DISCLAIMER

A Review of the Drilling R&D Program At Sandia*

H. M. Stoller
Sandia Laboratories
Albuquerque, NM 87185

ABSTRACT

Sandia Laboratories conducts drilling R&D projects in support of the Division of Oil, Gas, Shale and In Situ Technology (DOGSIST), DOE's Office of Energy Research (OER), and the Division of Geothermal Energy (DGE). This paper will review projects conducted for DGE and OER, since projects conducted for DOGSIST are described in detail elsewhere in the proceedings of this Symposium.

Sandia manages the DGE Well Technology Program which includes drilling, well completion and high temperature logging instrumentation R&D for geothermal applications. Accomplishments to date include successful laboratory testing of the continuous chain drill and development of temperature, pressure and flow sondes capable of operation at 275 C.

As part of the DGE Program, efforts are also under way to develop high temperature, high performance bits; high temperature drilling fluids; and high temperature downhole motors. Bearings, seals and lubricants for use in high temperature bits and motors are also being developed and tested. Recent results from this work will be presented.

Under OER sponsorship, and as part of Sandia's Magma Energy Research Project, a drilling experiment into a lava lake at Kilauea Iki, Hawaii, is being conducted. As part of the proposed Continental Drilling Program, materials and techniques for drilling into an active magma/hydrothermal system are in a preliminary phase of study.

INTRODUCTION

Sandia Laboratories is a contract laboratory to the Department of Energy operated by the Western Electric Company. While the primary mission of Sandia is in nuclear ordnance engineering, it has been engaged in energy research and development since the early 70's. One of the areas of primary emphasis in energy research is drilling technology. Here Sandia's expertise in mechanical design, materials, instrumentation, testing and evaluation has had direct application.

*Work performed for the U.S. Dept. of Energy, Contract No. AT(29-1)-789.

Under early sponsorship by the Division of Geothermal Energy, Sandia investigated novel approaches to drilling with the objective of increasing penetration rate and bit life to reduce costs. Concepts such as the downhole replaceable roller cone bit[1], the terra drill - a combination of projectiles with a tri-cone bit[2], the spark drill[3] and the continuous chain drill[4] all were studied. Efforts on the first two have been discontinued; a feasibility study has been concluded on the spark drill with the recommendation that a cost-effective increase in drilling rates is probably not attainable given the present state of technology[5]; and the continuous chain drill has undergone successful laboratory tests[6] which will be described in detail in this paper.

Under DOGSIST sponsorship, a variety of drilling related problems have been studied. For the Drilling and Offshore Technology Branch, these include the development of improved bonding techniques for the Stratapax* diamond cutters, as well as the application of Stratapax[R] to new drill bit designs.[7,8] Studies of drill string steels in corrosive environments have been conducted.[9] Coated elastomers for improved high temperature performance have been developed and are undergoing evaluation.[10] A portable mud viscometer has been developed which provides measurement of the rheological characteristics of drilling muds at simulated borehole conditions of high temperature and high pressure.[11] For the Enhanced Gas Recovery Program which is being conducted at the Bartlesville Energy Research Center, a pressurized core barrel is being developed in conjunction with Maurer Engineering, Inc.[12,13] As part of Sandia's efforts in in situ coal gasification, a contract has been placed with the University of Missouri at Rolla to evaluate erosion drilling as a method to obtain and control linkage between vertical boreholes.[14]

Many of these DOGSIST-sponsored efforts are subjects of papers presented at this symposium and will not be discussed further in this paper. We will concentrate on the review of Sandia's drilling R&D being conducted in association with programs sponsored by the Department of Energy's Division of Geothermal Energy and the Office of Energy Research.

DGE WELL TECHNOLOGY PROGRAM

Overview

To support attainment of the geothermal power-on-line goals, DGE is conducting a Well Technology Program which is managed by Sandia Laboratories.[15,16] The program includes research and development tasks in drilling, well completions and high temperature instrumentation for logging applications. A portion of this program is conducted in-house at Sandia, while the remainder of the research and development is conducted on contracts technically managed by Sandia.

*A registered trademark of the General Electric Company.

At Sandia, the well technology program is divided into two parts: Drilling and Well Completions, technically supervised by Dr. S. Varnado with the assistance of the advisory panel shown in Table I-A; and the Logging Program technically supervised by Dr. A. Veneruso with guidance provided by the advisory panel listed in Table 1-B.

Cost Benefit Analysis

A systems analysis study has been conducted to identify the potential impact that improvements in drilling and completions technology could make to achieving DOE's geothermal power-on-line goals.[17] This study started by defining the dependence of geothermal power-on-line goals on associated bus-bar energy costs, and then quantified the sensitivity of bus-bar energy costs to geothermal well costs. The study then examined current trends in well costs and outlined present deficiencies in geothermal drilling and well completion technologies. This allowed an assessment of the impact that improvements in drilling and well completions technology could make on improving the overall economic viability of geothermal energy, thus contributing to achieving the DOE power-on-line goals (Figure 1).

Current DOE geothermal goals are the equivalent of 115 gigawatts electric power-on-line by the year 2015. This systems study identified that a 20% reduction in drilling costs could probably be attained by improvements in rotary drilling technolgoy as applied to geothermal applications. However, the study concluded that it was unlikely that DGE goals could be met with this level of cost reduction. Rather, it appeared that a 50% reduction in costs associated with geothermal wells would be needed to attain the DGE goals. Based on this study, a broad program in drilling and well completions technology was defined and proposed to DGE. To achieve the 20% cost reduction goal, improvement in methods, tools and materials related to conventional rotary drilling were identified as the dominant approach. Achievement of the 50% cost reduction goal appears to be possible only through an expanded drilling technology development program that includes the development of advanced drilling systems, the extensive use of laboratory and field testing, inclusion of safety and training programs, and the application of integrated data and automation systems. Currently, DGE is funding only the first level of this program. Hopefully by FY'80, a program aimed at the 50% cost reduction goal will be approved.

Drilling Technology Development Program

Presently, contracts have been awarded for R&D activities as shown in Table 2. Major emphasis to date has been on improved drill bits and on high temperature drilling fluids research.

With respect to major accomplishments achieved by this program to date, Smith Tool Company and Christensen Diamond Products Co. are fabricating prototype full scale bits utilizing Stratapax^R cutters. These bits have been tested in the laboratory. Field tests are planned for the summer of 1978. Daedalean successfully tested their cavitating jet descaling method on geothermal equipment at Niland, CA, in January 1978. Facilities have been developed at the Terra Tek Drilling Research Laboratory to test seals and bearing-seal packages at simulated downhole geothermal conditions - 300°C and 500 psi. A 550°F flow loop facility for the testing of drilling muds has been completed at the University of Oklahoma.

Continuous Chain Drill Bit

At Sandia Laboratories, the Continuous Chain Drill, in which fresh cutting surfaces are cycled into place without removing the bit from the borehole, is under development. A Continuous Chain Drill prototype is shown in Figure 2. The cutting surface consists of natural and synthetic (Stratapax^R) diamonds set in a tungsten carbide matrix. The four Stratapax^R cut the center of the hole. The cutting structure is attached to the links of the continuous chain. Five links constitute the cutting surface. There are sufficient links to replace the cutting surface 15 times before a trip must be made.

Drilling fluid pressure is used to cycle the chain downhole. Drilling is done by a combination of bit load and rotation as in conventional rotary drilling.

