FINAL REPORT

Enhanced Geothermal Systems Technology Phase II

Animas Valley, New Mexico

United States Department of Energy

Idaho Operations Office

Cooperative Agreement No. DE-FC07-01ID14203

Submitted by:

Roy A. Cunniff and Roger L. Bowers

Lightning Dock Geothermal, Inc.
Las Cruces, New Mexico

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ABSTRACT

This Final Report for the Enhanced Geothermal Systems Technology, Phase II, Animas Valley, New Mexico is submitted in compliance with the terms of DOE Cooperative Agreement No. DE-FC07-01ID14203.

This report provides a summary of geotechnical and geophysical data that led to the siting, drilling, and completion of two (2) temperature gradient holes in the geothermal anomaly at Lightning Dock Known Geothermal Resource Area in the Animas Valley of New Mexico. Included in this report is a summary of institutional factors and data defining the well drilling process and acquiring drilling permits. Data covering the results of the drilling and temperature logging of these two holes are provided. The two gradient holes were sited on federal geothermal leases owned by Lightning Dock Geothermal, Inc. and both holes were drilled into lakebed sediments some distance from the intense shallow geothermal anomaly located in the eastern half of Section 7, Township 25 South, Range 19 West.

Gradient hole TG 56-14 was sited about 4 km southwest of the center of the intense shallow geothermal anomaly. This location was based on geological and geophysical data, and sited at that location partially to evaluate sonic velocity models used to interpret reflection seismic traverses completed within the Animas Valley. The hole was completed to a total depth of 305 m (1,000 ft.). Temperature gradient was positive to total depth, with a bottom hole gradient of 80 ^{o}C/km. This gradient can be extrapolated to a temperature of 150 ^{o}C (302 ^{o}F) at a depth of 1.2 km (3,900 ft.).

Gradient hole TG 12-7 was sited about one km to the west of the intense shallow geothermal anomaly. This location was based on geological and geophysical data, but more specifically, the location was chosen in an attempt to establish a boundary for the intense shallow anomaly. The hole was completed to a total depth of 305 m (1,000 ft.). Temperature gradient generally was positive to total depth, with a marked signature of a rollover near the midpoint of the depth. Bottom gradient was 120 ^{o}C/km. This gradient can be extrapolated to a temperature of 150 ^{o}C (302 ^{o}F) at a depth of 760 m (2,500 ft.).

Temperature data from these gradient holes were evaluated in context of comprehensive geophysical data developed under the Geothermal Resource Evaluation and Definition (GRED) program. As contrasted to the relatively small EGS reservoir evaluated in the Final Report for Phase I of the EGS program, the new data define a large increase in the volumetric size of the potential EGS reservoir. Hence, the new information supports the belief that a commercially viable EGS reservoir exists in the Animas Valley of New Mexico.

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INTRODUCTION

This EGS Final Report documents the geological and geophysical underpinning for the process of siting and completing two temperature gradient holes in the Lightning Dock Known Geothermal Resource Area (KGRA) in the Animas Valley of New Mexico. This KGRA is marked by an intense shallow anomaly located in the eastern half of Section 7, Township 25 S, Range 19 W. In 1984-85, a deep exploratory geothermal test well, TFD 55-7, was drilled in the resource. The shallow anomaly has been used for more than 25 years for greenhouse heating. Containing about 1.3 million square feet of heated space, this greenhouse complex is the largest geothermally heated greenhouse complex in the country. Figure 1 depicts the project location.

