Gall, A. R. Sattler, D. R. Maloney, C. J. Raible, Sandia National Laboratories, Proceedings of 1988 Rocky Mountain Regional Meeting, Casper, WY, May 16-18, 1988.

Formation damage studies using artificially fractured, low-permeability sandstone cores indicate that viscosified fracturing fluids can severely restrict gas flow through these types of narrow fractures. These studies were performed in support of the Department of Energy's Multiwell Experiment (MWX). The MWX program was a coordinated research effort to study methods to evaluate and enhance gas production from low-permeability lenticular reservoirs of the Western United States.

Extensive geological and production evaluations at the MWX site indicate that the presence of a natural fracture system is largely responsible for unstimulated gas production. The laboratory formation damage studies were designed to examine changes in cracked core permeability to gas caused by fracturing fluid residues introduced into such narrow fractures during fluid leakoff.

Polysaccharide polymers caused significant reduction (up to 95 percent) to gas flow through cracked cores. Polymer fracturing fluid gels used in this study included hydroxypropyl guar, hydroxyethyl cellulose, and xantham gum. In contrast, polyacrylamide gels caused little or no reduction in gas flow through cracked cores after liquid cleanup. Other components of fracturing fluids (surfactants, breakers, etc.) caused less damage to gas flows.

The results of fluid leakoff tests indicated that polysaccharide polymers caused a filter cake buildup at or near the crack entrance while polyacrylamide polymers did not cause a filtercake buildup within the time period of the tests. For xantham gum gels containing polymer breakers, 100 gels containing polymer breakers. For gels contain polymer breakers, 100 mesh sand was an effective fluid-loss control agent for narrow fractures.

Other factors affecting gas flow through cracked cores were investigated, including the effects of net confining stress and non-Darcy flow parameters.

Results are related to some of the problems observed during the stimulation program conducted for the MWX.

RESULTS OF THE MULTIWELL EXPERIMENT: IN SITU STRESSES NATURAL FRACTURES, AND OTHER GEOLOGICAL CONTROLS ON RESERVOIRS (SAND87-3064J), J. C. Lorenz, N. R. Warpinski, L. W. Teufel, P. T. Branagan, A. R. Sattler and D. A. Northrop, Sandia National Laboratories, EOS, Vol. 69, No. 35, pp. 817, 825-826, August 30, 1988.

Hundreds of millions of cubic meters of natural gas are locked up in low permeability natural gas reservoirs. The Multiwell Experiment (MWX) was designed to characterize such reservoirs, typical of much of the western United States, and to assess and develop a technology for the production of this unconventional resource. Flow-rate tests of the MWX reservoirs indicate a system permeability that is several orders of magnitude higher than laboratory permeability measurements made on matrix-rock sandstones. This enhanced permeability is caused by natural fractures. The single set of fractures present in the reservoirs provides a significant permeability anisotropy that is aligned with the maximum in situ horizontal stress. Hydraulic fractures therefore form parallel to the natural fractures and are consequently an inefficient mechanism for stimulation. Successful stimulation may be possible by perturbing the local stress field with a large hydraulic fracture in one well so that a second hydraulic fracture in an offset well propagates transverse to the natural fracture permeability trend.

INSIGHTS AND CONTRIBUTIONS FROM THE MULTIWELL EXPERIMENT--A FIELD LABORATORY IN TIGHT GAS SANDSTONE RESERVOIRS (SAND88-0268C), D A. Northrop, Sandia National Laboratories, K.-H. Frohne, Morgantown Energy Technology Center, SPE Proceedings of 63rd Annual Technical Conference and Exhibition, Houston, TX, October 2-5, 1988.

The US Department of Energy's Multiwell Experiment (MWX) has led to insights and contributions into the technology for natural gas production from low permeability sandstone reservoirs in the western United States. Three wells, between 110 and 215 ft (34-66 m) apart at depth, have been drilled in the Piceance Basin of Colorado, where the Cretaceous-age Mesaverde, the formation of interest, lies at a depth of 4,000 to 8,250 ft (1220-2520 m). Tests have been conducted in the lowermost Corcoran-/cozzette marine sandstones and in the overlying paludal, coastal, and fluvial nonmarine intervals. Insights were gained in the areas of: (1) depositional environments, (2) natural fractures, (3) techniques for accurate reservoir assessment, (4) effectiveness of hydraulic fracturing, and (5) in situ stress behavior. Contributions to technology include: (1) improved core analysis capability, (2) demonstration of Stratapax™ core bits, (3) importance of depositional environments and natural fractures to tight Mesaverde production, (4) a computerized log analysis system and service, (5) new stress testing procedures, (6) detailed geologic and reservoir model for the Mesaverde, (7) comprehensive technical data base for the Mesaverde. The paper draws upon several years of MWX results to illustrate these insights and contributions which have enhanced industry's ability to recover gas from this large resource.

A CASE STUDY OF A STIMULATION EXPERIMENT IN A FLUVIAL TIGHT SANDSTONE GAS RESERVOIR (SAND88-0206C), N. R. Warpinski, A. R. Sattler, J. C. Lorenz and B. J. Thorne, Sandia National Laboratories, P. T. Branagan and C. L. Cipolla, CER Corporation, SPE Proceedings of 63rd Annual Technical Conference and Exhibition, Houston, TX, October 2-5, 1988.

A successful stimulation experiment has been conducted in a fluvial sandstone of the Mesaverde Formation at the Department of Energy's Multiwell Experiment site in the Piceance basin of Colorado. This highly heterogeneous sandstone has submicrodarcy matrix permeability but also contains narrow natural fractures that increase the reservoir permeability to 15 microdarcies. Examination of the core showed a primary, unidirectional, natural fracture system with evidence (unlike previous zones) for second and third sets at oblique orientations. The stimulation experiment consisted of stress tests, a three-well prefrac interference test, step-rate/flow-back tests, a minifrac, a full stimulation treatment, borehole geophone diagnostics during fracturing, and a post-frac interference test. Prefrac rates of 65 MSCFD were measured and a permeability anisotripy ratio of 10:1 was inferred. Ten stress tests yielded containment barriers of 600-700 psi abutting the reservoir, lower than previous zones. Minifrac results showed that leakoff was very high during injection because of loss into the natural fractures. This leakoff was successfully controlled with 100 mesh sand during the treatment. A foam fluid with a new breaker system was used to minimize damage to the natural fractures. Borehole geophones in observation wells indicated that propped fracture length was at least 250 ft on each wing and fracture height was about 120 ft. After the stimulation, the well cleaned up readily and was flowing over 300 MSCFD within 24 hours. Flow rates after 16 days of production were 200-220 MSCFD and little damage to the natural fractures was evident. Anisotropic behavior persisted through a postfrac interference test.

MULTIWELL EXPERIMENT FINAL REPORT: II. THE PALUDAL INTERVAL OF THE MESAVERDE FORMATION (SAND88-1008), D. A. Northrop, Sandia National Laboratories, May 1988.

The Department of Energy's Multiwell Experiment (MWX) is a field laboratory in the Piceance Basin of Colorado which has two overall objectives: to characterize the low permeability gas reservoirs in the Mesaverde Formation and to develop technology for their production. Different depositional environments have created distinctly different reservoirs in the Mesaverde, and MWX has addressed each of these in turn. This report presents a comprehensive summary of results from the paludal interval which lies between 6600 ft and 7450 ft at the MWX site. The environment consisting of interbedded sandstone channels, carbonaceous siltstones and mudstones, and coals. Separate sections of this report log analysis; core analysis; in situ stress; well testing and analysis of one zone; well testing, stimulation, analysis and reservoir evaluation of another zone; supporting laboratory studies; hydraulic fracture diagnostics; and a bibliography. Additional detailed data, results, analyses, and data file references are given on microfiche in several appendices. Overall, the results show that the paludal is a complex, interesting, and productive interval.

STIMULATION-FLUID SYSTEMS FOR NATURALLY FRACTURED TIGHT GAS SANDSTONES: A GENERAL CASE STUDY FROM MULTIWELL EXPERIMENT STIMULATIONS (SPE-17717), A. R. Sattler, Sandia National Laboratories, C. J. Raibel and B. L. Gall National Institute for Petroleum and Energy Research, P. J. Gill, Schlumberger, Inc., SPE Gas Technology Symposium, Dallas, TX, June 1988.

Extensive production testing and core analyses show that prestimulation production from the low-permeability sandstones in the Mesaverde formation at the Department of Energy's Multiwell Experiment (MWX) field laboratory is dominated by natural fractures. Experience gained during MWX stimulations in these tight Mesaverde reservoirs strongly suggests that damage to the narrow natural fractures is an important factor affecting poststimulation production. This paper summarizes the field data showing both evidence for production from natural fractures and evidence for interactions between natural fractures and stimulation fluids resulting in decreased gas production. The nature of these interactions is clarified through a description of laboratory studies dealing with the degradation of the stimulation fluids and with the permeability damage of artificially fractured core exposed to the stimulation fluids. Evidence is very strong that damage from stimulation fluids to the narrow natural fractures restricted the production of gas in early MWX stimulations, a hypothesis that is consistent with the partial reversibility of fluid damage in the natural fractures of one zone following a long-term shut-in. A controlled breaker system was designed for use with the relatively clean, temperature-stable biopolymer foam. Use of this fluid system in a later MWX stimulation substantially increased gas production and reduced evidence of damage.

CHARACTERIZATION OF NATURAL FRACTURES IN MESAVERDE CORE FROM THE MULTIWELL EXPERIMENT (SAND88-1800), S. J. Finley and J. C. Lorenz, Sandia National Laboratories, September 1988.

Natural fractures dominate the permeability of tight sandstone reservoirs in the Mesaverde Formation of the Piceance Creek Basin, northwestern Colorado. Roughly 1900 natural fractures, detected in 4200 ft of Mesaverde core from the US Department of Energy's Multiwell Experiment (MWX), have been differentiated into ten different fracture types on the basis of fracture morphology, inclination, the presence of slickensides, the presence of dickite mineralization and/or host lithology. Approximately 75 percent of the MWX core fractures are dewatering planes in mudstone and are probably unimportant to reservoir permeability. The remaining 25 percent of the MWX core fractures include 275 mostly calcite-mineralized, vertical extension fractures, 61 irregular, dickite-mineralized extension fractures, 27 mostly calcite-mineralized, horizontal extension fractures, and 90 slickensided, occasionally mineralized shear fractures. These extension and shear fractures are all potentially important to reservoir permeability and consequently productivity.

FINAL TECHNICAL POSTER SESSION FOR THE MULTIWELL EXPERIMENT, SPE/DOE SYMPOSIUM ON LOW PERMEABILITY RESERVOIRS (SAND88-2678), S. J. Finley, Sandia National Laboratories, May 19, 1987.

A special technical poster session describing the Multiwell Experiment was held during the 1987 Society of Petroleum Engineers/US Department of Energy Symposium on Low Permeability Reservoirs, May 18-19, 1987, Denver, Colorado. Project activities and results were summarized by depositional environment. The overall project contributions were outlined. This summary provides a photographic record of the information presented at that technical session and identifies personnel associated with the various activities.

DISTRIBUTION OF REGIONAL FRACTURES AND FRACTURE PERMEABILITY CONTROLLED BY SEDIMENTOLOGICAL HETEROGENEITIES, MESAVERDE RESERVOIRS, COLORADO (SAND88-0826A), J. C. Lorenz and S. J. Finley, Sandia National Laboratories, 1988 Rocky Mountain Section Meeting, Bismarck, North Dakota, August 21-24, 1988.