Cutting structure design and bit hydraulics evolved in a fixed head bit development program, Figure 3. Ten fixed head bits that employed 8 different diamond configurations were built by Christensen Diamond Products, Inc. to Sandia specifications. These fixed head bits were tested at the Reed/Terra Tek Drilling Research Laboratory. Christensen provided consulting services on the eighth fixed head bit design. Features of this latter fixed head bit have been incorporated into the present chain link design.

The final cutting structure design employs several unique design features:

(1) Stratapax^R are used in the nose of the bit. This eliminated the nose area as a life limiting factor and increased the instantaneous penetration rate for a fixed bit load.

(2) A modular hydraulics design was incorporated which significantly improved bit cooling and cleaning. An increase in drilling life while drilling with the higher bit load resulted from this approach.

(3) A lighter-than-normal balanced diamond set was incorporated. Uniform wear rate and a load of 120 pounds per diamond were the design criteria. This resulted in fewer diamonds per

square inch compared to conventional bits which increased penetration rate for a given bit load with little loss in bit life.

Test results of the fixed head bits are summarized in Figure 4.

Two prototype 4 3/4 inch diameter chain drills have been designed and fabricated at Sandia. Both bits have been tested at the Reed/ Terra Tek DRL. The first utilized Christensen-built chain links, the second utilized an alternate design by N. L. Hycalog. Testing of both prototypes was done at room temperature and at atmospheric pressure in Sierra White Granite at 100 rpm. Bit loads were varied to maintain a 4-ft per hour penetration rate. Testing was terminated when the required bit load exceeded 15,000 pounds. The first prototype chain drill (Christensen) was tested in September 1977. The footage drilled versus bit load for all tests are shown in Figure 5. Some fluid erosion problems were noted but have been corrected utilizing harder materials and increased opening of the fluid entry holes. In the first prototype test, the chain cycling mechanism was overly sensitive to fluctuations in drilling fluid pressure but recent efforts have improved the reliability of this mechanism. This chain drill outdrilled the control bit (Christensen MD-24) by a factor of 2 on the average with generally lighter bit loads. Performance of the second prototype chain drill tests, conducted in April 1978, was not as successful as the first prototype test series.

Using the depth-versus-time data generated in the first prototype drilling test series, minimum cost-per-foot calculations have been made. A summary of these calculations is presented in Figure 6 which shows footage cost savings relative to a conventional bit as a function of depth. The chain drill offers appreciable cost savings under all conditions considered.

Well Completion Technology

The economics of geothermal energy is closely tied to the productivity and injectivity of geothermal wells over the 20 to 30 year power plant amortization period. The production or injection capacity and longevity of all geothermal wells can be greatly affected by the technology utilized during completion and initial production. In addition, the environmental impact that may result from under-utilization of completion technology in geothrmal energy development dictates the rapid and comprehensive development and implementation of this technology.

The completions technology program is in an initial state of development. Under contract with Completions Technology Company, a series of studies has been completed. These include a study of the current state-of-the-art in geothermal well completions as they have been adapted from the petroleum industry.[18] This report considers the following: corrosion in metals; scale deposition and controls;

general production and interval completion techniques; and an all-liquid heat recovery systems model. A second study addressed the question of water reinjection for geothermal systems and included sections on: water injection well fundamentals; the injection well model; sources of water contaminants; simulating the downhole behavior of injectors; and the overall influence of damage near the well bore.[19] A third study was an overview of existing methods of geothermal well completions in four types of reservoirs, (steam dominated, liquid dominated, hot dry rock, and geopressured).[20] Based on these studies, the problem areas have been identified, and research directed toward these areas will soon be initiated. These areas include thermal stress analysis, casing/cement interaction studies corrosion-erosion studies, steam well workover techniques, and artificial lifting techniques.

Specific activities to date in the well completions program include participation in the high temperature cement program being directed by the Brookhaven National Laboratories; participation as an advisor in the drilling and completions planning of the Brazoria, Texas, Geopressured Geothermal Test Well Program; the demonstration testing of the cavitating water jet scale removal system at the geothermal test loop facility at Niland, CA, and membrane filter testing of the injection fluid at the Magmamax #3 well in the Imperial Valley. These latter tests are being used to provide data for inclusion in a computer model of injection well performance that allows prediction of the half life of the well.[19] At the present time, the model does not accurately predict well performance; injectivity is higher than the model indicates. This discrepancy is thought to be due to the higher solubility of the solids in the fluid at the temperature of the injection zone. Laboratory tests are underway to confirm this indication and an improved model will be generated.

<u>High Temperature Logging Instrumentation</u>

Instrumentation for making geothermal borehole measurements is limited by the temperature capability (approximately 180°C) of existing logging equipment developed for the oil and gas industry. The Geothermal Logging Instrumentation Development Program being conducted by Sandia Laboratories for DGE is an industry-based effort to develop and apply the high temperature instrumentation needed to make geothermal borehole measurements.[21] The near term goal is to develop instrumentation for use at 275°C and pressures up to 48.3 mpa (7000 psi); subsequent goals are to extend capabilities to 350°C and 138 mpa (20,000 psi).

The repertoire of tools needed to enhance geothermal development, their development priority and performance requirements are listed in Table 3 based on information compiled by the 1975 Geothermal Logging Workshop[22] and updated by the industry-based Geothermal Logging Instrumentation Steering Committee.[23] The technical development of geothermal borehole instrumentation is divided into three tasks: (1) severe environment components development, (2) prototype system development, and (3) borehole tests and evaluations.

Efforts in components development are directed toward alleviating existing technical deficiencies by identifying, testing, and evaluating devices, materials, and components suitable for use in geothermal logging systems. Specific developments are under way in 275°C electronics, high temperature-high resolution pressure transducers, acoustic transducers, and high temperature, corrosion resistant elastomers, ceramics, and metals.

Based on the priority of needs listed in Table 3 the temperature, pressure, flow, and caliper tools are being addressed first. Prototype temperature tools capable of sustained operation at 275°C have been fabricated and successfully tested in geothermal wells in the Jemez Mountains and at Coso Hot Springs site at the China Lake Naval Air Station. Preliminary field tests of the prototype flow and caliper tools and probably the pressure gauge should be conducted by late summer 1978.

Two field tests previously mentioned have been conducted to the prototype temperature tool developed by Sandia and Gearhart-Owens, Inc. Figure 7 presents the data from the test run conducted in the hot dry rock well, GT-2, of the Los Alamos Scientific Laboratory at the Jemez Mountains, NM. Data from the Coso Geothermal Well, CGEH-1, indicated the maximum borehole temperature of 189°C at 834 m. Performance of the temperature instrument in both tests was considered excellent. Subsequent tests will be conducted to assess reliability and accuracy of the sensor at temperatures up to 275°C. As prototypes of the other sensors previously described become available, they too will be subject to field tests.

OER DRILLING STUDIES

DBES Magma Energy Research Program

For the Division of Basic Energy Sciences (DBES) of the Office of Energy Research, Sandia Laboratories is participating in two projects which have associated with them research and development in drilling and high temperature instrumentation. The first of these is the Magma Energy Research Program.[24] The second is the proposed DBES Magma/Hydrothermal System associated with the Continental Drilling Program.[25]

The Sandia Magma Energy Research Project is assessing the scientific feasibility of extracting energy directly from buried circulating magma resources. One of the tasks of the project is the study of geophysical measuring systems to locate and define buried molten rock bodies. A series of geophysical sensing experiments has been conducted at the Kilauea Iki Lava Lake in the Hawaiian Volcano National Park.[26] To verify the results of the molten rock sensing experiments that have been conducted, it will be necessary to drill into and through the lava lake to obtain physical confirmation of both the dimensions of the lava lake as well as in situ physical properties of the molten rock.