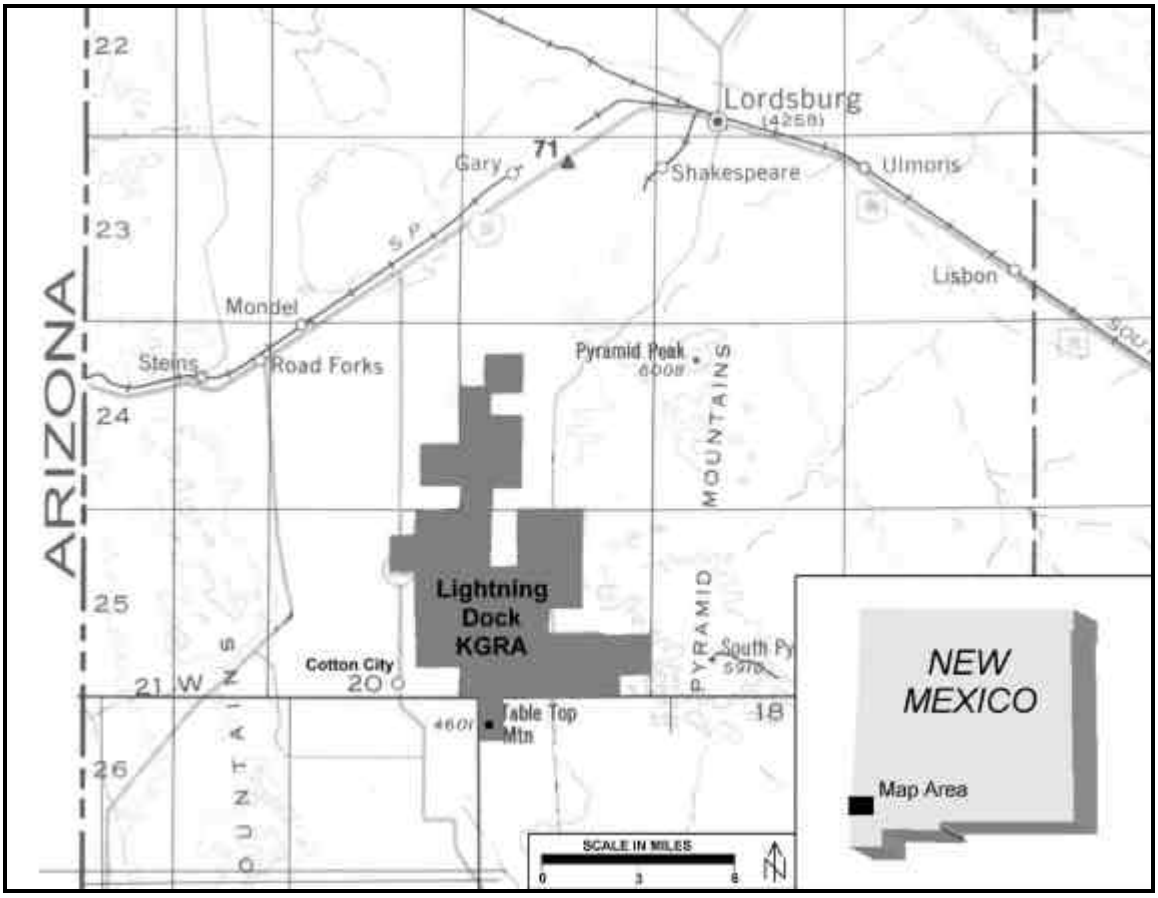

Figure 1. Lightning Dock Known Geothermal Resource Area.

DATA USED FOR GRADIENT HOLE SITING DECISIONS

This section of the EGS Final Report contains a summary and cross-reference to work performed under the DOE Geothermal Resource Evaluation and Definition (GRED) Program, administered by DOE-AAO under **Cooperative Agreement No. DE-FC07-00AL66977**, and also provides a summary correlation with work performed during earlier geothermal exploration programs.

Exploration and reservoir definition studies under the GRED program were used to remove some of the major uncertainties about the optimal locations to site and drill multiple temperature gradient holes to maximize resource assessment as well as to maximize the chances for early development success.

The following sections of this report provide the geological and geophysical underpinning for site selection and permitting. Included in the following paragraphs are summaries of aeromagnetic surveys, gravity and resisitivity surveys, reflection seismic traverses, and two special surveys, namely, carbon dioxide soil gas and thermal ion dispersion.

Structural Implications from Gravity, Aeromagnetic, and Resistivity Surveys.

Fieldwork approved for GRED Phase I was completed in October 2001. The integration of new and old data led to a new thermo/structural model of the geothermal circulation system, but the surveys also raised new questions about structural controls and did not provide adequate detail to select new drilling targets with minimal risk.

In 2001, new geophysical data were collected at the geothermal anomaly and surrounding lands. The new data included 304 additional gravity stations, two east-west oriented electrical resisitivity profiles, and nearly 2,000 line-km of aeromagnetic data collected at two nominal flight elevations (4500 ft. and 4800 ft. above mean sea level, or about 100 m and 200 m above average ground level, respectively) covering approximately 160 km^2. The areas covered by these various surveys are shown below in Figure 2.