Nonmarine sedimentation processes in lenticular Mesaverde sandstones of the Piceance basin, Colorado, created in irregular distribution of subunits within the present low-permeability reservoirs. The different lithologies have not only different porosities and permeabilities, but different mechanical and stress properties as well. These strata were fractured during horizontal tectonic compression, creating a regional fracture system. Because of low stress conditions during fracturing, the extent and distribution of fractures were governed by the differences in rock properties, pore pressures, and in situ stresses that were associated with the different reservoir heterogeneities. Well tests and laboratory measurements show that the fractures create economic (millidarcy) reservoirs out of submicrodarcy matrix rock. However, average fracture spacing and height - as measured in 4000 ft of core and observed in outcrop are commonly less than gross bed thickness by a factor of at least ten, and fractures are irregularly distributed within the reservoirs. No fractures extend the full thickness of any sandstone greater than six feet thick, whereas most reservoirs of interest are 20-50 ft thick. Between 20 and 25 percent of all vertical fracture terminations in core occur within a reservoir sandstone at mudstone partings, ripup-clast or carbonaceous zones, or at sandstone grain-size changes. Another 10 to 35 percent occur at no apparent lithologic discontinuity. Both of these categories may represent en echelon offsets of the fractures beyond the 4-inch diameter core, but hydraulic continuity across an offset of the first type is doubtful. Forty to 70 percent of fracture terminations are at contact between a sandstone and an adjacent thick mudstone, in large part because 80 percent of the observed fractures occur in sandstones that are less than 10 ft thick. This type of fracture and permeability system may be present but unrecognized in other strata that are otherwise structurally undeformed.

DUAL LEAKOFF BEHAVIOR IN HYDRAULIC FRACTURING OF TIGHT, LENTICULAR GAS SANDS (SAND88-0185C), N. R. Warpinski, Sandia National Laboratories, SPE Proceedings of 63rd Annual Technical Conference and Exhibition, Houston, TX, October 2-5, 1988.

Stimulation experiments conducted in anisotropic, naturally-fractured, tight, lenticular, gas sandstones have shown the existence of a dual leakoff phenomenon. Below a threshold pressure, the leakoff coefficient is very low and fluids are very efficient. Above the threshold, leakoff increases by a factor of 50, slurries dehydrate rapidly, and screenouts occur in minutes. The leakoff has been shown to be controllable to some extent with 100-mesh sand. Results of three stimulation experiments are presented; these include a treatment that screened out, a minifrac experiment that showed the effectiveness of 100-mesh sand, and a final successful stimulation.

TECTONISM, SUBSIDENCE, AND FRACTURING OF MESAVERDE RESERVOIRS IN THE PICEANCE BASIN, COLORADO, J. C. Lorenz and S. J. Finley, Sandia National Laboratories, D. I. Norman, New Mexico Institute of Mining and Technology, AAPG Bulletin, Vol. 72, No. 2, March 1988.

Cretaceous strata in the Piceance basin of northwestern Colorado were subjected to several phases of tectonic, burial, and uplift stress. However, extensive data on fractures in core from the US Department of Energy's Multiwell Experiment (MWX) wells suggest that most of the fractures in the Cretaceous strata in this part of the basin originated during one episode of stress. Time-depth relationships, fracture orientations, and fluid inclusion analyses all indicate that fracturing occurred about 35-40 m.y. during Laramide west-northwest horizontal compression. Most Cretaceous rocks at the MWX site contain a single set of west-northwest extension fractures. Isochore calculations indicate trapping pressures around 325 bars for fluid inclusions in 16 samples of quartz and calcite mineralization from the fractures, suggesting that mineralization occurred in a pressure-temperature regime compatible with the reconstructed burial depths of 10,000-12,000 ft. Younger episodes of stress are recorded in both the post-Cretaceous strata and in the less deeply buried Cretaceous strata near the basin boundaries. However, the effects of these younger stresses are not evident in deeply buried Mesaverde reservoirs at the MWX site in the east-central part of the basin. Moreover, if the orientation of the horizontal compressive stress rotated significantly during the late Laramide, as suggested by some authors, its effects are not apparent in the Cretaceous formations examined. Most measurements of ancient and present-day stress in Mesaverde strata at he MWX site indicate only west-northwest Laramide compression.

III C. Enhanced Oil Recovery

ELECTRICAL GEODIAGNOSTIC EVALUATION OF STEAMFLOOD PERFORMANCE (SAND88-1056A), A. R. Mansure, Sandia National Laboratories, SEG/EAEG Research Workshop on Reservoir Geophysics, Dallas, TX, August 1-3, 1988.

The ultimate recovery of oil and economic success of an EOR project depend on process control. Production period and rate, injection period and rate, and number and location of wells are the primary controls on the migration of fluids in the reservoir. Managing these controls based on a knowledge of the geometry of fluid migration and inferred velocity of the constitutive zones of an EOR process is essential to maximize oil recovery.

A variety of approaches can be applied to the problem of describing geometry of fluid migration in space and time. These include:

a. the use of observation and production well data,
b. the use of reservoir numerical simulators, or
c. direct measurement (e.g., cross-borehole seismic, surface electrical potential (SEP), controlled source audio magnetotellurics (CSAMT), or other geodiagnostic techniques, Leighton and Wayland, 1987).

Each of these approaches has inherent limitations and so they must be used in concert to confirm each other's description of the space and time progression of an EOR process.

The focus of Sandia National Laboratories' (SNL) current geodiagnostic effort is the application of electrical methods such as SEP and CSAMT to the mapping of steamflood processes. These techniques have been tried in the field, but there is considerable uncertainty in how to interpret the results. A geoelectric simulation facility is being built to perform controlled tests of these techniques. To assist the development of this facility, descriptions of the reservoir/recovery process have been developed from data from a steamflood pilot test.

These descriptions consider the geometry of the EOR process, the in situ resistivity changes that accompany the EOR process, and the relationship between in situ resistivity and the apparent surface resistivity that is measured. The descriptions will be used to define the resolution, sensitivity, and time base requirements placed on the geodiagnostic measurement. Also they will be used in defining the scale models that will be tested in the geoelectric simulation facility.

Typically a steamflood does not spread out from an injection well uniformly at a rate independent of depth and direction. This is expected even in homogeneous, isotropic reservoirs due to instabilities (e.g., viscous effects, buoyancy, and pattern effects). Hence, at any given location the volumetric, vertical, and areal sweep efficiencies are typically less than 100 percent. Knowledge of the directionality of flow is important for process control and for identifying unswept regions or by-passed oil. To be most useful to the production engineer, geodiagnostics of the flow pattern should show the vertical and areal sweep of the EOR process including anomalies in the flow pattern caused by heterogeneities and unstabilities.

To interpret field data gathered using an electrical geodiagnostic technique and thereby produce a map of a steamflood, it is essential to understand the processes that change the in situ electrical conductivity of a reservoir when steam is injected. As a result of work done SNL's Petroleum Extraction Simulation Laboratory (PESL), an understanding of the causes and magnitude of the electrical conductivity change has been gained. In situ conductivity is controlled by connate water, but is affected by saturation, temperature, pore structure, wettability, etc. and can go up or down depending on the EOR process. As the steamflood grows, it displaces connate water and thus sweeps away or dilutes the salt concentration changing the electrical conductivity of the reservoir.

The measured apparent surface resistivity is a volume average of in situ resistivities. Inversion techniques are required to determine in situ resistivity from apparent surface resistivity. Variations in the apparent surface resistivity can be due to the EOR process or variations in the reservoir (saturation, porosity, or thickness). While these are important reservoir engineering factors, they are not the primary factors in determining direction and quantity of flow. Of primary concern to the production engineer are heterogeneities that affect flow (e.g., permeability changes). While these are not directly measurable by geodiagnostics their effect on the geometric shape of the EOR process is observable by comparison of a baseline survey with subsequent surveys.

This paper will present a review of the work that has led to the current SNL program and a discussion of the reservoir/recovery process descriptions that have been developed. Emphasis will be on how these descriptions establish the resolution, sensitivity, and time base required for geodiagnostic evaluation of a thermal recovery process.

III D. Geothermal

ADVANCED GEOTHERMAL TECHNOLOGIES (SAND88-0335C), J. T. Whetten, H. D. Murphy, R. H. Hanold and C. W. Myers, Los Alamos National Laboratory; J. C. Dunn, Sandia National Laboratories, 15th Energy Technology Conference and Exposition, Washington, DC, February 17-19, 1988.

Research and development in advanced technologies for geothermal energy production continue to increase the energy production options for the Nation. The high-risk investment over the past few years by the US Department of Energy in geopressured, hot dry rock, and magma energy resources is producing new means to lower production costs and to take advantage of these resources. The Nation has far larger and more regionally extensive geothermal resources than heretofore realized. At the end of a short 30-day closed-loop flow test, the manmade hot dry rock reservoir at Fenton Hill, New Mexico, was producing 10 MW thermal--and still climbing--proving the technical feasibility of this new technology. The scientific feasibility of magma energy extraction has been demonstrated, and new field tests to evaluate this technology are planned. Analysis and field tests confirm the viability of geopressured-geothermal energy and the prospect that many dry-hole or depleted petroleum wells can be turned into producing geopressured-geothermal wells. Technological advances achieved through hot dry rock, magma, geopressured, and other geothermal research are making these resources and conventional hydrothermal resources more competitive. Noteworthy among these technological advances are techniques in computer simulation of geothermal reservoirs, new means for well stimulation, new high-temperature logging tools and packers, new hard-rock penetration techniques, and new methods for mapping fracture flow paths across large underground areas in reservoirs. In addition, many of these same technological advances can be applied by the petroleum industry to help lower production costs in domestic oil and gas fields.

IN SITU EXPERIMENTS OF GEOTHERMAL WELL STIMULATION USING PROPELLANT FRACTURING TECHNOLOGY (SAND87-2241), T. Y. Chu, N. R. Warpinski, R. D. Jacobson, Sandia National Laboratories, July 1988.

The results of an experimental study of gas fracturing technology for geothermal well stimulation demonstrated that multiple fractures could be created to link water-filled boreholes with existing fractures. The resulting fracture network and fracture interconnections were characterized by mineback as well as flow tests. Commercial oil field fracturing tools were used successfully in these experiments. Simple scaling laws for gas fracturing and a brief discussion of the application of this technique to actual geothermal well stimulation are presented.

IV. GeoDiagnostics

IV A. Instrumentation

HIGH TEMPERATURE INSTRUMENTATION (SAND88-2063C), L. E. Duda, Sandia National Laboratories, Advances in Geothermal Reservoir Technology Tech. Rev., Lawrence Berkeley Laboratories, Berkeley, CA, June 14-15, 1988.

In the next several years the need for high temperature instrumentation will grow as drilling into high temperature regimes increases for both the Continental Scientific Drilling Program and the Magma Energy Extraction Program. Sandia National Labs has developed some high temperature downhole instruments over recent years and will continue the development of instruments for the new drilling programs underway. In this paper, past efforts in high temperature instrumentation, current activity in this area, and future plans for high temperature instrumentation are presented. Over the past five years, Sandia has modified a commercial acoustic borehole televiewer for high temperature use in geothermal wells and developed five high temperature instruments for use in the Salton Sea Scientific Drilling Project. These five SSSDP tools were completely self contained and all were designed to operate with a slickline cable.