In 1976, Sandia Laboratories, with the permission of the National Park Service and the assistance of the USGS Hawaiian Volcano Observatory (HVO), attempted to drill two holes into and through the molten lava lake.[27] Two methods of penetrating through the melt were considered. They were: (1) drill, using a conventional diamond core bit with water as the drilling fluid, to the solid/melt interface and let the drill string fall or be pushed to the bottom crust of the molten zone; and (2) drill with conventional methods to the solid/melt interface, then attempt to chill a solid zone below the interface with the drilling fluid and drill through this chilled zone (chill and drill).

Hole KI76-1 was initiated on August 18, 1976. Solid/melt interface was reached at a depth of 149.3 feet and core recovery was 99% of the rock drilled. Upon encountering the molten rock, the drill string was pushed by the drill rig feed cylinders a distance of 2.5 feet into the melt where progress was stopped by an unexpected obstruction. At the same time the drill string was frozen in the melt so that no movement rotational or vertical was possible. Upon achieving temperature equilibrium, (24 hours later) the drill string could be rotated and raised but could not be pushed deeper. It was assumed that no cutting surfaces were available on the bit. Use of a 300-pound hammer was unsuccessful in attempting to punch through the solid obstruction. The drill string was removed with the results as illustrated in Figure 8.

The drilling of KI76-2 used the same sequence and equipment down to the solid/melt interface as that employed on the first hole. The solid/melt interface was reached at 149.9 feet. The chill and drill method was unsuccessful because available pressure for water injection was less than the hydrostatic pressure of the lava lake; hence upon touching the molten zone, the molten rock flowed into the core bit, stopping the water flow and allowing the melt to solidify (Figure 8). Two attempts resulted in sufficient damage to the drill bit that drillhole KI76-2 was abandoned.

While the Sandia/HVO experience in 1976 did not achieve its objective of drilling through the molten zone, the experience gained did define requirements for a new approach into drilling at Kilauea Iki.

Planned for the fall in 1978 will be a new series of field drilling tests at Kilauea Iki. Two additional drilling concepts will be employed. The first will use a double tube insulated drill string with an uncooled Mar-M 509 drag bit (Figure 9). The purpose of a double tube insulated drill string is to allow the outer tube to maintain the temperature of the lava lake, minimizing the chilling of the magma in which it will come in contact. The inner tube whose temperature will not exceed 300°C will be used to transmit the torque to the drag bit. High pressure air will be used to cool the inner tube and clear the cuttings from the bit when drilling in the molten zone. An instrumentation section will be contained between the drag bit and the drill stem to make physical measurements of the magma while the drill stem is in the lava lake. The second drilling approach to be tried is a modification of the chill and drill method in which sufficient quantities of water will be injected through a modified drag bit to foam and chill the magma into a small porous solid volume. The drag bit will then be used to drill through this solid material. The chilling, foaming and drilling sequence will then be repeated until the bottom of the lava lake is reached.

<u>DBES Magma/Hydrothermal System Continental Drilling Program</u>

Under discussion among several federal agencies is the desirability of conducting a Continental Drilling Program for scientific purposes. Of specific interest to DBES is the scientific knowledge that could be obtained from a borehole drilled through one or more active hydrothermal systems and into or close to a magma body. The proposed DBES Magma/Hydrothermal System portion of the Continental Drilling Program is still in its formative stages. Assisting DBES with its definition of this program have been the National Academy of Sciences, the Los Alamos Scientific Laboratories, the Lawrence Livermore Laboratory and Sandia Laboratories. A summer workshop to define the geoscience interest in continental drilling for scientific purposes was held in July under the auspices of the National Academy of Sciences.[28]

Sandia Laboratories has been assigned the responsibility of studying the drilling and instrumentation research and development needs necessary to attain the objectives of the DBES Magma/Hydrothermal portion of the Continental Drilling Program. To assist in this definition, a Magma/Hydrothermal Drilling and Instrumentation Workshop sponsored by Sandia Laboratories was held this past summer in Albuquerque.[29] The Advisory Panel to this workshop is shown in Table 4. The major thrust of the R&D activity identified by this workshop will be to develop the technology required to drill into an active magma body at probable depths on the order of 5 to 10 km. The future of this activity is not clear, but certainly in FY'79 the emphasis will be on establishing a program plan for the development of the needed technology and hopefully to initiate, at least at a low level, research into the high priority items identified by that workshop.

SUMMARY

This review of the drilling activities at Sandia Laboratories was intended to provide a picture of the breadth of studies underway. Specific details can be obtained from the numerous references quoted in this paper.

It has been a basic philosophy within the Sandia Program to establish collaborative or joint programs with private industry in as many of our R&D activities as possible. There are two reasons for this: first, that association clearly benefits Sandia in allowing us to share in the expertise that exists in industry which combined with our capabilities can hopefully lead to improvements in the state-of-the-art and secondly, if successful developments do occur, this joint relationship should aid the transfer of the newly developed technology more effectively into the private sector for commercial use. Additionally, it is appropriate to emphasize the close relationship we maintain with the Bartlesville Energy Research Center which plays a major role in the technical management of many of the DOE/Fossil Energy contracts in drilling R&D.

From a standpoint of accomplishments, I think Sandia has played a lead role in demonstrating that utilization of Stratapax^R may provide a significant advance in drill bit technology. We have successfully applied Stratapax in core bits with significant results.[30] We have applied Stratapax^R in a new full-faced bit design again with significantly improved drilling rates.[31] Finally, the continuous chain drill has the potential of providing significant cost benefits to the industry. Additionally, the cutting stucture design of this revolutionary drill has features that could improve conventional diamond bits; namely, Stratapax^R in the nose area of the bit could allow bullet nose diamond bits to be designed; the use of modular hydraulics should provide improvements in cleaning, and cooling; and the use of the minimum diamond set pattern will allow increased drilling rates and uniform wear rates. In the area of logging instrumentation, the development of sensors capable of operating at 275°C will find applications, not only in the geothermal industry, but also in the hot and corrosive environments associated with deep oil and gas wells. In fact, transfer of the micro-electronics technology associated with these high temperature sensors is already under way to private industry.[32]

I hope that in the years ahead additional technical accomplishments will be attained and that they can be reported at subsequent meetings sponsored by the Division of Oil, Gas, Shale and In Situ Technology.

REFERENCES

1. "The Downhole Replaceable Drill Bit -- Progress Report and Program Plan," SAND 76-0227, M. M. Newsom, J. A. St. Clair, R. F. Ashmore, H. M. Dodd, Jr., June 1976, Sandia Laboratories.

2. The Terra-Drill Program, A Progress Report and Program Plan," SAND76-0228, M. M. Newsom, R. L. Alvis, D. Dardick, June 1976, Sandia Laboratories.

3. "Drilling Research on the Electrical Detonation and Subsequent Cavitation in a Liquid Technique (Spark Drilling)," SAND76-0086, Drilling Research Division, April 1976, Sandia Laboratories.

4. "The Continuous Chain Bit -- Progress Report and Program Plan," SAND76-0186, M. M. Newsom, J. A. St. Clair, H. K. Togami, H. M. Dodd, Jr., May 1976, Sandia Laboratories.

5. "Drilling Research on the Electrical Detonation and Subsequent Cavitation in a Liquid Technique (Spark Drilling) -- Final Report," SAND77-1631, R. Wardlaw, G. L. Harvey, O. Milton, to be published, Sandia Laboratories.

6. "Continuous Chain Drill Bit Advances Through Lab Tests," M. M. Newsom, Oil and Gas Journal, Jan. 30, 1978, pp.151-160.