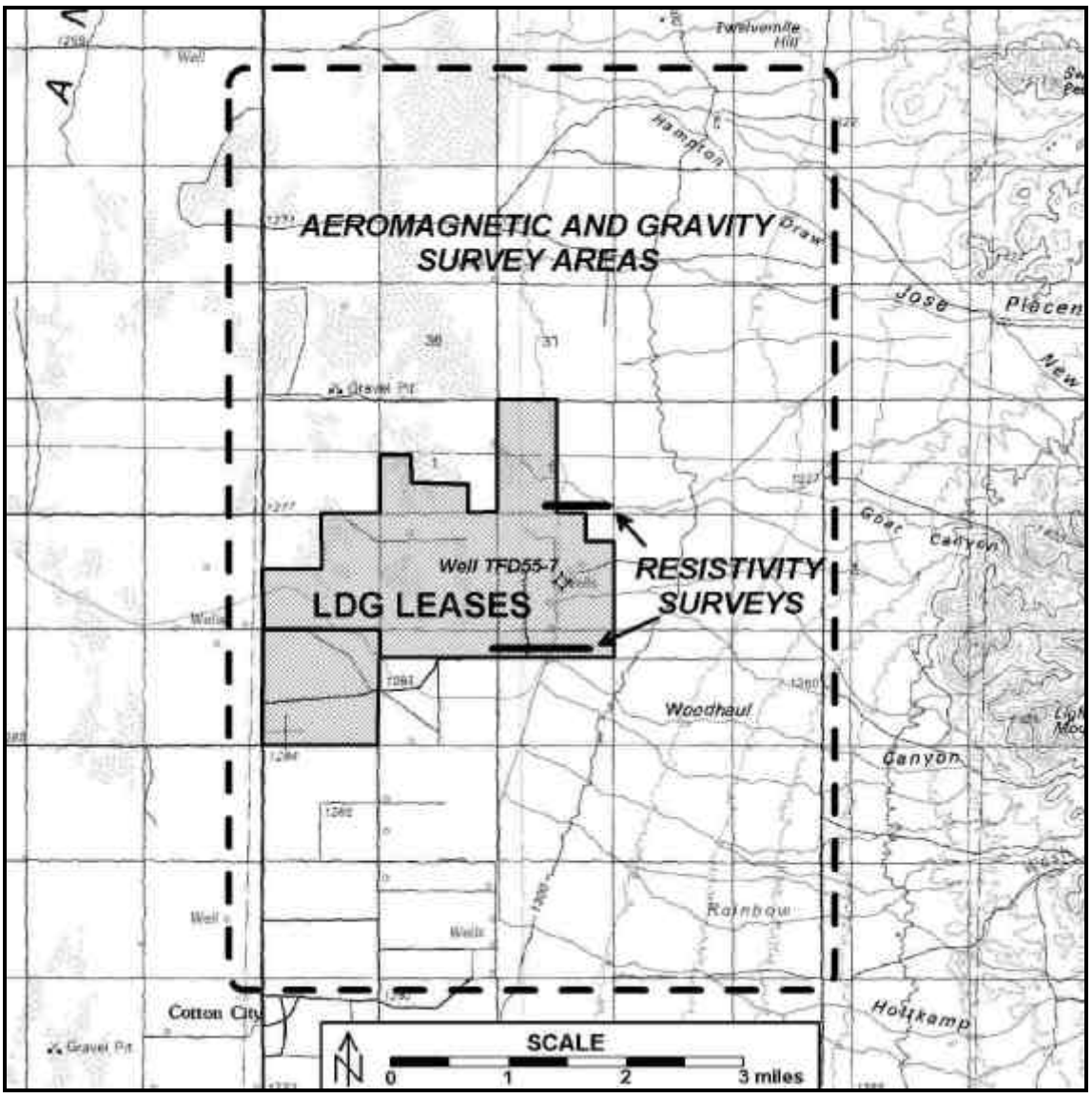

Figure 2. Geophysical surveys conducted for GRED Phase I.

Structural Implications from Seismic Surveys

Under the GRED program, LDG reviewed in detail more than 60 miles of older vibroseis data, and purchased a data license to some 32 lineal miles of very usable data. In addition, LDG completed new seismic traverses covering almost 18 miles. Hence, LDG owns about 50 line miles of seismic traverses, covering most of the lower Animas Valley. Details are contained in the following paragraphs.

Harvey Seismic Services, Inc. completed almost 65 line miles of seismic vibroseis surveys in the lower Animas Valley in 1982. These are 12-fold data, and the location and measurement methods meet modern standards. LDG was allowed to review all of the older data in our area of geographical interest. Using the services of Excel Geophysical Services, LDG reprocessed a total of more than 40 miles of data, and eventually purchased the data rights to 32 line miles.

After reviewing bids from six firms, LDG contracted with Bird Geophysical Services to run new traverses totaling about 18 line miles along roads leading through the center of LDG's geothermal leases and the center of the intense shallow geothermal anomaly. Figure 3 depicts the area in and around LDG leases covered by the seismic traverses purchased and completed by LDG in the Animas Valley.