Because of the 300°C temperature limitation of the insulation on commercial logging cables, we have concluded that self-contained electronic tools having an internal memory for data storage are the best current approach for high temperature (>300°C) logging. Current activity by Sandia in this area includes modifications to the digital temperature/pressure tool developed for the SSSDP to allow the tool to simultaneously measure external temperature and temperature-compensated external pressure. In support of the Baca Flats well, on which drilling will begin in July 1988, a two inch diameter downhole temperature probe capable of surviving to 400°C is being developed in cooperation with Geophysical Research Corp. of Tulsa, Oklahoma.

Future instrumentation plans include the development of modular/memory controller systems. These instruments will use interchangeable memory units and be capable of both wireline and slickline operation. Very high temperature instruments, i.e., for temperatures approaching 500°C, must be developed for the logging of the well drilled for the magma energy extraction program.

DETECTION OF A TARGET IN A ROCK FORMATION USING THE RADAR FRACTURE MAPPING TOOL (SAND88-1582C), L. E. Duda, J. E. Uhl, J. Gabaldon and H. T. Chang, Sandia National Laboratories, Geothermal Resources Council 1988 Meeting, San Diego, CA, October 9-12, 1988.

A method to locate fractures adjacent to, but not intersecting, an uncased wellbore would be a great aid to the geothermal industry. A prototype downhole radar probe was recently completed with the aim of locating fractures near a single wellbore. This probe, operating in the pulse mode with a bandwidth of 30 to 300 MHz, contains two identical directional antennas. As with any prototype instrumentation, extensive field work is required to completely understand the characteristics of the system. A first step in that understanding is to operate the instrument under known or controlled conditions. In this paper, some tests of the radar probe in a travertine quarry using a known target are reported. In the tests, the target is clearly detected from a borehole located 14 ft away.

HIGH TEMPERATURE INSTRUMENTATION FOR GEOTHERMAL WELL LOGGING (SAND88-0555A), R. K. Traeger, Sandia National Laboratories, High Temperature Electronics Workshop at AFWAL, Albuquerque, NM, April 12-14, 1988.

Logging of wells provides information for drilling decisions, for analysis of potential productions zones, and for reservoir engineering. The first two needs are met by running tools (instrumentation) in and out of the hole at the maximum speed still allowing acceptable data recovery. The reservoir engineering requires pressure, temperature and flow measurements over extended time periods while the well is producing. In geothermal systems, the fluids are frequently corrosive brines with temperatures of 200-250°C, although temperatures to 350°C have been encountered. Logging tools for rapid round trips can be dewared, but high temperature cables and connections are required. Logging tools for reservoir analyses must rely on high temperature electronics to provide the needed information. These high temperature logging systems will be reviewed in this paper.

Cables: Cables using PTFE insulation are available for use to 300°C. Cable heads and connections are available for use at these temperatures, but always pose a reliability problem in the fields. Higher temperature cables are available with steel sheathing and MgO insulation, but these have limited data handling capabilities and handling problems. Fiber optics may be available in the future.

Sensors: Sensors that must be exposed to the well environment (e.g., temperature, acoustic, electrical) are available for high temperature use. Calibration and drift become prime concerns.

Devices: Active and passive components are available for use up to 275°C with appropriate circuit designs. The commercial availability fluctuates depending on market needs. Power switching devices such as SCR's are still limited to uses below about 200°C.

Interconnections: Imide boards, high temperature brazes or solders with screened devices can be used for most geothermal logging tools. Higher temperature systems can use thick film circuits which also have the advantage of providing high temperature resistors and capacitors.

Temperatures over 300°C: The current solution to logging at higher temperatures is to use insulated, self-contained logging tools that do not require electrical connections to the surface. Dewared temperature and pressure tools have been built and successfully used in a geothermal well at 375°C.

TIME-DEPENDENT CHANGES IN VELOCITY AND ATTENUATION IN SALT AT THE WASTE ISOLATION PILOT PLANT (SAND87-3016C), D. J. Holcomb, Sandia National Laboratories, 29th US Symposium on Rock Mechanics, Minneapolis, MN, June 1988.

Cross-hole ultrasonic measurements were made at the Waste Isolation Pilot Plant (near Carlsbad, New Mexico) to delineate the disturbed zone around drifts and rooms. Using compressional mode waves it was found that there was a small decrease in velocity and a large increase in attenuation immediately after the test room was mined. Disturbances extended at least 3 metres from a room with a width of 5.5 metres. The results are interpreted as resulting from the introduction of about 0.5% crack-like, pore space.

IV B. Laboratory and Mathematical Simulation

SOMMERFELD INTEGRALS AND ELECTROMAGNETIC FIELDS (SAND88-1116), T. W. H. Caffey, Sandia National Laboratories, September 1988.

The complete electromagnetic fields for both elementary electric and magnetic dipoles are listed for both horizontal and vertical orientations of the dipoles. All combinations of dipole and field point locations above or below the boundary between two conducting half-spaces are included.

THE DESIGN, CONSTRUCTION, AND OPERATION OF A PHYSICAL SIMULATOR FOR EVALUATING GEOPHYSICAL ELECTRICAL TECHNIQUES (SAND88-1494C), T. C. Bickel and P. J. Hommert, Sandia National Laboratories, 1988 Annual International SEG Meeting, Anaheim, CA, October 30-November 3, 1988.

A laboratory facility has been constructed for studying DC and very low frequency geophysical methods. This facility will be used to evaluate geophysical electrical methods that have the potential to spacially map fossil energy recovery processes and delineate reservoir heterogeneities. The physical simulator, an electrolytic tank slightly more than one meter in diameter, was built with a unique treatment of the boundary. The electrolytic tank boundary is comprised of sixty individual elements, where each element is electrically isolated from adjacent elements. Design calculations and operational data validate that by minimizing boundary effects, this approach results in a threefold increase in the model size that can be used in the tank. This approach will also permit scale model layering studies, a phenomenon which has often frustrated field application of DC electrical methods. The facility is being used to validate inversion models for surface DC methods and to study alternative geometries involving either downhole current injection or potential measurement.

A DIAGRAM APPROACH TO THE PLANE-WAVE ELECTROMAGNETIC WAVE IMPEDANCE (SAND88-1366A), L. C. Bartel, Sandia National Laboratories, Society of Exploration Geophysicists 58th Annual International Meeting, Anaheim, CA, October 30-November 3, 1988.

The impedance function determined for electromagnetic plane waves impinging upon a horizontally-stratified earth can be expressed in terms of an infinite series. Each term in the series represents primary and/or primary plus multiple reflections from interfaces of conductivity contrasts in the earth. A methodology is outlined for determining terms in the summation where the terms are obtained from diagrams representing the reflection terms. The terms in the sum are transformed into the time domain using a cosine transform. The transform of the real part of the impedance function, normalized by the transform of the uniform earth response for the upper most layer, is found to be quite useful in analysis of magnetotelluric type data. The character of the resultant function can be interpreted in terms of boundaries where there is a conductivity contrast. Peaks in the normalized impedance function are identified as due to two-way travel of the electromagnetic wave in the earth. However, due to dispersion, the peaks broaden for increasing time.

OPTIMUM SWEEP FUNCTIONS FOR RESONANT SEISMIC SOURCES (SAND87-2285), H. C. Hardee, Sandia National Laboratories, 1988.

Controlled seismic sources with constant amplitude output are usually swept in frequency at a linear rate to produce good autocorrelation functions. Controlled seismic sources with embedded resonances in the sweep range show better autocorrelation results when certain non-linear sweeps are used. A closed form solution is developed in this paper for the autocorrelation function in terms of Fresnel Integrals for both linear and non-linear sweeps. A reduced form of this solution shows that the peak amplitude of the autocorrelation function is directly proportional to the sweep time and that the width of the initial autocorrelation pulse is inversely proportional to the bandwidth of the sweep. Numerical autocorrelation calculations and supporting analytical results for constant amplitude and resonant amplitude sources show that while the usual linear sweep is satisfactory for the constant amplitude source, a power-function sweep between $n=1.5$ and $n=2.0$ is superior for the resonant amplitude source.

IV C. Field Studies

NEUTRONIC PROPERTIES OF MESAVERDE SANDS-I: CALIBRATION OF THE ADVANCED REACTIVITY MEASUREMENT FACILITY, P. C. Lysne, Sandia National Laboratories, Nuclear Geophysics, Int. J. Radiat. Appl. Instrum. Part E, Vol. 2, No. 2. pp. 105-112, Great Britain, 1988.

Three adjacent wells have been drilled and cored through the Mesaverde formation near Rifle, Colorado. To understand better the response of neutron porosity logs that were utilized in these wells, a study of the important neutronic parameters of formation material was undertaken. This first paper deals with the calibration of the facility used to evaluate thermal neutron absorption cross sections; a following paper presents the results of petrographic and cross section measurements on 120 specimens of Mesaverde material.

The Advanced Reactivity Measurement Facility (ARMF) at the Idaho National Engineering laboratory is a small, light water moderated reactor. Access to this reactor is made through six experimental holes which possess neutron flexes with different energy characteristics. When specimens are placed in these holes, thermal and higher energy absorption and scattering produce a linear perturbation to the reactor which is measured by movement of the regulating rod. Calibration was accomplished by placing eleven standard specimens in each of the six holes and solving for the appropriate calibration numbers in a least-squares sense. In the course of this calibration, it was found that two of the holes are redundant in that their fluxes are not significantly different from fluxes in the remaining holes. The resulting four-hole calibration yields cross section values with uncertainties of $\pm$0.2 CU (gm/cm^3) for cross sections less than 9 CU (gm/cm^3).

NEUTRONIC PROPERTIES OF MESAVERDE SANDS-II: RESULTS, P. C. Lysne, Sandia National Laboratories, Nuclear Geophysics, Int. J. Radiat. Appl. Instrum. Part E, Vol. 2, No. 2, pp. 113-122, 1988.

Thermal neutron absorption cross section measurements were conducted on 120 specimens obtained from the Mesaverde formation as it occurs in two Department of Energy wells located near Rifle, Colorado. The specimens represented several marine, near-shore and on-shore depositional environments and they contained various amounts and types of detrital and authigenic minerals. Specimens comprised entirely of claystone, mudstone, siltstone and coal were found to have the largest cross sections with typical values in the range of 6-10 CU/(gm/cm^3). Alternatively, specimens with

1 percent or less clast or parting material, possess cross sections of 4.1 ± 0.6 CU/(gm/cm^3) for Mesaverde as a whole, whereas some individual units are characterized by nearly uniform cross section values. A petrographic analysis enabled an estimate of the shale water content and this information, together with the cross section values, was used to estimate the uncertainty in neutron porosity logs run in the DOE wells. This uncertainty is about ±3 volume percent and it is due more to uncertainty in the shale water content than to jitter in the matrix cross section values.

CORRELATION OF CORE AND LOG DATA TO DETERMINE STRESS INFORMATION AT AND NEAR DOE'S MULTIWELL EXPERIMENT SITE (SAND88-1359A), A. R. Sattler, Sandia National Laboratories, SPWLA 29th Annual Logging Symposium, San Antonio, TX, June 5-8, 1988.

This poster paper shows correlations of stress-related core data with the borehole televiewer and oriented caliper logs from the DOE's Multiwell Experiment (MWX) site in the Piceance basin, Colorado. Core data are principally from anelastic strain recovery (ASR) and different strain curve analyses (DSCA) although directional permeability and epifluorescence data are included also.

ASR and DSCA analyses predicted hydraulic fracture azimuth at the MWX site. This was verified independently by borehole geophones during actual stimulation operations. The borehole televiewer and oriented caliper logs can also provide present-day stress information from the display of breakouts and paleostress information from the display of natural fractures. It is assumed that the breakouts identified in the televiewer and caliper logs from the vertical MWX-3 well are perpendicular to the maximum principal horizontal stress directions.