7. "Sandia Laboratories Drilling Technology Research Program," SAND77-1160C, C. F. Huff, M. M. Newsom, Proceedings of 3rd Annual DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, Tulsa, OK, Sept. 1, 1977.

8. "Development of a Diffusion Bonding Technique for Attaching Stratapax[R] Cutters to Drill Bits," SAND78-0677, S. G. Varnado, C. F. Huff, to be presented at 4th Annual DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, Tulsa, OK, Aug. 29-31, 1978.

9. "Fatigue of Steel in Simulated Drilling Environments," SAND78-0530, K. H. Eckelmeyer, April 1978.

10. "Evaluation of Seals for a Geothermal Logging Tool," SAND78-0423C, C. Arnold, Jr., J. A. Coquet, L. E. Baker, to be presented at Geothermal Resources Council 1978 Annual Meeting, Hilo, Hawaii, July 25-28, 1978.

11. "A Portable High Temperature, High Pressure Mud Viscometer," SAND78-0678C, R. C. Reineke, S. G. Varnado, to be presented at 4th Annual DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, Tulsa, OK, August 29-31, 1978.

12. "Selected Drilling Research Project," W. J. McDonald, et al., 3rd Annual Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, Tulsa, OK, Aug. 30-Sept. 1, 1977.

13. "An Improved Pressure Coring System for Fluid Content Measurements," SAND78-0679, A. L. McFall, to be presented at 4th Annual Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, Tulsa, OK, Aug. 29-31, 1978.

14. Personal communication with D. A. Northrop, Sandia Laboratories.

15. "Geothermal Well Technology Drilling and Completions Program Plan," SAND77-1630, M. M. Newsom, J. H. Barnette, L. E. Baker, S. G. Varnado, J. Polito, Mar. 1978, Sandia Laboratories.

16. "Geothermal Logging Instrumentation Development Program Plan," SAND78-0316, A. F. Veneruso, Apr. 1978, Sandia Laboratories.

17. "A Program in Geothermal Well Technology Directed Toward Achieving DGE Power-on-Line Goals," SAND78-0766, J. Polito, S. Varnado, May 1978, Sandia Laboratories.

18. "State of the Art in Well Completion Technology as Applied to Geothermal Development," SAND78-7008, R. M. Jorda, R. C. Ellis, Completion Technology Company and Sandia Laboratories.

19. "An Engineering Study of Water Reinjection for Geothermal Systems," SAND78-7009, R. M. Jorda, Completion Technology Company and Sandia Laboratories.

20. "Geothermal Well Completions," SAND78-7010, R. E. Snyder, Completion Technology Company and Sandia Laboratories.

21. "Geothermal Logging Instrumentation Development Program Plan," SAND78-0316, A. F. Veneruso, April 1978, Sandia Laboratories.

22. "Report of the Geophysical Measurements in Geothermal Wells Workshop," SAND75-0608, L. E. Baker, R. P. Baker, R. L. Hughen, December 1975, Sandia Laboratories.

23. "Minutes of the First Meeting of the Geothermal Logging Steering Committee," June 28, 1977, Sandia Laboratories.

24. "Magma Tap: The Ultimate Geothermal Energy Program," John L. Colp, AAPG Memoir 25, Papers from the Circum-Pacific Energy & Mineral Resources Conference, Honolulu, Aug. 1974, American Association of Petroleum Geologists, Tulsa, OK, 1976, pp. 124-129.

25. Private Communication, Dr. George Kolstad, Division of Basic Energy Sciences, DBES.

26. "A Critical Assessment of Geophysical Sensing Experiments on Kilauea Iki Lava Lake," J. F. Hermance, D. W. Forsyth, and J. L. Colp, EOS, American Geophysical Union, Apr. 1978, also SAND77-0828, Sandia Laboratories, in publication.

27. "Drilling into Molten Rock at Kilauea Iki," John L. Colp, Proceedings Annual Meeting, July 1978, Geothermal Resources Council, Davis, CA.

28. "Continental Drillng for Scientific Purposes," July 17-21, 1977, Los Alamos Scientific Laboratory.

29. "Magma/Hydrothermal Drilling & Instrumentation Workshop," May 31, June 1-2, 1978, Sandia Laboratories, Proceedings in publication.

30. "An Improved Pressure Coring System for Fluid Content Measurements," SAND78-0679, A. L. McFall, to be presented at 4th Annual Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, Tulsa, OK, Aug. 29-31, 1978.

31. "Development of a Diffusion Bonding Technique for Attaching Stratapax[R] Cutters to Drill Bits," SAND78-0677, S. G. Varnado C. F. Huff, Ibid.

32. Private Communication, A. F. Veneruso, Sandia Laboratories.

TABLE 1-A

GEOTHERMAL DRILLING AND COMPLETIONS STEERING COMMITTEE

Larry W. Diamond
Vice President-Technical Services
American Coldset Corp.

William A. Glass
President
Big Chief Drilling Company

Wilton Gravley
Engineering Associate
Mobil Research and Development Corp.

George Kemnitz, Jr.
General Division Manager
Four Corners Division
Loffland Brothers Company

Jim Kingsolver
Manager, Geothermal Operations
Smith Tool

Dr. B. J. Livesay
Consultant

Delbert E. Pyle
Manager of Operations
Union Geothermal Division
Union Oil Company of California

Dr. John Rowley
Los Alamos Scientific Laboratory

Robert Jorda
Completion Technology Company

Kurt H. Trzeciak
Chief Design Engineer
Dyna-Drill

Prof. M. Friedman
Center for Tectonophysics and
  Department of Geology
Texas A&M University

Dr. Charles William Berge
Manager, Geothermal Exploration
Phillips Petroleum Company

Dr. R. Nicholson
Republic Geothermal

TABLE 1-B

LOGGING PROGRAM STEERING COMMITTEE MEMBERS

Mike Lamers	Measurement Analysis Corp.
Dr. Bill Brigham	Stanford University
Jack Burgen	Gearhart-Owen Industries, Inc.
Ed Basham	Gearhart-Owen Industries, Inc.
Lyman Edwards	Dresser-Industries, Inc.
Bill Wilson	Dresser-Atlas
Don Hill	Chevron
Dr. John Howard	Lawrence Berkeley Laboratories
Werner Schwartz	Lawrence Berkeley Laboratories
Dr. George Keller	Colorado School of Mines
Dr. B. E. Kenyon	Schlumberger
Dr. P. Sinclair	Schlumberger
W. Scott Keys	USGS-WRD
Mark Mathews	Los Alamos Scientific Laboratories
Robert C. Ransom	Union Oil Research Center
Dr. Roger Wall	Aminoil USA, Inc.
Carl Zimmerman	Halliburton Services
Bob Lawson	Phillips Petroleum
Donald A. Campbell	Republic Geothermal, Inc.