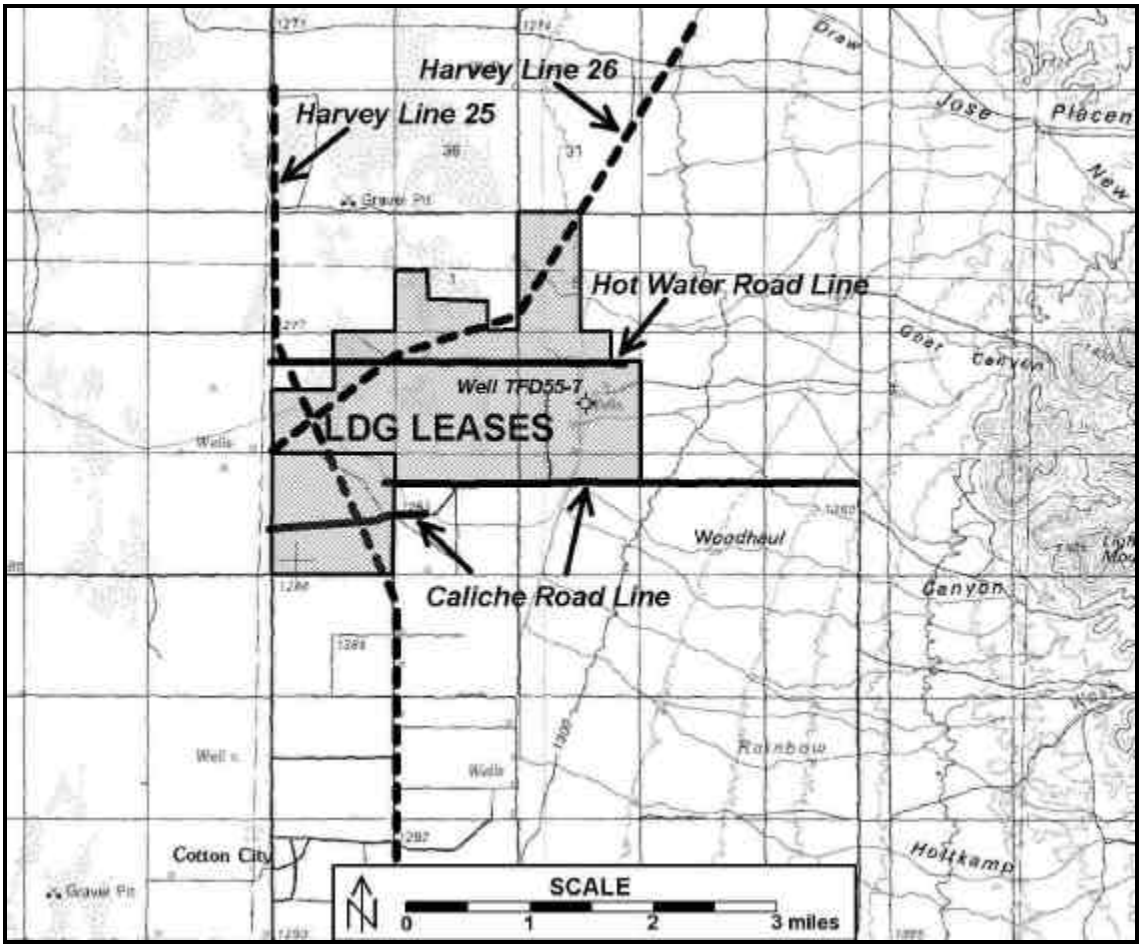

Figure 3. Seismic traverses conducted and purchased by LDG.

Carbon Dioxide Soil-Gas Studies

These studies were completed with the assistance of graduate students from New Mexico Tech University. Field surveys were completed using a portable LICOR unit to measure values for CO_2 flux in shallow soils, and to assess whether or not it was possible to detect and map leakage of CO_2 along possible subsurface faults.

Preliminary results indicate there is a possible correlation between the CO_2 results and the NE-SW magnetic linear features that run through the center of the intense shallow geothermal anomaly. This correlation could suggest that the thermal plume extends at depth to the southwest, an area of the thermal anomaly that has been suggested for years by other researchers as the possible deep heat source of the anomaly, but has never been explored by deep drilling.

Thermal Ion Dispersion

Thermal Ion Dispersion (TID) is a method, used for years in the precious and base metals exploration business, to determine the movement of hot, mineral-bearing waters through rocks, gravels, and soils. The TID method had not been applied to the geothermal industry before. In July 2002, LDG contracted MagmaChem of Sonoita, AZ to conduct a TID survey in the center of the shallow geothermal anomaly. The goals of the soil sampling were: 1) to test whether or not the technique could detect the overall thermal anomaly, and 2) if the overall thermal feature could be detected, then subsequently to examine whether or not surface geochemistry could define internal geothermal features.

A total of 77 soil samples were collected from July 22 through July 28, 2002. The sampling program was initially designed to sample the main geothermal feature in a profile and open-grid fashion. Samples were submitted to ACTLABS in Tucson for analysis by their enhanced, enzyme leach technique.

The results depicted a new "picture" of the shallow thermal anomaly. The data not only detected the thermal anomaly and showed zonation of mineral assemblages outward from the hottest area, but the results also suggested a much more specific fluid-flow path for shallow thermal leakage.

GRADIENT HOLE SITING AND PERMITTING

Gradient Hole Siting Process

Based on information developed from LDG's resource exploration in 2001 and 2002, LDG developed a working model of the structures controlling and influencing the shallow anomaly within lease NM 34790 and adjoining terrain, with sufficient information to site and drill deep temperature gradient holes to test that model. However, one consequence of the large amount of data is that multiple desirable drill locations can be deduced from the data. LDG initially determined that four different areas showed a high degree of promise for deep temperature gradient holes. Fiscal constraints for the EGS Cooperative Agreement dictated that not more than two of these areas could be explored within existing budget limits. Accordingly, two drill sites were nominated as an optimization of known geological and geophysical data used to develop the working model for structural controls.

Candidate gradient hole locations were selected based on the following criteria:

- Enhance knowledge of potential subsurface structures and thermal regime.
- Develop structural and thermal data for an area largely unexplored from gradient hole drilling in the late 1970's and early 1980's.
- Drill site selection should include all relevant information from our geological and geophysical explorations.
- Drill on land and mineral rights under LDG control.
- Drilling operations should cause minimal environmental disturbance.

Evaluation of prospective drill sites was made in accordance with the stated criteria. All four of the best sites met the first three criteria. However, two sites were located in areas that would optimize the first three criteria. Moreover, both sites were on LDG existing federal geothermal leases, and LDG has current Operating Agreements with the private surface landowners that allow drilling operations. In addition, both sites were located such that drilling operations would cause minimal environmental disturbance.

Two locations were selected for final permitting applications under the EGS Cooperative Agreement. The first of these locations was considered a "step-out" hole to explore a relatively large distance from the known anomaly, with the selected site located along a southwest-trending photo linear and a deduced parallel magnetic linear feature, and located at a distance of about 4 km from the intense shallow geothermal. This hole was designated TG 56-14 using the Kettleman numbering system. This hole also was designed to serve as a correlation of the sonic velocity models used to image reflection seismic traverses completed in north-south and east-west orientations near the chosen gradient hole location. LDG expected that this hole would be completed in alluvium to total depth, and would be a relatively low-temperature gradient hole.