Three breakouts from the televiewer log show the following:

- Clockwise rotation of the stress field with depth, at least in the upper zone. This rotation was predicted by Clark (1983), based upon the effect of local topographic loading.

- A distinct pattern of breakouts involving all lithologies in the fluvial zone, but a less clear pattern in the coastal and paludal zones.

- Similar breakout displays with respect to the depositional environment in MWX-3 and in the 1XM9 well, located three miles north of the MWX site.

The display of natural fractures from the televiewer log shows the following:

- Correlation between core and log natural fracture directions depth.
- Similarity of fracture patterns in the three wells, which are <250 ft apart.
- Fractures perpendicular to breakouts which imply that the paleo- and present-day stress directions are parallel.

The display of breakouts from the oriented caliper logs also show some indication of clockwise rotation of the stress field in the upper part of the hole (fluvial, coastal, upper paludal) but not necessarily in the marine zone at the bottom of the Mesaverde. The display of the ratio of the minor/major wellbore axes from the MWX-3 oriented caliper log suggests both a larger number and deeper breakouts/washouts in the fluvial zone than in the coastal or paludal zones.

The ASR/DSCA data also show a clockwise rotation on the maximum horizontal stress from the fluvial through the upper paludal zone. The maximum stress is vertical, except perhaps in the marine zone. The strains in sandstones are usually greater than in mudstones and the strain of some mudstones in nearly isotropic.

Permeabilities measured in core seem to be largest perpendicular to the maximum horizontal stress. An epifluorescence measurement made on coastal zone core shows that the microcracks are aligned in the direction of highest permeability.

In conclusion, there is an overlap in the predictions of maximum horizontal stress from the core data and the predictions from the televiewer and caliper logs. Any one of the three measurements may be adequate for stress azimuth predictions. Also:

- Rotation of stress azimuth is seen with depth.
- Televiewer, caliper log displays, directional permeability data suggest that there is a greater degree of horizontal anisotropy in the fluvial zone.
- In the fluvial zone, breakouts appear to occur in all lithologies.

AN ASSESSMENT OF BOREHOLE SEISMIC FRACTURE DIAGNOSTICS (SAND88-1869C), B. J. Thorne and H. E. Morris, Sandia National Laboratories, SPE Annual Technical Conference and Exhibition, Houston, TX, October 2-5, 1988.

A five year effort to apply triaxial borehole seismometer technology to mapping hydraulic fractures by detecting microseismic events associated with the fracturing process has been completed. During this time, a number of evolutionary improvements to the borehole receiver have lead to a unique sensor array geometry consisting of four geophone axes, positioned so that each axis makes the same angle with both the horizontal plane and the plane of the clamp arm. This geometry is designed to allow the use of identical geophones on all axes in order to avoid differences in resonance properties of horizontal and vertical geophones, and to distribute any effects of clamp arm resonance uniformly to all axes. Each axis consists of four geophones wired in series to provide four times the sensitivity of a single geophone.

The receiver includes downhole amplifiers which provides two gains, 112 dB for weak seismic sources and 100 dB to avoid saturation from strong seismic sources. The amplified seismic signals from the eight data channels are frequency division multiplexed onto frequency modulation subcarriers for transmission to the surface through a single conductor wire line. This combination of multi-geophone reception, downhole amplification and frequency modulation data transmission results in a very sensitive receiver, almost completely free of electric noise. The data from two downhole receivers in offset wells are recorded on tape to provide a continuous record of all signals. Simultaneously, all channels are demodulated, filtered and sent to a signal analyzer which triggers analog-to-digital conversion when any channel exceeds a preset voltage.

An event location scheme, based on primary wave polarization and using directional statistics, computes the location of microseismic events with error estimates. Over 700 microseismic events were digitized during a recent stimulation experiment. Analysis of these data resulted in 160 microseismic event locations, some as far as 450 ft (137 m) from the receiver. The azimuth determined from event locations agrees reasonably well with the predicted fracture azimuth, the head agrees with temperature log tops, and fracture height is in good agreement with fracture model calculations. Wing lengths are less than fracture model predictions unless fracture width is larger than expected.

PASSIVE SEISMIC MONITORING OF HYDRAULIC FRACTURE EXPERIMENTS AT THE MULTIWELL EXPERIMENT SITE (SAND88-1284),
B. J. Thorne and H. E. Morris, Sandia National Laboratories, August 1988.

Redesign of hardware, software, and data-reduction techniques associated with the Sandia National Laboratories' Borehole Seismic System (BSS) have made possible better estimates of hydraulic fracture geometry at the Multiwell Experiment (MWX) site. The redesigned system now incorporates four geophones per axis and provides up to 112 dB of downhole gain, for 100 times the sensitivity of the original system. Improved signal-to-noise ratios, extended frequency response and increased digitization rates have made possible the acquisition and processing of data which were previously inaccessible. A maximum likelihood event location scheme, which incorporates an algorithm based on the sue of spherical statistics, is used to compute the location of microseismic events and error estimates for these locations. Accuracy estimates for the redesigned system, based on the ability to locate perforation shots, indicates a 25 ft (7.6 m) uncertainty in the location of individual microseismic events using data from two BSS receivers. This resulted in a high level of confidence in determination of the azimuth of the November 1, 1986 hydraulic fracture in the Fluvial B sandstone. A reasonable determination of the azimuth, propped wing length and height for the September 23, 1987, hydraulic fracture in the Fluvial E sandstone was possible using data from only one BSS receiver.

V. Geoscience

V A. Continental Scientific Drilling Program

INYO DRILLING: A SUMMARY (SAND88-2421A), J. C. Eichelberger, Sandia National Laboratories, L. W. Younker, Lawrence Livermore National Laboratory, Fall AGU Meeting, San Francisco, CA, December 5-9, 1988.

A research program of four core holes has been completed in the 600-year-old portion of the Inyo Domes volcanic chain of eastern California. Its purpose was to investigate aspects of the chemical, mechanical, and thermal behavior of magma by probing the concealed portions of a very young and relatively simple igneous system. Complete sections were sampled through the distal and proximal portions of the largest lava dome (Obsidian Dome), its conduit, and unvented portion of the underlying feeder dike, and the conduit of the largest phreatic crater (South Inyo Crater). The holes confirmed some hypotheses developed from surface observations, rejected others, and provided new information concerning vent structures associated with explosive, effusive, and phreatic eruptions. Of special interest are the following: 1. Presence of a feeder dike at shallow depth under the northern, magmatic portion of the chain but absence of the expected large intrusion at comparable depth beneath the southern, phreatic portion. 2. Variation of magmatic water content with depth near the lithostatically controlled solubility value and presence of vesicles throughout the system except in distal lava, indicating equilibrium degassing of vesiculated magma with collapse to obsidian. 3. Orders-of-magnitude thicker glass zones on the lava than the intrusions, indicating quenching by water loss. 4. Reverse (mafic to silicic) zoning of the lava dome and its feeder. 5. Evidence for mobilization of the chlorine during second boiling. 6. Identification of the phreatic feeder as a lithic-rich, juvenile rhyolite pumic-bearing "tuff." Continuing studies may elucidate the petrogenesis of the unexpectedly complex magma composition sequence and the thermal history of both the magmatic and phreatic feeders.

VOLCANIC EQUIVALENTS OF MAFIC INCLUSIONS IN GRANITES (SAND88-2399A), J. C. Eichelberger, Sandia National Laboratories, Fall AGU Meeting, San Francisco, CA, December 5-9, 1988.

If silicic volcanic rocks are a reliable guide, then most mafic inclusions in granites represent mafic magma injected into active silicic magma chambers (1-4). Mafic inclusions are best developed in lavas of areally extensive, chemically diverse volcanic fields (e.g., Lassen, Clear Lake, and Medicine

Lake, CA; Crater Lake, OR; and Jemez Mtns., NM). Such fields probably overlie large, long-lived crustal magma systems that are sustained by upward flux of basalt. The inclusions consist of hornblende or pyroxene and plagioclase, with abundant vesicles and subordinate interstitial silicic glass. Evidence for their origin as mafic magma includes bulk composition, chilled and/or mixed margins, euhedral crystal morphology and strong crystal zoning, and the presence of phenocrysts of Mg-rich olivine and Ca-rich plagioclase. Some of these features survive crystallization in the plutonic environment and can be recognized in mafic inclusions in granites. Upon injection into a silicic chamber, mafic magma breaks into a spray of globules. These thermally equilibrate in hours or less, crystallizing and undergoing second boiling to form a buoyant or at least lower-density crystal-mush foam. (Although I previously argued that mafic inclusions in obsidian flows display a primary density relation ship, I now believe that host as well as inclusions have vesiculated, and that subsequent collapse of vesicles within the inclusions was prevented by their much higher crystal content.) The presence of interstitial melt and abundant bubbles facilitates dispersal of the mafic debris as clots and individual crystals during convective circulation in the chamber. Heating due to mafic magma injection is recorded by partial resorption of any present in the reservoir magma. Not all encounters between mafic and silicic magma produce significant inclusions and mixing (e.g. Katmai, AK) and apparently mixing can occur without formation of-or with formation and complete dispersal of-inclusions (e.g., Obsidian Dome, CA, Questa, NM). Factors favoring formation and preservation of inclusions are a small volume of introduced mafic magma relative to the reservoir volume, low temperature and high viscosity of the reservoir magma, short time (but at least hours) between injection and eruption or cooling, and a high liquidus of mixtures. Circulation can concentrate mixing products in a thin outer boundary of reservoirs, and hence in the outer boundary of reservoirs, and hence in the outer margin of dikes and distal and/or lower portions of lava flows they feed.

INVESTIGATION OF MAGMATIC PROCESSES BY DRILLING (SAND88-0085A), J. C. Eichelberger, Sandia National Laboratories, International Seminar on Super-Deep Drilling and Deep Geophysical Sounding, Moscow, USSR, August 23-29, 1988.

The behavior of magma in the crust can be divided into those processes that occur during storage in reservoirs, and those that occur during intrusion and eruption in response to decompression and cooling. The former comprise the classic problems of igneous petrology, but direct observation of the deep magmatic environment will require significant advances in drilling technology. The latter encompass volcanic and hydrothermal phenomena. They are therefore of at least equal importance, and they can be investigated now through rather modest drilling projects. Significant problems include the causes of explosive and nonexplosive eruptions, the processes of and mechanism of cooling of intrusions. New observations that drilling in young volcanic systems can contribute toward solution of these problems include vent geometry and structure in relation to eruptive history, magmatic degassing and crystallization behavior in relation to conditions of emplacement, and the distribution of heat and mobile elements within and around recently emplaced intrusions. This represents an advance over traditional volcanological approaches, which have relied heavily upon uncertain analogies between modern volcanic systems where eruptive phenomena are well described, and their presumed ancient eroded counterparts where intrusive structures are well understood.