TABLE 2

	Subject	Contractor	Principal Investigator	Duration
1.	Geothermal Drill Bit	Terra Tek	S. J. Green	5/75-continuing
2.	Water Jet Drill	Univ. of Missouri-Rolla	D. A. Summers	6/75-5/78
3.	Stratapax Drill Bit	General Electric Co.	L. A. Hibbs	6/75-5/79
4.	Mud Effects/Cavitating Jet	Hydronautics, Inc.	A. F. Kann	1/78-1/79
5.	Improvement of Downhole Drilling Motor Bearings and Seals	Terra Tek	S. J. Green	?/76-continuing
6.	Development of High Temperature, High Pressure Drilling Mud Research Instrumentation	NL/Baroid	K. Reed	4/78-3/80
7.	Improvements of Geothermal Drilling Fluid Technology	Maurer Engineering	W. J. McDonald	7/77-6/78
8.	Temperature Limits of Drilling Fluids	Univ. of Oklahoma	J. D. Thuren	9/76-continuing
9.	State-of-the-Art Study of Foam Drilling Fluids	Maurer Engineering	W. J. McDonald	4/78-9/78
10.	Wellbore Thermal Simulator	Enertech	M. A. Goodman	6/78-7/79
11.	Cavitating Jet Descaling	Daedalean	A. A. Hochrein	2/76-3/78

TABLE 3

PROTOTYPE GEOTHERMAL LOGGING TOOLS
(Up to 275°C operation)

Tool	Performance Goal
Temperature	1.0°C accuracy, 0.5°C resolution
Pressure	0-7000 psi, 0.1 psi accuracy, 0.01 psi resolution
Flow	0-2000 gpm in diphasic flow
Caliper	6 arm borehole geometry, 0.1 in accuracy with fracture indication
Casing Collar Locator	Detect standard collars
Formation Resistivity	To be determined
Fracture Mapping	To be determined
Casing & Cementing Inspection	To be determined
Directional Survey	To be determined
Sonde Refrigeration	50 watts cooling to 125°C for at least 100 hours

TABLE 4

DBES CONTINENTAL DRILLING PROGRAM
HYDROTHERMAL/MAGMA DRILLING AND INSTRUMENTATION STEERING COMMITTEE

Don Brown
Los Alamos Scientific Laboratory

Jack Burgen
Vice-President, Wireline
G.O.I. Computer Center

Dr. Robert Christiansen
U. S. Geological Survey

Lyman Edwards
Technical Consultant
Dresser Industries, Inc.

Dr. Mel Friedman
Center for Tectonophysics
Texas A&M University

T. M. Gerlach
Sandia Laboratories

Conway C. Grayson
Department of Energy
Nevada Operations Office

Dr. Hugh C. Heard
Lawrence Livermore Laboratory

W. J. Holbert
Division Manager
Rowan Drilling - U.S.

Prof. A. J. Horn
Petroleum Engineering Department
Stanford University

Dr. W. E. Kenyon
Schlumberger-Doll Research Center

Dr. Art Lachenbruch
U. S. Geological Survey

Dr. B. J. Livesay
Livesay Consultants

Dr. W. C. Maurer
Maurer Engineering, Inc.