The second location selected, TG 12-7, is about one kilometer to the west of the center of the intense shallow geothermal anomaly, and was designed to probe the western portion of the shallow anomaly in an area where no deep drilling has been done. LDG expected this hole would be completed in alluvium to total depth, and the temperature was expected to be similar to an earlier AMAX hole drilled about ¼-mile to the northeast of this location. The specific location was based on a vertical displacement deduced from one of the seismic traverses, the intersection of two linear features deduced from the aeromagnetic survey, and a possible structural feature deduced from the thermal ion dispersion survey.

Gradient Hole Permitting Process

Initial Permit Applications

LDG expected that the permitting process would be difficult and time consuming because of the lack of geothermal drilling activity in New Mexico in the past 20 years. The permitting agencies had no current experience for reviewing and approving geothermal gradient holes drilled on federal lands. This problem was magnified by the fact that permits are required from three separate agencies; namely, the Bureau of Land Management (BLM) for federal geothermal gradient holes, the State of New Mexico Oil Conservation Division (OCD) for all gradient holes drilled on privately-owned surface or State land, and the State of New Mexico Engineer for all wells drilled into a Declared

Underground Water Basin or Closed Basin (with the Animas Valley designated in both categories). Each of these permitting actions required lead time for processing; moreover, the State Engineer Permit Application required submittal to that office of the approved OCD Permit. To further compound the difficulties, both the OCD and the State Engineer Permit Applications required identification of the driller to be used, with the State Engineer also requiring identification of the NM Drilling License for the chosen driller. Hence, permit applications had to wait for completion of the bidding and selection process for the contracted well driller.

Another factor also impacted the process for permit approval for the two gradient holes to be drilled under the EGS program. As part of the GRED program, two additional gradient holes were nominated by LDG. Hence, the permitting process entailed acquiring permits for four gradient holes, with provisions to change locations based on results from initial drilling. Moreover, to avoid delays to the contracted driller, permits had to be in place for all of the candidate locations in a timely manner.

The Drilling Plan and Sundry Notice for the initial gradient hole, TG 12-7, were submitted on December 29, 2002 to the BLM Las Cruces Field Office. Concurrently, on the same date, LDG submitted a permit application to the New Mexico OCD. Subsequent coordination was made with the BLM, and LDG was provided information that BLM wanted the drilling permits submitted on an older form. This revised permit application was submitted on January 31, 2003. Concurrently, to assure that OCD would be acting on the same information, LDG submitted a new application to that office, and this permit was approved on February 6, 2003.

LDG was required to submit a second revised Drilling Plan transmitted to the BLM on February 20, 2003. In the interim, the BLM had conducted a preliminary environmental investigation and concluded there was minimal to no environmental impact from the proposed drilling. Subsequently, on February 25, 2003, the BLM provided LDG with approval for the proposed drilling activity.

Permit Application for an Exploratory Well (the State Engineer has no category for a gradient hole, per se) was submitted to the NM State Engineer on March 13, 2003. This application finally was approved on March 20, 2003, some two days after the driller had mobilized to the site for TG 12-7. From initiation to completion, the permitting process for gradient hole TG 12-7 required almost three months.

Subsequent Permit Applications

A different strategy was adopted for subsequent permits. As part of the GRED Program, two additional gradient holes were nominated by LDG. Hence, the permitting process entailed acquiring permits for three additional gradient holes, with provisions to change locations based on results from initial drilling as data were acquired from each successive gradient hole. Moreover, to avoid delays to the contracted driller, permits had to be in place for all of the candidate locations in a timely manner. Further, as noted earlier, applications to the New Mexico OCD and the State Engineer required identification of the specific drilling firm. Hence, permit applications had to wait for completion of the bidding and selection process for the contracted well driller.

Decision was made by LDG to use a batch-type process for permit applications. Accordingly, a new Plan of Operations and Drilling Plan were developed and submitted to the BLM; these documents identified a total of nine (9) separate locations for which environmental clearance and drilling permit approval were needed, with the caveat that only three of the locations would be drilled. Concurrently, LDG used acceptable procurement policies, and contracted with a single driller for all three new gradient holes.

However, since the New Mexico OCD required submittal of individual drilling permits, simultaneous transmittal was made for all nine permit applications. The OCD approved the multiple permits on April 12, 2003, and BLM approval for the multiple gradient holes was issued on April 25, 2003. Separate permit applications were submitted to the New Mexico State Engineer for each well, with the initial application for TG 56-14 submitted on April 4, 2004 and approved on April 22, 2003.

Figure 4 shows the locations for the nine candidate gradient holes for which BLM and New Mexico OCD approval was given. Also depicted is the location for gradient hole TG 12-7.