A program of drilling into the youngest hyolitic volcanic system in the contiguous United States has just been completed, and drilling into an even younger system in the Aleutian Arc of Alaska is being planned. Six hundred years ago, three magmatic vents and about ten significant phreatic vents erupted along a 10-km-long linear segment of a Sierra Nevada frontal fault in eastern California to form the Inyo Domes and Craters. The vent chain cuts across the northwest rim of the 700,000-year-old Long Valley Caldera. Recent recognition that the vents were active simultaneously led to the hypothesis that the eruption was the surface expression of the shallow emplacement of a rhyolite dike. A program of drilling was developed to test this hypothesis and investigate the relationship of degassing and crystallization behavior to depth of emplacement and to the contrasting intra- and extra-caldera environments of intrusion. Four holes totalling 2.5 km were cored into the Inyo system. The existence of a shallow rhyolitic feeder dike beneath the northern portion of the chain was confirmed. However, the phreatic activity at the southern, intra-caldera portion of the chain was found to be due to the simultaneous intrusion of basaltic magma, indicating that the eruption was a chemically bimodal, and probably basalt-triggered, event. Distribution of volatiles in the rhyolitic portion of the system indicates a close approach to locally controlled pressure equilibrium during degassing. This requires loss of a large volume of water vapor during the final 1 km of ascent. There is evidence that the magma ascended as highly inflated gas-permeable foam that collapsed to obsidian during extrusion, with the implication that a permeable shallow intrusive environment is necessary for rhyolitic magma to erupt nonexplosively. Water loss rather than cooling rate dominated crystallization behavior so that thick extrusions are glassy, whereas thin comagmatic intrusions are crystalline. The intrusions, which reach a maximum of 50 m in intersected width, have cooled completely in the 600 years since emplacement.

An eruption in 1912 near Katmai Volcano in the Aleutian Arc, Alaska, was nearly one hundred times the volume of the Inyo eruption and is little more than a tenth the age. Almost certainly, the feeder retains significant magmatic heat at shallow depth. Because the vent did not collapse following eruption, and because it lies within uniform sedimentary basement rocks where little previous volcanic activity had occurred, conditions are unusually favorable for interpreting the mechanical, chemical, and thermal consequences of a magmatic event. The vent is thought to be a flared funnel with a surface diameter of 2 km, containing pyroclastic debris and a central intrusion. A series of holes are planned to probe the central intrusion, vent wall, and near-vent and far-vent portions of the 200-m-thick pyroclastic outflow sheet. These holes will provide tests of models for explosive eruption of rhyolitic tephra, cooling of intrusions, and transport of metals.

SCIENTIFIC DRILLING IN THERMAL REGIMES (SAND88-0362A and SAND88-2371A), R. K. Traeger, Sandia National Laboratories, International Seminar on Super-Deep Drilling and Deep Sounding, Yaroslavl/Wolga, USSR, August 23-29, 1988.

A geosciences program using the drill as a geophysical tool has been exploring thermal regimes under the auspices of the US Department of Energy's Basic Energy Sciences programs. Cores and data have been obtained from research wells in the Inyo Chain, CA; the Valles Caldera, NM; the Salton Sea, CA; and Long Valley, CA. A three kilometer research well was also drilled at the Salton Sea, CA, under the auspices of the US DOE's Geothermal Program. Plans are under way to obtain core from hot regions in the Valles Caldera, NM, and in Katmai, AK, for the DOE BES program. The Magma Energy program in DOE geothermal Technologies Division is initiating a 3-5 kilometer well in Long Valley, CA, to obtain data into the melt of the hypothesized magma body underlying that area.

This paper will review the technologies used or planned for these research activities. Methods of dealing with high temperature will be outlined and major problem areas will be discussed. Current plans for the use of insulated drill strings and dewared, self-contained logging tools will also be reviewed. Major technological uncertainties (such as cements and drilling fluids) will be highlighted to encourage increased exchange of information.

FRACTURE FILLINGS AND INTRUSIVE PYROCLASTS, INYO DOMES, CALIFORNIA (SAND87-1604J); G. K. Heiken and K. Woletz, Los Alamos National Laboratory, J. C. Eichelberger, Sandia National Laboratories, J. Geophysical Research, Vol. 93, No. B5, pp. 4335-4350, 1988.

Fractures containing juvenile magmatic pyroclasts were encountered during drilling into a 600-year-old feeder dike beneath the Inyo Domes chain, California. The Inyo Domes consist of a north-south trending, 10 km-long chain of domes, rhyolitic tuff rings, and phreatic craters. Boreholes were cored through the 51 m diameter conduit of Obsidian Dome, the largest of the Inyo Domes, and through an unvented portion of the intrusion (dike) 1 km to the south. Pyroclast-bearing fractures were intersected in both holes: (1) 7 to 40 cm thick fractures in welded basaltic scoria and quartz monzonite country rock are adjacent to the conduit at depths of 400-411 m and 492-533 m; they contain gray, clastic deposits, which show truncated cross-bedding and convolute bedding. (2) adjacent to the dike, massive fracture fillings occur at depths of 289-302 m (129 m east of the dike) and 366-384 m (95-87 m east of the dike). The fracture fillings consist of mineral clasts derived from the quartz monzonite, quartz monzonitic and basaltic lithic clasts, and juvenile glass pyroclasts. Angular mineral components are present in the same ratio as in the surrounding quartz monzonite country rock. Juvenile glassy and hyalocrystalline pyroclastic make up from less than one percent to 22 percent of the deposits. They consist of blocky obsidian clasts, equant, blocky glass pyroclasts with vesicularities of 0-30 percent, and small pumices with vesicularities of 30-40 percent. Intrusive pyroclasts differ from erupted pyroclasts in their generally lower vesicularity, higher crystallinity, and the presence of solution pits and clay coatings indicative of prolonged contact with water.

The presence, orientation, and texture of fracture fillings strongly resemble those of propped, manmade hydrofractures. We interpret these fractures as naturally occurring hydrofractures. The apparently horizontal fracture orientations may have been controlled by perturbations of maximum principal stress by the dikes or by preexisting sheet fractures in the quartz monzonite country rock. Assumption of elastic moduli and fracturing properties for the Sierran basement rock allows calculation of fluid overpressures 5 to 9 Mpa in excess of overburden stress. These overpressures are consistent with either vapor exsolution from decompressed magma or rapid heating of ground water. However, the textural and chemical similarity of the pyroclasts to phreatomagmatic tephra that appears late in the explosive eruption sequence suggests that heating of ground water by the dike/conduit caused the fracturing. Such fracturing around volcanic conduits may play an important role in the development of hydrothermal circulation.

OBSIDIAN LAVA: EVIDENCE FOR A DEGASSED MAGMA (SAND88-2431A), H. R. Westrich, J. C. Eichelberger, Sandia National Laboratories, AGU 1988 Fall Meeting, San Francisco, CA, December 5-9, 1988.

Erupted rhyolite obsidians vary in water content from 0.1 wt.% in lava flows to over 3.0 wt.% in tephra. The question is, does this trend in water content represent sequential eruption of a zoned magma body (wet margins) or continuous degassing of a hydrous magma during ascent? The degassing model is supported by geochemical data from the Inyo drilling and experimental phase equilibria. Estimated eruption temperatures (900-950°C by Fe-Ti oxides; Vogel, et al., 1985) are much lower than the water-saturated rhyolite liquidus (1060°C and 1.2 wt.%) at 20 MPa, but they are entirely consistent with liquidus temperatures for the Inyo magma (ca. 4.0 wt.% H_2O).

The degassing model requires that magma act as a permeable foam, eventually equilibrating at 0.1 MPa water vapor pressure near the surface. After extrusion, the lithostatic load at the base of the flow (1.0 MPa) would cause bubble collapse and vapor resorption. Critics of this model have suggested that relict textures similar to those found in welded tuffs should be preserved in obsidian lava flows. To address this question, vesiculated samples of hydrous obsidian (0.1-1.5 wt.% H_2O) were heated at 900°C and 1.0 MPa for two days. Results indicate that bubbles are resorbed completely at low water contents (<0.3 wt.%) and significantly reduced at higher water contents. Additional tests with obsidian from the Wineglass welded tuff indicate that relict textures from "welding" are also eliminated after similar treatment. These results lend credence to the permeable foam hypothesis for eruption of rhyolite lavas.

V B. Rock Mechanics

USING HYDRAULIC FRACTURING AND MINEBACK TO DETERMINE IN SITU STRESSES IN ROCK SALT (SAND88-1113A), W. R. Wawersik, Sandia National Laboratories, ASME-SES Joint Applied Mechanics Conference, Berkeley, CA, June 20-22, 1988.

Hydraulic fracturing was applied in horizontal drillholes in the Salado salt formation at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. Tests were performed approximately 650 m below surface primarily to determine whether the virgin in situ stress state is isotropic and whether the magnitude of the virgin in situ stresses corresponds to the weight of the overburden. Additionally, measurements were made to evaluate the usefulness of hydraulic fracturing under anisotropic stress conditions in rock salt and in other rocks that exhibit creep and stress relaxation. To achieve these objectives, hydraulic fracturing tests were carried out in orthogonal drillholes at distances from 14 m to 560 m from existing mine panels, up to 50 m from the face of an isolated drift, and in a three-year-old mine pillar. Several tests were followed by observations of the hydraulically induced fracture patterns during mining of a drift at a later date. Field measurements were aided by finite element analyses to infer the likely shape of the pressure-time records of hydraulic fracturing operations in rock salt for comparison with the corresponding pressure-time records in approximately linearly elastic, "hard" rock.

The main results obtained were as follows: (1) The existence of an isotropic virgin in situ stress state at the WIPP site could be demonstrated solely by means of a very characteristic, randomly oriented fracture patterns distant from the effects of prior mining as opposed to preferentially aligned fracture patterns near existing excavations. (2) Isotropic or nearly isotropic in situ stresses resulted in stable pressure-time records with little loss in pressure after primary breakdown, contrary to observations in competent hard rock. The attendant peak pressure, fracture reopening pressure, and fracture driving pressure were consistent with numerical predictions. (3) Fracture pinching under isotropic or nearly isotropic stress conditions produced a characteristic pressure rise during fracture reopening and appeared to raise the fracture driving pressure. It also obscured the identification of the instantaneous shut-in pressures. (4) Anisotropic stress states were qualitatively indicated by unstable pressure-time records. However, the effect of rock salt creep under these conditions appeared to preclude unique interpretations of hydraulic fracturing tests in rock salt, at least in initially traction-free, open drillholes and up to far-field principal stress ratios on 1.4.

A CHARACTERIZATION OF PRESSURE RECORDS IN INELASTIC ROCK DEMONSTRATED BY HYDRAULIC FRACTURING MEASUREMENTS IN SALT (SAND87-2569J), W. R. Wawersik and Charles M. Stone, Sandia National Laboratories, Pre-Proceedings of the 2nd International Workshop on Hydraulic Fracturing Stress Measurements and International Journal of Rock Mechanics and Mining Sciences, Minneapolis, MN, June 16-18, 1988

The use of hydraulic fracturing in inelastic rock is described in terms of comprehensive hydraulic fracturing observations in rock salt in the Salado formation in southeastern New Mexico. Inelastic rock behavior involves both rate-independent and rate-dependent permanent deformations. A combination of small-volume tests in initially open, horizontal drillholes; finite-element analyses, and in situ fracture observations demonstrates that the pressure-time data in inelastic rock can differ fundamentally from those typically recorded in competent hard rock. Stable pressure-time signatures with little or no pressure drop between peak and driving pressure are obtained in isotropic stress fields. Increasingly unstable records appear to be characteristic for anisotropic stress conditions. Qualitatively, the shapes of the pressure-time records of hydraulic fracturing tests in rock salt appear to be remarkable sensitive to the ratio of the in situ principal stresses normal to the fractures. Obtaining quantitative estimates of in situ stress magnitudes in rock salt and other highly inelastic rocks, however, hinges on the existence of reliable rate-dependent constitutive models in conjunction with relatively complex numerical analyses. Exaggerated contrasts in the greatest and least in situ compressive stresses are inferred from applications of classical elasticity solutions. Time-dependent effects on the characteristics of hydraulic fracturing in rock salt and associated difficulties in data interpretations arise even if hydraulic fracturing is performed almost immediately after drilling.