Dr. Roger Staehle
Metallurgical Engineering
Ohio State University

Bill Wilson
Systems Manager
Dresser Atlas Research & Engineering

INFLUENCE OF GEOTHERMAL WELL COSTS ON POWER-ON-LINE GOALS

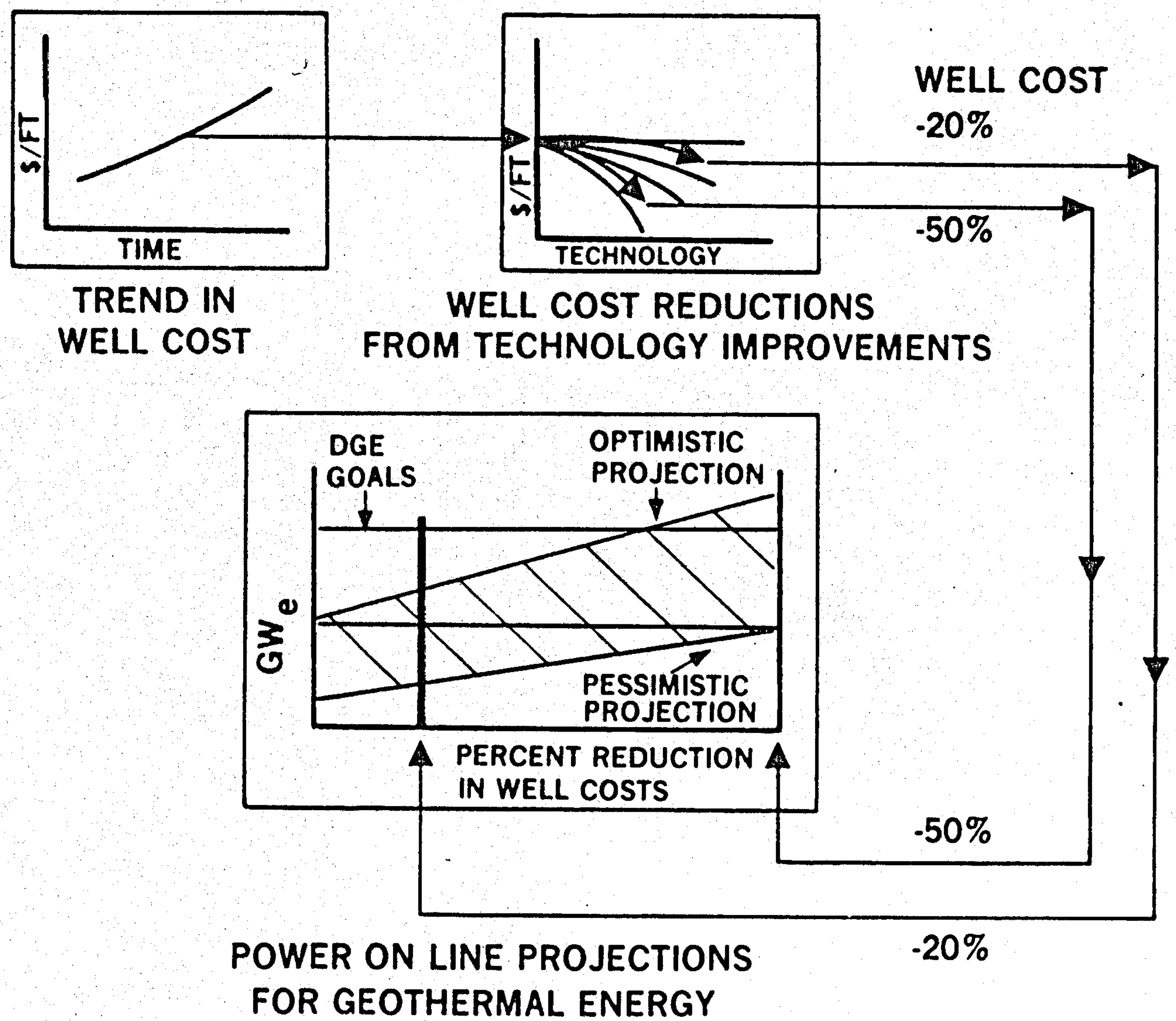

FIGURE 1

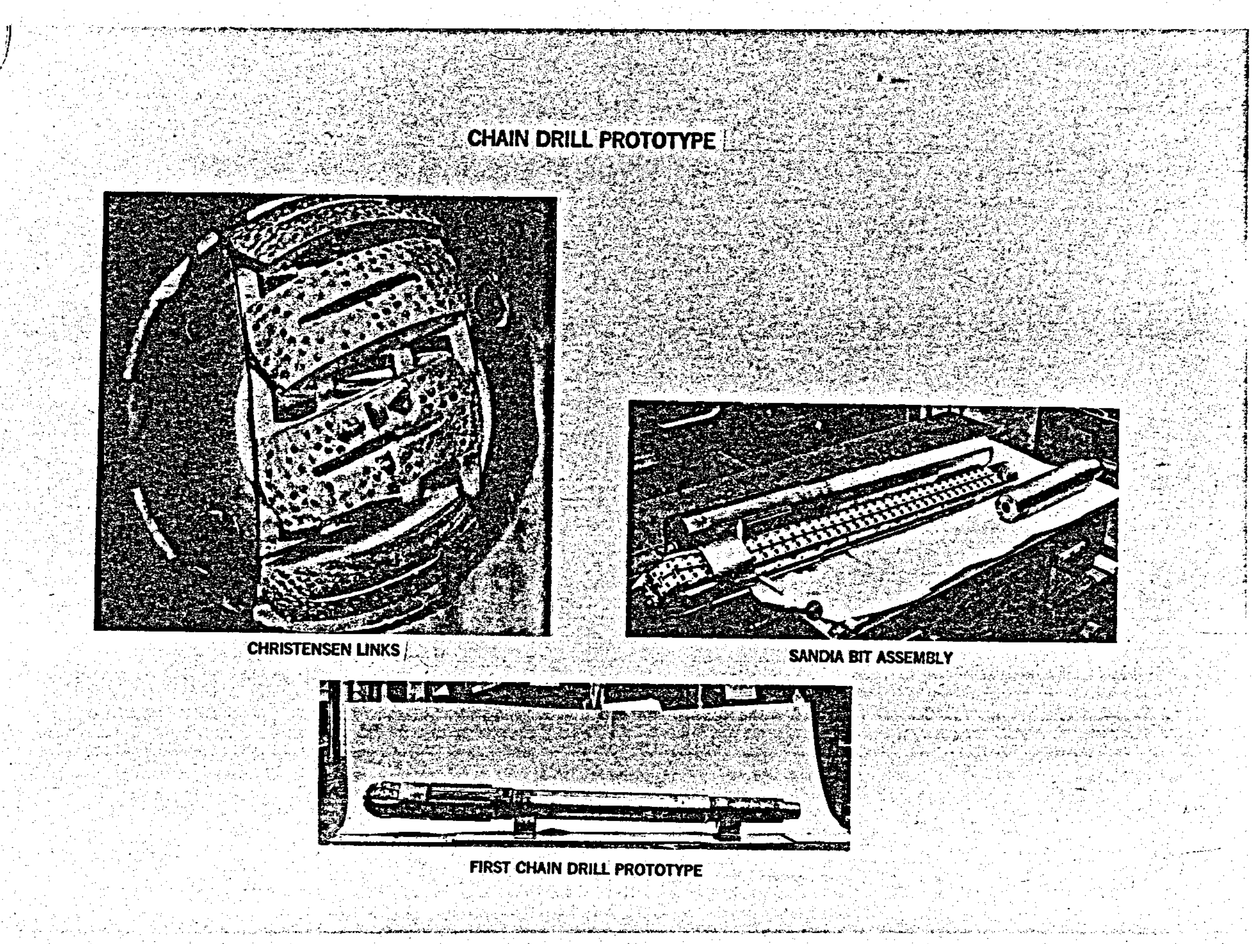
CHAIN DRILL PROTOTYPE
CHRISTENSEN LINKS
SANDIA BIT ASSEMBLY
FIRST CHAIN DRILL PROTOTYPE

Figure 2

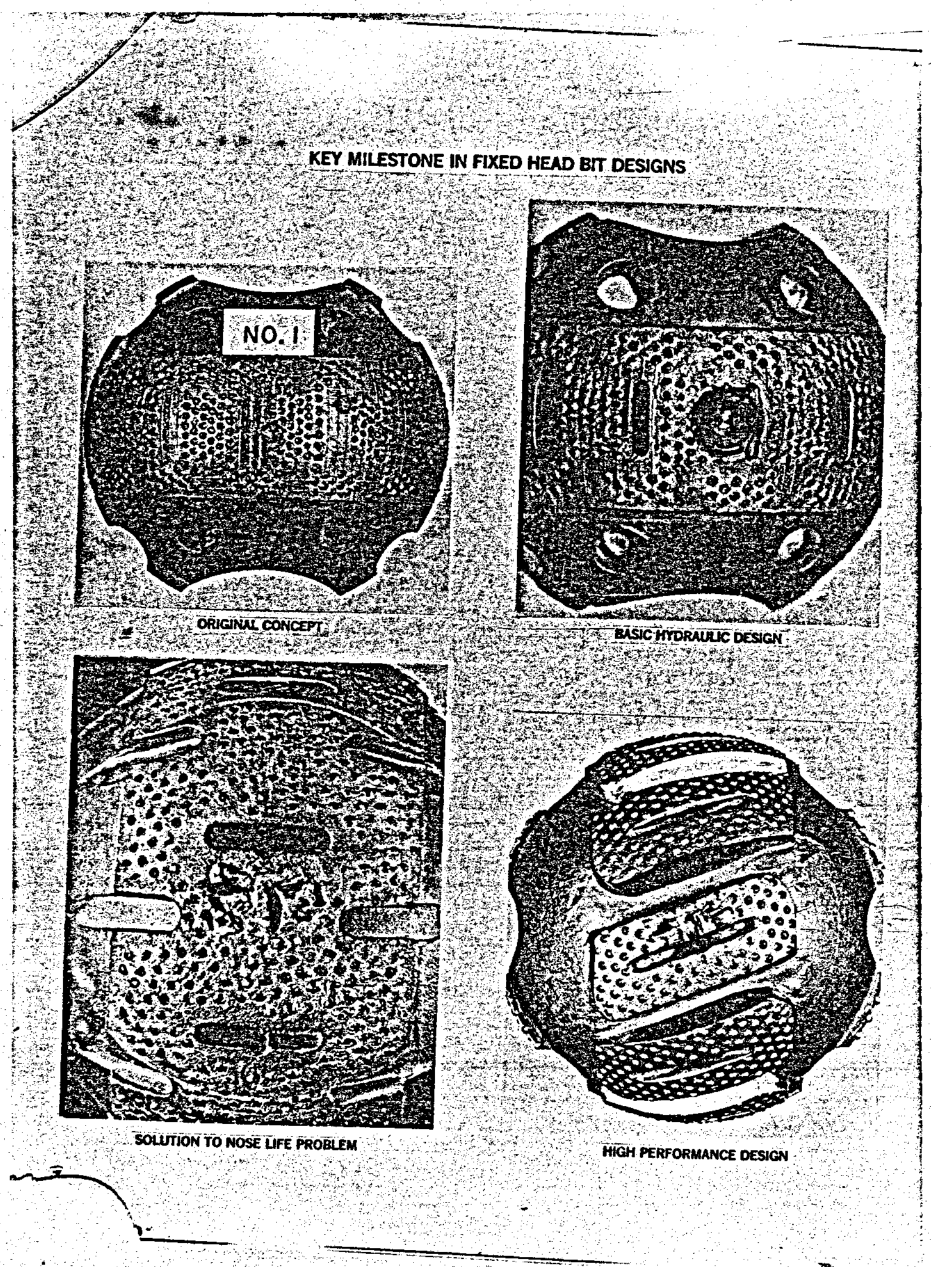
KEY MILESTONE IN FIXED HEAD BIT DESIGNS
NO. I
ORIGINAL CONCEPT
BASIC HYDRAULIC DESIGN
SOLUTION TO NOSE LIFE PROBLEM
HIGH PERFORMANCE DESIGN