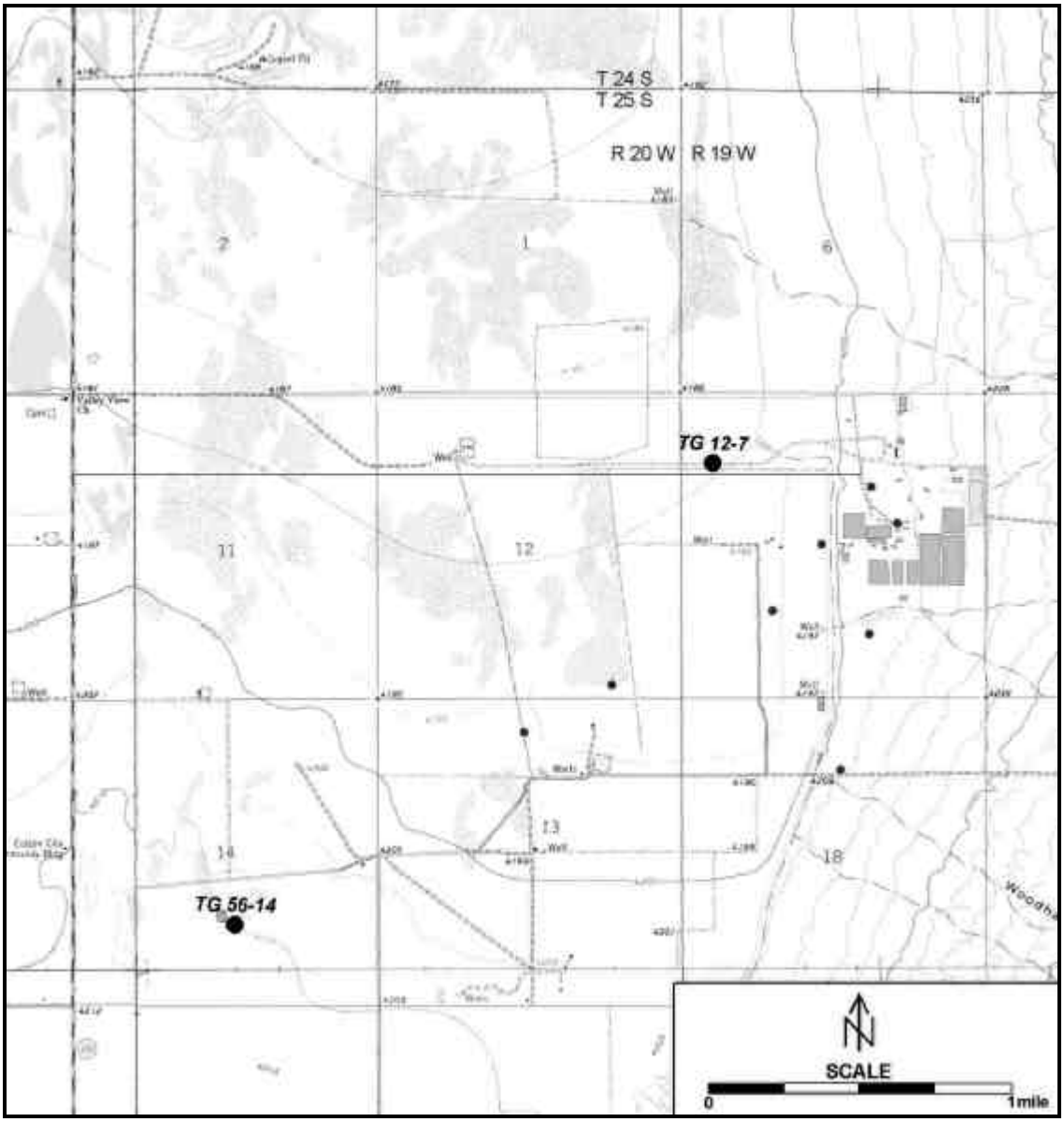

Figure 4. Candidate locations for geothermal gradient holes.

GRADIENT HOLE DRILLING AND COMPLETION

Selection of Drilling Contractors

Competitive bidding practices were used to select the driller for TG 12-7. After reviewing bids and statements of interest, the drilling contractor was selected and placed on contract on December 20, 2002 to drill and complete the gradient hole to 1,000 feet of depth. The contract provided an optional second gradient hole, depending on satisfactory completion of the first hole.

Because of drilling problems with the initial driller (see below), a second round of Invitation for Bid (IFB) was prepared for the second EGS hole, with this IDB also including the two gradient holes to be drilled under the GRED program. This time frame represented a period in which qualified and interested bidders were in short supply because of a high degree of activity in oil and gas well drilling. Only one responsive bid was received, and a drilling contract was awarded to E. Dale Burgett on April 12, 2003 for gradient hole TG 56-14. The contract contained options for drilling the two GRED holes.

Drilling and Completion of Hole TG 12-7

Hole TG 12-7 was spudded on March 21, 2003, and drilled to a depth of 600 feet. Because of difficult drilling conditions, the driller was unable to drill below 600 feet of depth. Decision was made by LDG to complete the gradient hole to that depth by inserting water-filled 2-inch steel pipe. However, the hole bridged at 500 feet, so that gradient pipe could be set only to 500 feet. The hole then was shut in, and was used for temperature observations over the next few months.

Subsequently, a contract modification was awarded to Burgett to remove the old gradient pipe, and to reenter and to complete the hole to the original target depth of 1,000 feet. New drilling started on May 29, 2003, and was completed on June 2, 2003. Water-filled, 2-3/8-inch steel pipe was landed at 1,000 feet (305 m) of depth. This hole was used for temperature measurements through September 19, 2003. Figure 5 depicts hole completion and lithology for TG 12-7.