DETERMINING THE MINIMUM IN SITU STRESS FROM HYDRAULIC FRACTURING THROUGH PERFORATIONS (SAND87-2500C), N. R. Warpinski, Sandia National Laboratories, Proceedings of the 2nd International Workshop in Hydraulic Fracturing Measurements, Minneapolis, MN, June 16-18, 1988.

Hydraulic fracture stress measurements have been performed through perforations at depths from 1310 to 2470 m at the US Department of Energy's Multiwell Experiment site. The results of over sixty stress tests conducted through perforations have shown that small-volume hydraulic fractures generally provide an accurate, reproducible measurement of the minimum in situ stress. However, unusual behavior can occur in some tests and techniques to evaluate the behavior are suggested. Unclear instantaneous shut-in pressures, which are found on occasional tests, are difficult to evaluate, but the problem appears to be a complex stress state; reprocessing the data using log-log or other functions does not necessarily provide the correct stress value. The possible error in such tests should be assessed from the original pressure-time data and not the reprocessing techniques. Stress results show that the stress distribution is dependent on lithology at this site; mudstones, shales and other nonreservoir rocks generally have a near-lithostatic stress, while sandstones have a considerably lower minimum stress value.

ALTERED-STRESS FRACTURING (SAND87-2510C), N. R. Warpinski, Sandia National Laboratories, P. T. Branagan, CER Corporation, Proceedings of 1988 SPE Rocky Mountain Regional Meeting, Casper, WY, May 16-18, 1988.

Altered-stress fracturing is a concept whereby a hydraulic fracture in one well is reoriented by another hydraulic fracture in a nearby location. The application is in tight, naturally fractured, anisotripic reservoirs in which conventional hydraulic fractures parallel the highly permeable natural fractures and little production enhancement is achieved by conventional hydraulic fracturing. Altered-stress fracturing can modify the stress field so that the hydraulic fractures propagate across the permeable natural fractures. A field test was conducted in which stress changes of 250-300 psi (1.7-2.1 MPa) were measured in an offset well 120 ft (37 m) away during relatively small minifracs in a production well. These results show that stress-altered fracturing is possible at this site and others. Analytic and finite element calculations quantify the effects of layers, stresses, and crack size. Reservoir calculations show significant enhancement compared to conventional treatments.

VI. Industry Programs

VI A. Geothermal Drilling Office

GOVERNMENT-INDUSTRY COOPERATION AT WORK: EXAMPLE OF THE GEOTHERMAL DRILLING ORGANIZATION (SAND88-1019A), J. C. Dunn, Sandia National Laboratories, Annual DOE Geothermal Program Review VI, San Francisco, CA, April 19-21, 1988.

The Geothermal Drilling Organization (GDO) is a joint DOE/Industry group that acts to identify and fund technology development that will have near-term impact on costs of geothermal wells. The emphasis is on products or services that can be commercialized after project completion. Each project is jointly funded by DOE and participating industry partners with industry providing at least 50% of the total cost. Currently the GDO has 23 members with both geothermal operators and service companies represented. Four separate projects with different participating groups are under way. A high temperature borehole acoustic televiewer is being commercialized for fracture detection and casing inspection in the Geysers. A downhole pneumatic turbine has been developed and will be tested in the Geysers. A tool that emplaces two-part urethane foam in lost circulation zones has been designed and fabricated and will be tested in actual lost circulation zones. Drill pipe protectors are being constructed using new high temperature elastomers; compatibility tests in geothermal wells will be conducted. After two years of operation, at least two major benefits of this DOE/Industry association can be identified. (1) Industry has direct access to the DOE technology base through the GDO projects, thus enhancing technology transfer. (2) Researchers carrying out geothermal technology development have the opportunity to observe first-hand the real problems facing the geothermal industry today and this leads to relevant ideas for future research.

POTENTIAL IMPACT ON R&D ON HYDROTHERMAL ENERGY COST, (SAND87-2409), (A Preliminary Application of IMGEO to the DOE/GTD Technology Programs), R. K. Traeger, Sandia National Laboratories, January 1988.

The potential impact of the DOE/Geothermal Technology Development programs on the cost of geothermal power has been estimated using the computer program IMGEO.300. Results indicate a potential 30-40 percent cost reduction for hydrothermal systems with a 40-50 percent cost reduction potential for binary systems.

The purpose of this document is to demonstrate the use of IMGEO. The initial results are tentative because the R&D goals have not be finalized and the code has not been completely validated.

IMPACT ON R&D ON COST OF GEOTHERMAL POWER DOCUMENTATION OF MODEL VERSION 2.09 (SAND87-7018), R. K. Traeger, Sandia National Laboratories; S. Petty, the Mesquite Group; D. Entingh, Meridian Corporation; B. J. Livesay, Livesay Consultants, February 1988.

IMGEO is an analysis used to estimate the impact of technology improvements on the relative cost of hydrothermal power. The analysis is available in a tutorial program for use on personal computers. It is designed for use by R&D program managers to evaluation R&D options. Only the potential impact of technologies is considered with all economic factors being held constant. This analysis has one unique feature. The economic impact of reducing risk by improving reservoir characterization is included using a strategy currently employed by financial institutions.

This report describes the basis of the calculations, documents the code, and describes the operational procedures. Application of the code to study potential cost reductions due to R&D success will be done by R&D managers to evaluate and direct their own programs.

VI B. Strategic Petroleum Reserve

ANALYSIS OF SURFACE SUBSIDENCE OF THE STRATEGIC PETROLEUM RESERVE CRUDE OIL STORAGE SITES FROM DECEMBER 1982 TO JANUARY 1988 (SAND88-1309), K. L. Goin J. T. Neal, Sandia National Laboratories, June 1988.

Surface elevation surveys have been made at five Strategic Petroleum Reserve oil storage sites at approximate one-year intervals beginning in 1982. The surveys have indicated significant surface subsidence rates at all sites, with maximum values varying from about -0.06 ft/yr at the Bryan Mound site to -0.30 ft.yr at the West Hackberry site. Thirty-year projections of the indicated subsidence rates suggest that surface subsidence could lead to surface flooding problems at the West Hackberry site and to a lesser degree at the Bayou Choctaw site. No such flooding problems are foreseen for the other three sites. However, subsidence rates at the Weeks Island site of up to -0.19 ft/yr are large enough to cause concern regarding possible salt fractures in the vicinity of shafts, which could in turn lead to water incursion into the mine.

COLLAPSE WARNING SYSTEM FOR BAYOU CHOCTAW CAVERN 4 (SAND88-1510), J. L. Todd, Sandia National Laboratories, August 1988.

This report documents the development, installation, operation and evaluation of a system which is designed to provide early warning of the failure of an abandoned brine-filled cavern leached in a subsurface salt dome. Failure of a cavern can cause rapid and substantial surface subsidence. The system is installed on Cavern 4, at the US Department of Energy Strategic Petroleum Reserve Bayou Choctaw Site, Iberville Parish, Louisiana.

SUBSIDENCE MONITORING AND EVALUATION PLAN FOR STRATEGIC PETROLEUM RESERVE STORAGE SITES (SAND88-1175), J. T. Neal, Sandia National Laboratories, August 1988.

Subsidence is occurring at all six Strategic Petroleum Reserve (SPR) sites. It results from a combination of cavern closure, Frasch-process sulphur extraction, fluid withdrawal, and other natural causes. Of these, cavern closure resulting from salt creep is the predominant source.

Wherever subsurface materials or fluids are extracted in large quantity, subsidence is usually inevitable; this was anticipated in planning the SPR. A range in rate of subsidence (0.02 to 0.30 ft/yr) has been observed at five sites, reflecting individual site conditions and salt creep properties. No adverse effects have been documented in five years of monitoring subsidence, but future flooding protection must be planned for at West Hackberry, Bryan Mound, and Bayou Choctaw. Stability of surface structures, including oil delivery systems, has been affected at other locations and requires surveillance at SPR sites. Shaft stability is important to monitor at Weeks Island.

A subsidence monitoring program is developed and recommended. It includes: (a) continuation of annual releveling; (b) quadrennial determination of horizontal drift; (c) triennial measurement of gravity values to determine elevation change, and to validate releveling data; (d) obtaining 1/2400 air photos quadrennially; (e) coordination of other subsidence monitoring efforts, especially involving regional subsidence; (f) continuation of cavern creep modeling; (g) engineering evaluation of observed and predicted subsidence effects; (h) information dissemination in the form of an annual review and report.

A priority sequence is suggested that considers observed subsidence and operational factors such as oil inventories and risk appraisal. First (highest) priority is assigned to Weeks Island and West Hackberry. Second (intermediate) priority is given to Bayou Choctaw and Bryan Mound. Third, (lowest) priority is assigned to Sulphur Mines and Big Hill. The priority strategy can be used as a management tool in allocating resources and in determining relative attention that is required at the six sites.

MICROWAVE TRANSMISSION THROUGH STRATEGIC PETROLEUM RESERVE CRUDE OIL SAMPLES FROM BAYOU CHOCTAW CAVERNS (SAND88-1895), J. G. Castle, Sandia National Laboratories, November 1988.

Transmission of microwave power at frequencies from 1 to 11 GHz has been observed through a short, slotted, coaxial line filled with crude oil from each of five wellhead samples collected at Bayou Choctaw (BC) and one sample from a West Hackberry cavern (WH105). An accurate model for the filled slotted line is used to derive the dielectric constant and loss tangent for each oil. The highest loss occurs in oil from BC19 whose loss tangent is 0.0103 at 1 GHz; the lowest, in WH105 whose loss tangent at 1 GHz is 0.0026. These data suggest favorable prospects for high-resolution radar mapping of SPR cavern walls. Sulphur compounds in the oil appear to be the major source of the microwave attenuation.

DEVELOPMENT AND VALIDATION OF THE SPR CAVERN FLUID VELOCITY MODEL (SAND88-2711), S. W. Webb, Sandia National Laboratories, September 1988.

In order to understand a number of processes that occur in an SPR cavern, such a fluid mixing and temperature stratification, a comprehensive thermofluid model for the cavern fluid velocity flow pattern has been developed. Based on a review of other analytical and experimental data, a two-region fluid velocity model is proposed. The to regions are a boundary layer region along the vertical walls and a central core region in the middle. The boundary layer behavior is analyzed by the local similarity method which has been modified to conserve energy and to include mixed convection and other effects. The central core region uses a simple plug flow model. Mass and energy exchange between the two regions is calculated by the boundary layer model. The velocity and temperature distribution results of this model compare favorably with the limited available data. Additional data are needed, however, to completely validate the model for the conditions encountered in an SPR cavern.

3-D FINITE ELEMENT CALCULATION OF SUBSIDENCE INDUCED DEFORMATION OF THE WEEKS ISLAND SERVICE SHAFT (SAND87-2365), D. S. Preece, Sandia National Laboratories, December 1987.

The service shaft at the Weeks Island SPR facility has experienced vertical and lateral movement since it was constructed in 1905. Movement of the shaft over the past few years has been confirmed through survey levels of the shaft collar and two plumbline surveys of the top 100 feet of the shaft. This 3-D finite element calculation was done to gain an understanding of the deformation of the Service Shaft due to the subsidence of the surrounding material. Subsidence at the site results from creep closure of the bi-level room-and-pillar salt mine which is currently the reservoir for 73 million-barrels of crude oil. The 3-D finite element model treats the southwest corner of the mine and contains 118 pillars on two levels of the mine. The deformation of the Service Shaft is determined from the displacement of a vertical line of nodes in the model which is assumed to be the axis of the Service Shaft. The calculation shows that the Service Shaft is tilting to the northeast and moving downward. The movement, however, is mostly a rigid body rotation and translation with very slight bending and stretching of the shaft. Because the bending and tensile strains are insignificant, this calculation indicates that rupture of the shaft is unlikely.