Figure 3

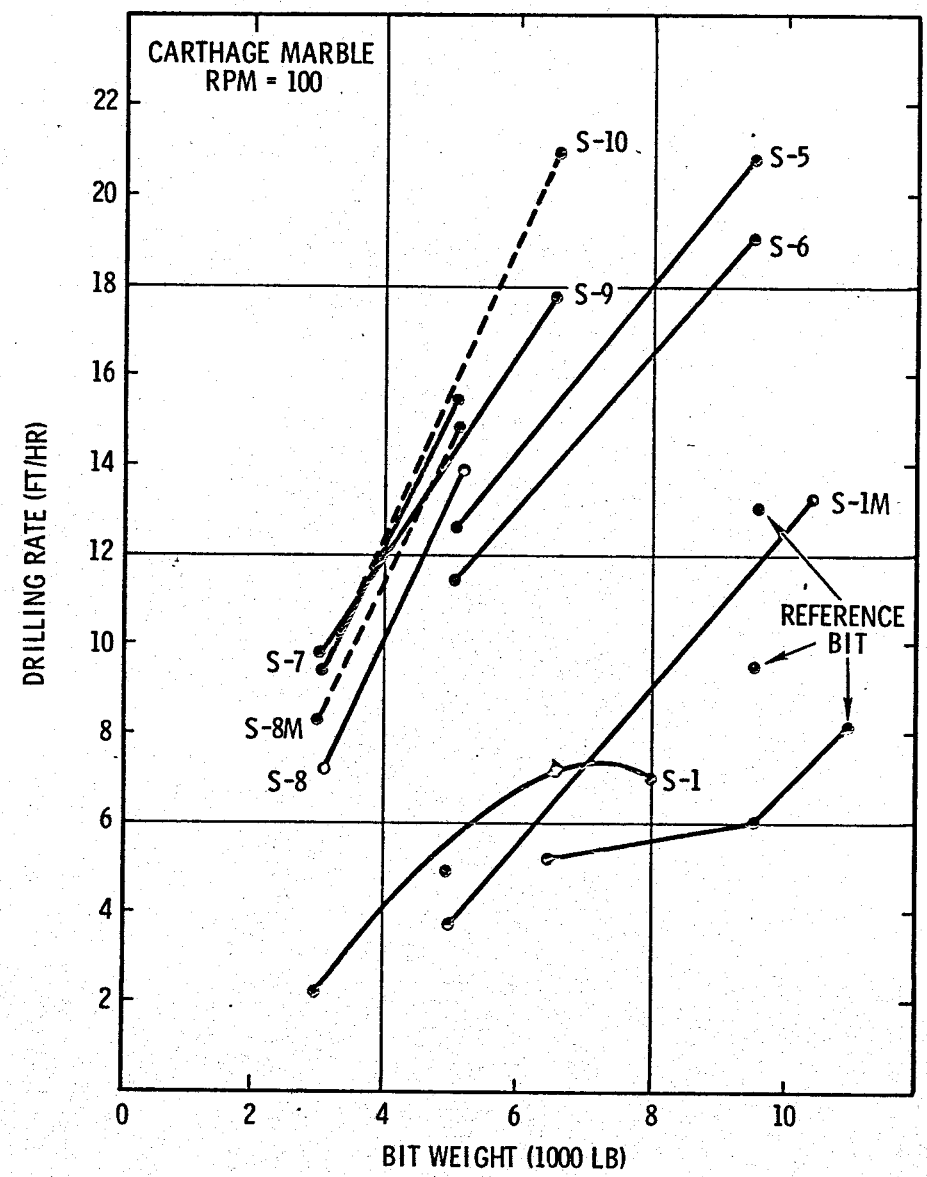

Figure 4

Test Results of The Fixed Head Bits

COMPARATIVE DRILLING PERFORMANCE

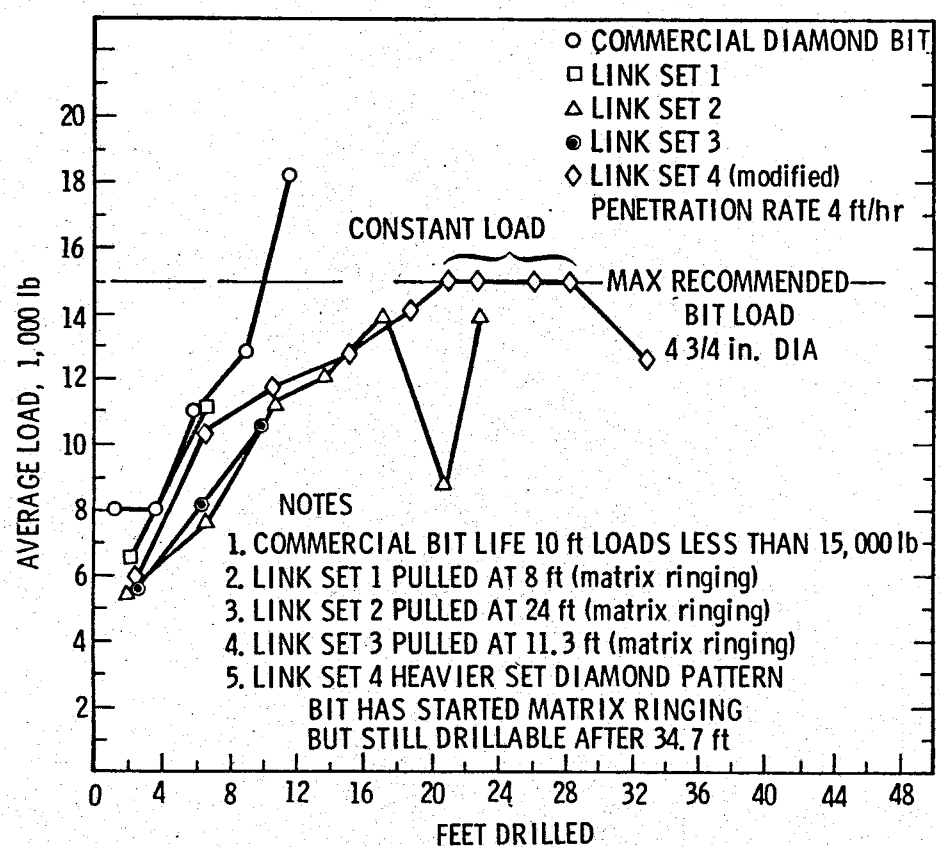

Figure 5

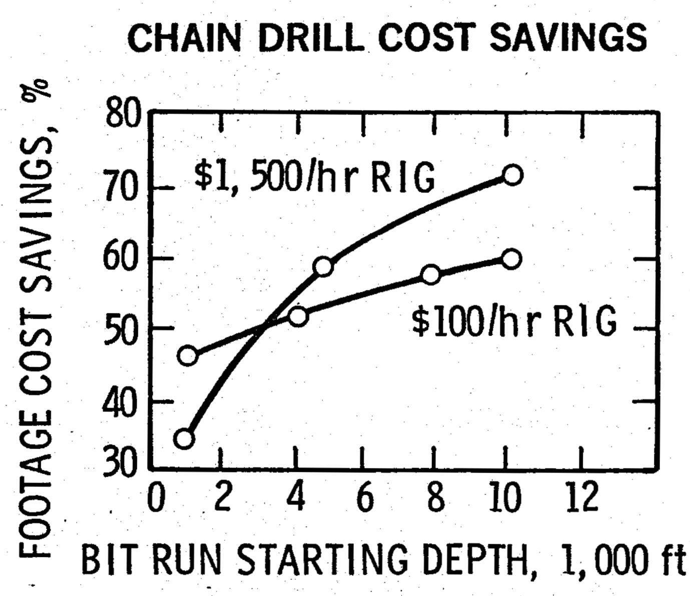

Figure 6

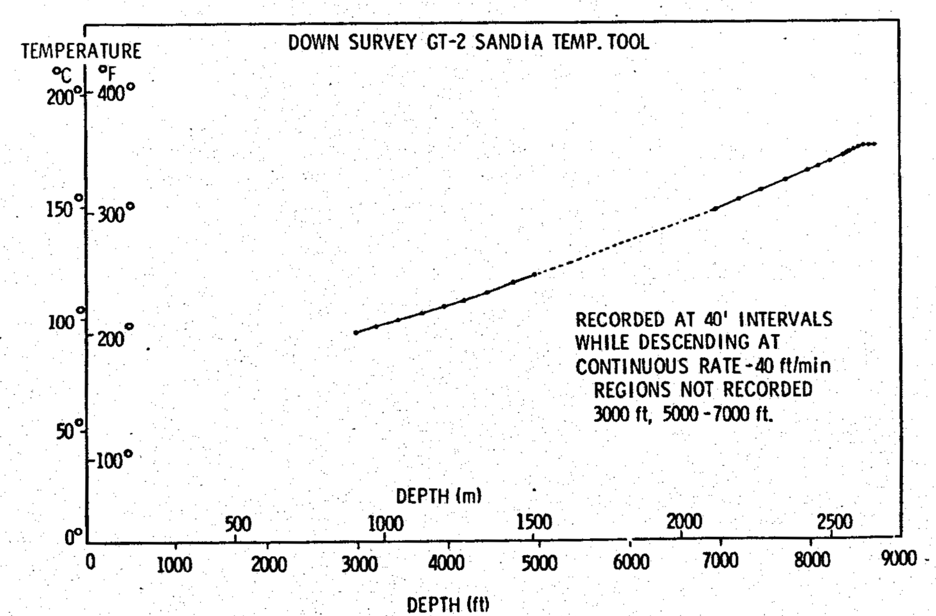

Figure 7

LAVA LAKE DRILLING PROGRAM

RESULTS OF KILAUEA IKI DRILLING-1976

BOREHOLE 76-1

METHOD - CONVENTIONAL CORE BIT. DRILL TO MELT INTERFACE, LET DRILL STEM DROP TO BOTTOM OF MOLTEN LENSE.

PROBLEM - DRILL STEM HIT SOLID OBSTRUCTION 1 m.BELOW INTERFACE.

RESULTS - COLD STEM FROZE IN PLACE. CONVENTIONAL BIT MELTED.

BOREHOLE 76-2