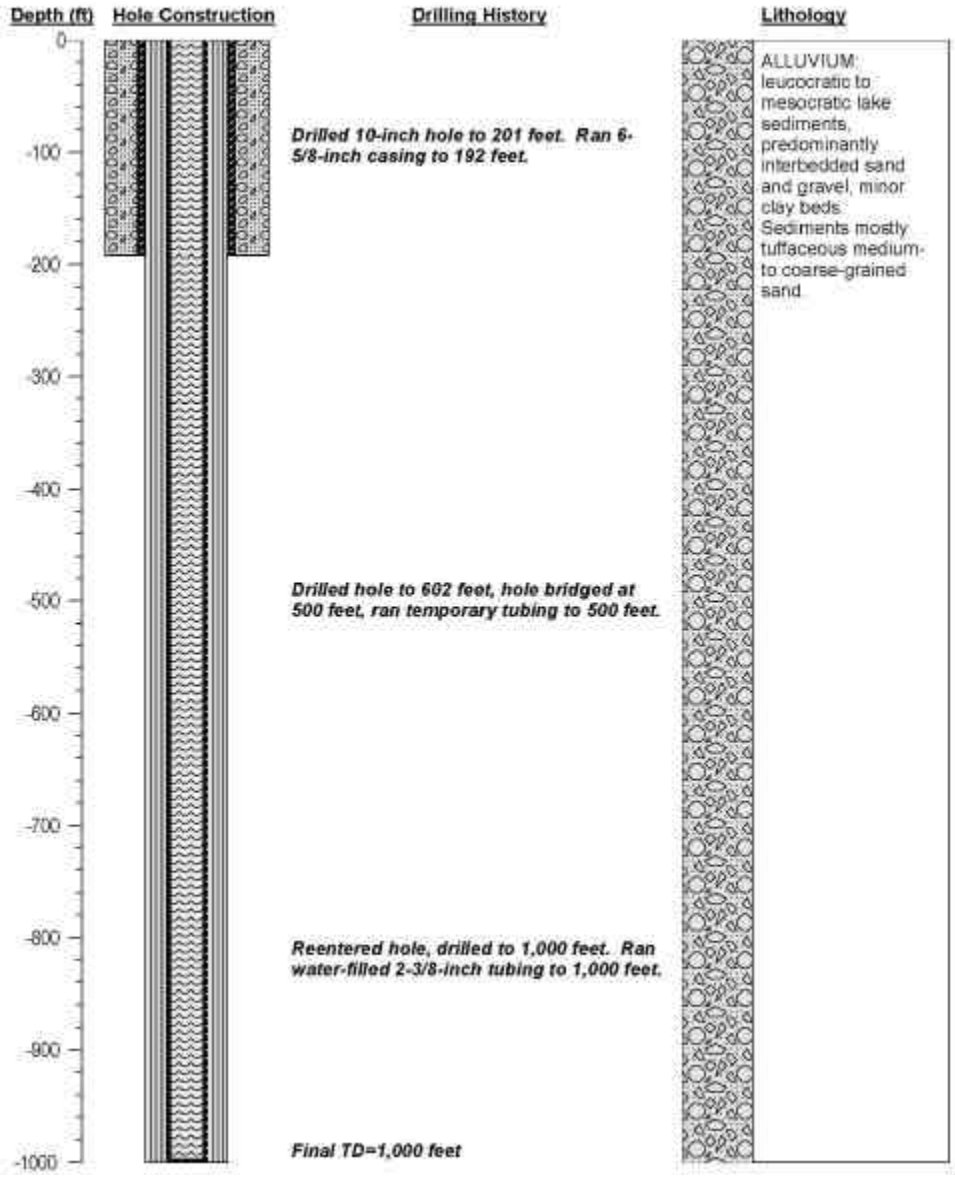

Figure 5. Hole completion diagram and lithology for TG 12-7.

Drilling and Completion of Hole TG 56-14

Hole TG 56-14 was spudded on April 30, 2003, and was completed to the programmed depth of 1,000 feet on May 10, 2003. Drilling was uneventful after the surface casing was landed and cemented. Completion was made using water-filled 2-3/8-inch steel pipe to total depth. The hole was used for temperature measurements through August 2003. Figure 6 provides a completion schematic and lithology for hole TG 56-14.