CALCULATION OF CREEP INDUCED VOLUME REDUCTION OF THE WEEKS ISLAND SPR FACILITY USING 3-D FINITE ELEMENT METHODS (SAND87-3096C), D. S. Preece, Sandia National Laboratories, Proceedings of the 29th US Symposium on Rock Mechanics, University of Minnesota, Minneapolis, MN, pp. 343-350, June 1988.

Creep induced volume reduction of the Weeks Island Strategic Petroleum Reserve (SPR) Facility has been calculated using 3-D finite element models. Crude oil is stored in this room and pillar salt mine where the pillars can be sorted into three different categories based on depth and geometry. A 3-D finite element model was created to represent each of the three different pillar categories. The volume change of the three models was proportioned according to the number of pillars in each category to obtain the total volumetric response of the mine. The calculated volumetric response compares well with the measured volumetric response.

VI. C. Technology Transfer - General

TECHNOLOGY TRANSFER: PLUMBING THE EARTH'S DEPTHS (SAND88-2245J), R. K. Traeger, Sandia National Laboratories, H. D. Murphy, Los Alamos National Laboratory, Mechanical Engineering, Vol. 110, No. 9, pp. 62-28, September, 1988.

Although the earth supplies us with energy, minerals, and food, and also receives most of our solid and liquid wastes, we know less about what lies 1000 meters beneath our feet than we do about the depths of the ocean or the outer reaches of space. When the energy crisis of the 1970s occurred, the national laboratories and industry began to work together on problems related to the production of energy from oil, gas, and geothermal resources. The alliance was successful because of the complementary strengths of its components. While the national labs offered advanced hardware and software, large-scale testing facilities, and a multidisciplinary approach, industry's perspective on economics and the market place provided the effort with a focus. The result was the development and commercialization of geotechnologies running the gamut from exploration and drilling to extraction and processing.

VII. Past Bibliographies

GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS: A BIBLIOGRAPHY, JANUARY THROUGH DECEMBER 1981, S. R. Hudson, Editor, Sandia National Laboratories May 1982.

GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS: A BIBLIOGRAPHY, JANUARY THROUGH DECEMBER 1982, S. R. Hudson, Editor, Sandia National Laboratories, March 1983.

GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS: A BIBLIOGRAPHY, JANUARY THROUGH DECEMBER 1983, D. L. Cooper, Editor, Sandia National Laboratories, September 1984.

GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS: A BIBLIOGRAPHY, JANUARY 1984 THROUGH DECEMBER 1985, D. L. Cooper, Editor, Sandia National Laboratories, September 1986.

GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS: A BIBLIOGRAPHY, JANUARY 1986 THROUGH DECEMBER 1987 (SAND88-0753), C. D. Tolendino, Editor, Sandia National Laboratories, August, 1988.

VIII. Author Index

Bartel, L. C., A DIAGRAM APPROACH TO THE PLANE-WAVE ELECTROMAGNETIC WAVE IMPEDANCE (SAND88-1366A), Sandia National Laboratories, Society of Exploration Geophysicists 58th Annual International Meeting, Anaheim, CA, October 30-November 3, 1988.

Bickel, T. C. and P. J. Hommert, THE DESIGN, CONSTRUCTION, AND OPERATION OF A PHYSICAL SIMULATOR FOR EVALUATING GEOPHYSICAL ELECTRICAL TECHNIQUES (SAND88-1494C), Sandia National Laboratories, 1988 Annual International SEG Meeting, Anaheim, CA, October 30-November 3, 1988.

Caffey, T. W. H., SOMMERFELD INTEGRALS AND ELECTROMAGNETIC FIELDS (SAND88-1116), Sandia National Laboratories, September 1988.

Carrigan, C. R., THE BIOT NUMBER AND THE "THERMOS BOTTLE" EFFECT: IMPLICATIONS FOR MAGMA CHAMBER CONVECTION (SAND87-0659J), Sandia National Laboratories, Geology, Vol. 16, No. 9, pp. 771-774, September 1988.

Castle, J. G., MICROWAVE TRANSMISSION THROUGH STRATEGIC PETROLEUM RESERVE CRUDE OIL SAMPLES FROM BAYOU CHOCTAW CAVERNS (SAND88-1895), Sandia National Laboratories, November 1988.

Chu, T. Y. and C. E. Hickox, THERMAL CONVECTION WITH LARGE VISCOSITY VARIATION IN AN ENCLOSURE WITH LOCALIZED HEATING (SAND88-0271C), Sandia National Laboratories, ASME Winter Meeting, Chicago, IL, November 28-December 2, 1988.

Chu, T. Y., RECENT ADVANCES IN MAGMA ENERGY EXTRACTION (SAND88-0876A), Sandia National Laboratories, Annual DOE Geothermal Program Review VI, San Francisco, CA, April 19-21, 1988.

Chu, T. Y., N. R. Warpinski, and R. D. Jacobson, IN SITU EXPERIMENTS OF GEOTHERMAL WELL STIMULATION USING PROPELLANT FRACTURING TECHNOLOGY (SAND87-2241), Sandia National Laboratories, July 1988.

Drumheller, D. S., CORING IN DEEP HARDROCK FORMATIONS (SAND88-1018), Sandia National Laboratories, July 1988.

Duda, L. E., HIGH TEMPERATURE INSTRUMENTATION (SAND88-2063C), Sandia National Laboratories, Advances in Geothermal Reservoir Technology Tech. Rev., Lawrence Berkeley Laboratories, Berkeley, CA, June 14-15, 1988.

Duda, L. E., J. E. Uhl, J. Gabaldon, and H. T. Chang, DETECTION OF A TARGET IN A ROCK FORMATION USING THE RADAR FRACTURE MAPPING TOOL (SAND88-1582C), Sandia National Laboratories, Geothermal Resources Council 1988 Meeting, San Diego, CA, October 9-12, 1988.

Dunn, J. C., RESEARCH TO TAP THE CRUSTAL MAGMA SOURCE (SAND88-1020A), Sandia National Laboratories, Annual DOE Geothermal Program Review VI, San Francisco, CA, April 19-21, 1988.

Dunn, J. C., REDUCING DRILLING AND COMPLETION COSTS--HARD ROCK PENETRATION RESEARCH (SAND88-1021A), Sandia National Laboratories, Annual DOE Geothermal Program Review VI, San Francisco, CA, April 19-21, 1988.

Dunn, J. C., GOVERNMENT-INDUSTRY COOPERATION AT WORK: EXAMPLE OF THE GEOTHERMAL DRILLING ORGANIZATION (SAND88-1019A), Sandia National Laboratories, Annual DOE Geothermal Program Review VI, San Francisco, CA, April 19-21, 1988.

Eichelberger, J. C. and L. W. Younker, INYO DRILLING: A SUMMARY (SAND88-2421A), Sandia National Laboratories and Lawrence Livermore National Laboratory, Fall AGU Meeting, San Francisco, CA, December 5-9, 1988.

Eichelberger, J. C., VOLCANIC EQUIVALENTS OF MAFIC INCLUSIONS IN GRANITES (SAND88-2399A), Sandia National Laboratories, Fall AGU Meeting, San Francisco, CA, December 5-9, 1988.

Eichelberger, J. C., INVESTIGATION OF MAGMATIC PROCESSES BY DRILLING (SAND88-0085A), Sandia National Laboratories, International Seminar on Super-Deep Drilling and Deep Geophysical Sounding, Moscow, USSR, August 23-29, 1988.

Finger, J. T., DRILLING PROGRAM FOR LONG VALLEY CALDERA (SAND88-0820C), Sandia National Laboratories, Annual DOE Geothermal Program Review VI, San Francisco, CA, April 19-21, 1988.

Finley, S. J. and J. C. Lorenz, CHARACTERIZATION OF NATURAL FRACTURES IN MESAVERDE CORE FROM THE MULTIWELL EXPERIMENT (SAND88-1800), Sandia National Laboratories, September 1988.

Finley, S. J., FINAL TECHNICAL POSTER SESSION FOR THE MULTIWELL EXPERIMENT, SPE/DOE SYMPOSIUM ON LOW PERMEABILITY RESERVOIRS (SAND88-2678), Sandia National Laboratories, May 19, 1987.

Gall, B. L., A. R. Sattler, D. R. Maloney, and C. J. Raible, PERMEABILITY DAMAGE TO NATURAL FRACTURES CAUSED BY FRACTURING FLUID POLYMERS (SAND87-2514C), Sandia National Laboratories, Proceedings of 1988 Rocky Mountain Regional Meeting, Casper, WY, May 16-18, 1988.

Glowka, D. A., THE THERMAL RESPONSE OF ROCK TO FRICTION IN THE DRAG CUTTING PROCESS (SAND88-1481C), Sandia National Laboratories, International Conference on Friction Phenomena in Rock, Fredericton, New Brunswick, Canada, August 24-26, 1988.

Goin, K. L. and J. T. Neal, ANALYSIS OF SURFACE SUBSIDENCE OF THE STRATEGIC PETROLEUM RESERVE CRUDE OIL STORAGE SITES FROM DECEMBER 1982 TO JANUARY 1988 (SAND88-1309), Sandia National Laboratories, June 1988.

Hardee, H. C., MAGMA ENERGY (SAND83-1842J), Sandia National Laboratories, Geothermal Science & Technology, Vol 1, No. 2, pp. 165-224, 1988.

Hardee, H. C., OPTIMUM SWEEP FUNCTIONS FOR RESONANT SEISMIC SOURCES (SAND87-2285), Sandia National Laboratories, 1988.

Heiken, G. K., K. Woletz and J. C. Eichelberger, FRACTURE FILLINGS AND INTRUSIVE PYROCLASTS, INYO DOMES, CALIFORNIA (SAND87-1604J), Los Alamos National Laboratory and Sandia National Laboratories, J. Geophysical Research, Vol. 93, No. B5, pp. 4335-4350, 1988.

Hickox, C. E. and T. Y. Chu, THERMAL CONVECTION WITH LARGE VISCOSITY VARIATION IN AN ENCLOSURE WITH LOCALIZED HEATING (SAND88-2122A), Sandia National Laboratories, 8th Biennial CUBE Symposium, Albuquerque, NM, November 16-18, 1988.

Holcomb, D. J., TIME-DEPENDENT CHANGES IN VELOCITY AND ATTENUATION IN SALT AT THE WASTE ISOLATION PILOT PLANT (SAND87-3016C), Sandia National Laboratories, 29th US Symposium on Rock Mechanics, Minneapolis, MN, June 1988.

Loeppke, G. E., D. A. Glowka, E. K. Wright, DESIGN AND EVALUATION OF LOST CIRCULATION MATERIALS FOR SEVERE ENVIRONMENTS (SAND88-1910C), Sandia National Laboratories, 1988 SPE Annual Technical Conference and Exhibition, Houston, TX, October 2-5, 1988.

Loeppke, G. E., DESIGN AND EVALUATION OF LOST CIRCULATION MATERIALS FOR SEVERE ENVIRONMENTS (SAND87-2568A), Sandia National Laboratories, IADC/SPE 1988 Drilling Conference, Dallas, TX, February 28-March 2, 1988.