METHOD CONVENTIONAL CORE BIT. DRILL TO MELT INTERFACE, RETRACT BIT A FEW FEET, PUMP WATER TO CHILL MELT, ADVANCE DRILL & REPEAT.

PROBLEM - MOLTEN ROCK SURGED UP INTO BIT, FROZE, AND BLOCKED WATER FLOW.

RESULTS - UNABLE TO CHILL MELT & ADVANCE DRILL IN TWO ATTEMPTS.

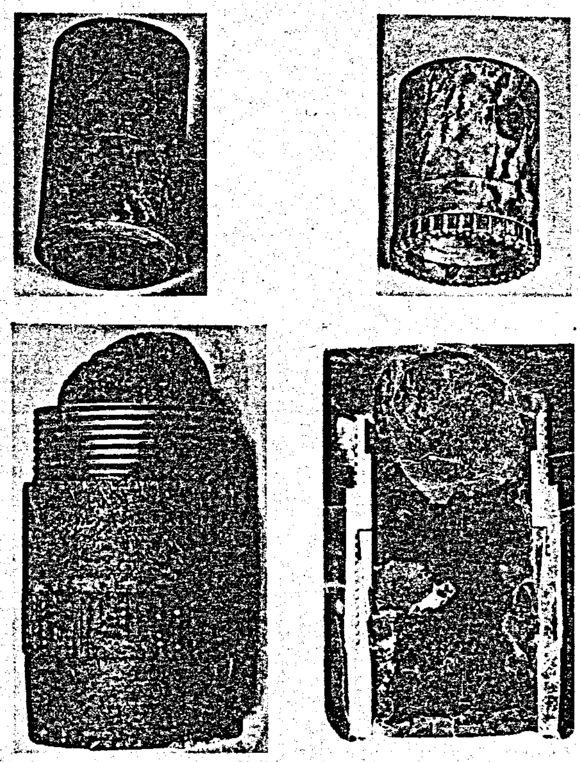

Figure 8

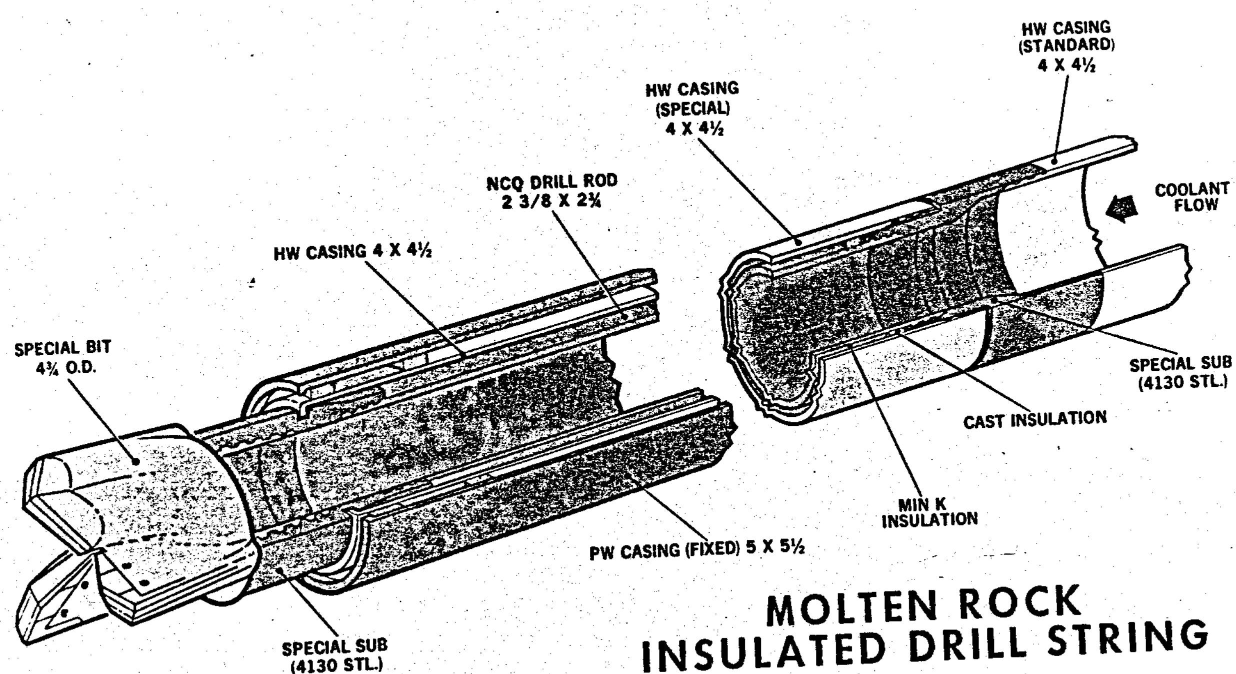
HW CASING
(STANDARD)
4 X 4½
HW CASING
(SPECIAL)
4 X 4½
COOLANT
FLOW
NCQ DRILL ROD
2 3/8 X 2¾
HW CASING 4 X 4½
SPECIAL BIT
4¾ O.D.
SPECIAL SUB
(4130 STL.)
CAST INSULATION
MIN K
INSULATION
PW CASING (FIXED) 5 X 5½
SPECIAL SUB
(4130 STL.)
MOLTEN ROCK
INSULATED DRILL STRING

Figure 9