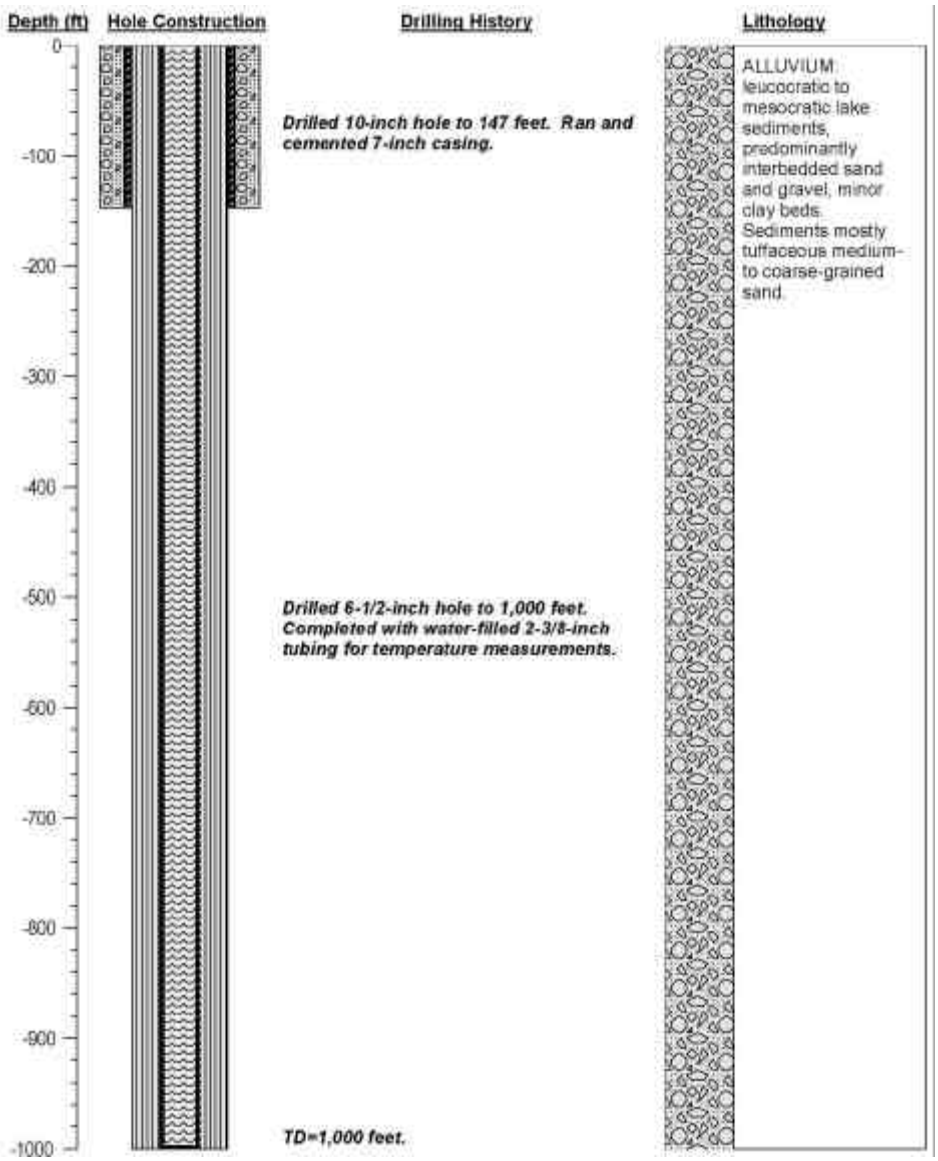

Figure 6. Hole completion diagram and lithology for TG 56-14.

Hole Lithologies

Lithologies encountered in both holes were predominantly lakebed sediments deposited in the Pleistocene and Recent Lake Animas. Unconsolidated sand and gravel beds averaged about two feet thick and were interbedded with thin layers of greenish clay. Some of the clay beds were rich in organic material and had a distinctive odor. Sand and gravel sediments were volcanic in origin, commonly andesitic and rhyolitic in composition, and derived from the Pyramid Mountains.

SUMMARY RESULTS OF THE EGS DRILLING PROGRAM

Summary of the Gradient Hole Drilling Program

This report provides a summary of geotechnical and geophysical data that led to the siting, drilling, and completion of two (2) geothermal temperature gradient holes in the geothermal anomaly at Lightning Dock Known Geothermal Resource Area in the Animas Valley of New Mexico. The two gradient holes were sited on federal geothermal leases owned by Lightning Dock Geothermal, Inc. and both were drilled into lake bed sediments some distance from the intense shallow geothermal anomaly located in the eastern half of Section 7, Township 25 South, Range 19 West.

Gradient hole TG 56-14 was sited about 4 km southwest of the center of the intense shallow geothermal anomaly. The hole was completed to a total depth of 305 m (1,000 feet). Temperature gradient was positive to total depth, with a bottom hole gradient of 80 ^{o}C/km. This gradient can be extrapolated to a temperature of 150 ^{o}C (302 ^{o}F) at a depth of 1.2 km (3,900 feet).

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Evaluation of EGS Potential

From the Phase I Final Report (Ormat and LDG, 2001), an estimate was provided that a confirmed geothermal resource base was capable of supporting at least 6.5 MW (net) commercial power production. This same report also summarized available geotechnical information that suggested a larger resource appeared to be attainable based on historical productivity of shallow geothermal wells in the area and the resemblance to other geothermal resources in the Basin and Range.

This Phase I Final Report also summarized the case for use of a combined technologies proposed for this project as the best, and perhaps only, method to develop and evaluate the commercial viability of the EGS portion of the reservoir. Commercial productivity requires that both fluid flow and temperatures to be sustained over a period of years. Fluid production from both the hydrothermal and EGS reservoirs reduces the risk of failure of any critical component of the system, which is an essential element of successful commercial geothermal power plants.

Based on the successful completion of these two new temperature gradient holes, the subsurface temperature regime was delineated in a region almost six fold larger than previous estimates of the potential size of this geothermal resource. Moreover, the resource base in the Animas Valley now appears to be capable of at least 15 MW of commercial geothermal power production. Based on these new findings, it is expected that the Lightning Dock Known Geothermal Resource Area could be developed for commercial scale electricity generation in the relatively near future. However, additional well drilling and testing would be needed to prove resource capacity.

REFERENCES

Ormat and LDG, 2001, Development of a Plan to Implement Enhanced Geothermal Systems (EGS) in the Animas Valley, New Mexico: DOE-Idaho Operations Office, Final Report, Grant No. DE-FG07-001D13989, Feb. 1, 2001.