Lorenz, J. C., N. R. Warpinski, L. W. Teufel, P. T. Branagan, A. R. Sattler and D. A. Northrop, RESULTS OF THE MULTIWELL EXPERIMENT: IN SITU STRESSES NATURAL FRACTURES, AND OTHER GEOLOGICAL CONTROLS ON RESERVOIRS (SAND87-3064J), Sandia National Laboratories, EOS, Vol. 69, No. 35, pp. 817, 825-826, August 30, 1988.

Lorenz, J. C. and S. J. Finley, DISTRIBUTION OF REGIONAL FRACTURES AND FRACTURE PERMEABILITY CONTROLLED BY SEDIMENTOLOGICAL HETEROGENEITIES, MESAVERDE RESERVOIRS, COLORADO (SAND88-0826A), Sandia National Laboratories, 1988 Rocky Mountain Section Meeting, Bismarck, North Dakota, August 21-24, 1988.

Lorenz, J. C. and S. J. Finley, SIGNIFICANCE OF DRILLING- AND CORING-INDUCED FRACTURES IN MESAVERDE CORE, NORTHWESTERN COLORADO (SAND87-1111), Sandia National Laboratories, June 1988.

Lorenz, J. C., S. J. Finley, and D. I. Norman, TECTONISM, SUBSIDENCE, AND FRACTURING OF MESAVERDE RESERVOIRS IN THE PICEANCE BASIN, COLORADO, Sandia National Laboratories, New Mexico Institute of Mining and Technology, AAPG Bulletin, Vol. 72, No. 2, March 1988.

Lysne, P. C., NEUTRONIC PROPERTIES OF MESAVERDE SANDS-I: CALIBRATION OF THE ADVANCED REACTIVITY MEASUREMENT FACILITY, Sandia National Laboratories, Nuclear Geophysics, Vol. 2, No. 2. pp. 105-112, Int. J. Radiat. Appl. Instrum., Part E, Great Britain, 1988.

Lysne, P. C., NEUTRONIC PROPERTIES OF MESAVERDE SANDS-II: RESULTS, Sandia National Laboratories, Nuclear Geophysics, Vol. 2, No. 2, pp. 113-122, Int. J. Radiat. Appl. Instrum. Part E, 1988.

Mansure, A. R., ELECTRICAL GEODIAGNOSTIC EVALUATION OF STEAMFLOOD PERFORMANCE (SAND88-1056A), Sandia National Laboratories, SEG/EAEG Research Workshop on Reservoir Geophysics, Dallas, TX, August 1-3, 1988.

Neal, J. T., SUBSIDENCE MONITORING AND EVALUATION PLAN FOR STRATEGIC PETROLEUM RESERVE STORAGE SITES (SAND88-1175), Sandia National Laboratories, August 1988.

Northrop, D. A., INSIGHTS INTO NATURAL GAS PRODUCTION FROM LOW PERMEABILITY RESERVOIRS (SAND87-3057C), Sandia National Laboratories, Proceedings of the 1988 SPE Gas Technology Symposium, Dallas, TX, June 13-15, 1988.

Northrop, D. A. and K.-H. Frohne, INSIGHTS AND CONTRIBUTIONS FROM THE MULTIWELL EXPERIMENT--A FIELD LABORATORY IN TIGHT GAS SANDSTONE RESERVOIRS (SAND88-0268C), Sandia National Laboratories and Morgantown Energy Technology Center, SPE Proceedings of 63rd Annual Technical Conference and Exhibition, Houston, TX, October 2-5, 1988.

Northrop, D. A., MULTIWELL EXPERIMENT FINAL REPORT: II. THE PALUDAL INTERVAL OF THE MESAVERDE FORMATION (SAND88-1008), Sandia National Laboratories, May 1988.

Preece, D. S. and P. M. Drozda, DESIGN AND PRETEST NUMERICAL SIMULATIONS OF BENCH-SCALE BLASTING EXPERIMENTS IN GRANITE (SAND88-2729A), Sandia National Laboratories, 30th US Symposium on Rock Mechanics, University of West Virginia, Morgantown, WV, June 19-21, 1989.

Preece, D. S., A SPHERICAL ELEMENT MESH GENERATOR USING A SCAN-LINE TECHNIQUE (SAND88-1897A), 8th CUBE Symposium, Sandia National Laboratories, November 16-18, 1988.

Preece, D. S., 3-D FINITE ELEMENT CALCULATION OF SUBSIDENCE INDUCED DEFORMATION OF THE WEEKS ISLAND SERVICE SHAFT (SAND87-2365), Sandia National Laboratories, December 1987.

Preece, D. S., CALCULATION OF CREEP INDUCED VOLUME REDUCTION OF THE WEEKS ISLAND SPR FACILITY USING 3-D FINITE ELEMENT METHODS (SAND87-3096C), Sandia National Laboratories, Proceedings of the 29th US Symposium on Rock Mechanics, University of Minnesota, Minneapolis, MN, pp. 343-350, June 1988.

Sattler, A. R., C. J. Raibel, B. L. Gall, and P. J. Gill, STIMULATION-FLUID SYSTEMS FOR NATURALLY FRACTURED TIGHT GAS SANDSTONES: A GENERAL CASE STUDY FROM MULTIWELL EXPERIMENT STIMULATIONS (SPE-17717), Sandia National Laboratories and National Institute for Petroleum and Energy Research, Schlumberger, Inc., SPE Gas Technology Symposium, Dallas, TX, June 1988.

Sattler, A. R., CORRELATION OF CORE AND LOG DATA TO DETERMINE STRESS INFORMATION AT AND NEAR DOE'S MULTIWELL EXPERIMENT SITE (SAND88-1359A), Sandia National Laboratories, SPWLA 29th Annual Logging Symposium, San Antonio, TX, June 5-8, 1988.

Thorne, B. J. and H. E. Morris, AN ASSESSMENT OF BOREHOLE SEISMIC FRACTURE DIAGNOSTICS (SAND88-1869C), Sandia National Laboratories, SPE Annual Technical Conference and Exhibition, Houston, TX, October 2-5, 1988.

Thorne, B. J. and H. E. Morris, PASSIVE SEISMIC MONITORING OF HYDRAULIC FRACTURE EXPERIMENTS AT THE MULTIWELL EXPERIMENT SITE (SAND88-1284), Sandia National Laboratories, August 1988.

Todd, J. L., COLLAPSE WARNING SYSTEM FOR BAYOU CHOCTAW CAVERN 4 (SAND88-1510), Sandia National Laboratories, August 1988.

Traeger, R. K., HIGH TEMPERATURE INSTRUMENTATION FOR GEOTHERMAL WELL LOGGING (SAND88-0555A), Sandia National Laboratories, High Temperature Electronics Workshop at AFWAL, Albuquerque, NM, April 12-14, 1988.

Traeger, R. K., BOREHOLE TECHNOLOGIES FOR EXTREME ENVIRONMENTS (SAND88-2370C), Sandia National Laboratories, Proceedings of International Symposium on Super-Deep Continental Drilling and Deep Geophysical Research, Yaroslavl, USSR, August 23-29, 1988.

Traeger, R. K., POTENTIAL IMPACT ON R&D ON HYDROTHERMAL ENERGY COST, (SAND87-2409), (A Preliminary Application of IMGEO to the DOE/GTD Technology Programs), Sandia National Laboratories, January 1988.

Traeger, R. K., S. Petty, D. Entingh, and B. J. Livesay, IMPACT ON R&D ON COST OF GEOTHERMAL POWER DOCUMENTATION OF MODEL VERSION 2.09 (SAND87-7018), Sandia National Laboratories; the Mesquite Group; Meridian Corporation; Livesay Consultants, February 1988.

Traeger, R. K., SCIENTIFIC DRILLING IN THERMAL REGIMES (SAND88-0362A and SAND88-2371A), Sandia National Laboratories, International Seminar on Super-Deep Drilling and Deep Sounding, Yaroslavl/Wolga, USSR, August 23-29, 1988.

Traeger, R. K., H. D. Murphy, TECHNOLOGY TRANSFER: PLUMBING THE EARTH'S DEPTHS (SAND88-2245J), Sandia National Laboratories and Los Alamos National Laboratory, Mechanical Engineering, Vol. 110, No. 9, pp. 62-28, September, 1988.

Warpinski, N. R., A. R. Sattler, J. C. Lorenz B. J. Thorne, P. T. Branagan and C. L. Cipolla, A CASE STUDY OF A STIMULATION EXPERIMENT IN A FLUVIAL TIGHT SANDSTONE GAS RESERVOIR (SAND88-0206C), Sandia National Laboratories and CER Corporation, SPE Proceedings of 63rd Annual Technical Conference and Exhibition, Houston, TX, October 2-5, 1988.

Warpinski, N. R., DETERMINING THE MINIMUM IN SITU STRESS FROM HYDRAULIC FRACTURING THROUGH PERFORATIONS (SAND87-2500C), Sandia National Laboratories, Proceedings of the 2nd International Workshop in Hydraulic Fracturing Measurements, Minneapolis, MN, June 16-18, 1988.

Warpinski, N. R. and P. T. Branagan, ALTERED-STRESS FRACTURING (SAND87-2510C), Sandia National Laboratories and CER Corporation, Proceedings of 1988 SPE Rocky Mountain Regional Meeting, Casper, WY, May 16-18, 1988.

Warpinski, N. R., DUAL LEAKOFF BEHAVIOR IN HYDRAULIC FRACTURING OF TIGHT, LENTICULAR GAS SANDS (SAND88-0185C), Sandia National Laboratories, SPE Proceedings of 63rd Annual Technical Conference and Exhibition, Houston, TX, October 2-5, 1988.

Wawersik, W. R., USING HYDRAULIC FRACTURING AND MINEBACK TO DETERMINE IN SITU STRESSES IN ROCK SALT (SAND88-1113A), Sandia National Laboratories, ASME-SES Joint Applied Mechanics Conference, Berkeley, CA, June 20-22, 1988.

Wawersik, W. R. and Charles M. Stone, A CHARACTERIZATION OF PRESSURE RECORDS IN INELASTIC ROCK DEMONSTRATED BY HYDRAULIC FRACTURING MEASUREMENTS IN SALT (SAND87-2569J), Sandia National Laboratories, Pre-Proceedings of the 2nd International Workshop on Hydraulic Fracturing Stress Measurements and International Journal of Rock Mechanics and Mining Sciences, Minneapolis, MN, June 16-18, 1988

Westrich, H. R., H. W. Stockman and J. C. Eichelberger, DEGASSING OF RHYOLITIC MAGMA DURING ASCENT AND EMPLACEMENT (SAND87-1419J), Sandia National Laboratories, J. Geophysical Research, Vol. 93, No. B6, pp. 6503-6511, 1988.

Westrich, H. R. and J. C. Eichelberger, OBSIDIAN LAVA: EVIDENCE FOR A DEGASSED MAGMA (SAND88-2431A), Sandia National Laboratories, AGU 1988 Fall Meeting, San Francisco, CA, December 5-9, 1988.

Whetten, J. T., H. D. Murphy, R. H. Hanold, C. W. Myers, and J. C. Dunn, ADVANCED GEOTHERMAL TECHNOLOGIES (SAND88-0335C), Los Alamos National Laboratory and Sandia National Laboratories, 15th Energy Technology Conference and Exposition, Washington, DC, February 17-19, 1988.

Webb, S. W., DEVELOPMENT AND VALIDATION OF THE SPR CAVERN FLUID VELOCITY MODEL (SAND88-2711), Sandia National Laboratories, September, 1988.

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