Energy Research and Development Division
FINAL PROJECT REPORT

DRILLING AND TESTING OF AN EXPLORATORY WELL TRUCKHAVEN GEOTHERMAL AREA IMPERIAL COUNTY CALIFORNIA

Prepared for: California Energy Commission
Prepared by: Layman Energy Associates, Inc.

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GRDA GEOTHERMAL RESOURCES DEVELOPMENT ACCOUNT ENERGY FROM THE EARTH

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PREFACE

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Drilling and testing of an exploratory well, Truckhaven geothermal area, Imperial County California is the final report for the Geothermal Resources Development Account Program project (contract number GEO-04-007) conducted by Layman Energy Associates, Inc. The information from this project contributes to Energy Research and Development Division's Energy-Related Environmental Research Program.

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ABSTRACT

Iceland America Energy, Inc. drilled and tested an exploratory geothermal well at the Truckhaven area in northwest Imperial County, California. The project was partially funded by the Energy Commission's Geothermal Resources Development Account Program. The project goals were to obtain necessary permits; procure services and equipment; construct the wellpad; drill and test an exploratory well; and prove that a commercially productive resource was present. Well IAE Trk-1 was completed to a depth of 7,139 feet and the project team subsequently ran temperature, pressure and spinner logs and flow tested the well.

Flow testing indicated IAE Trk-1 was a marginally productive geothermal well. Equilibrated temperature logs indicated a maximum temperature of 350 degrees Fahrenheit at 7,000 feet. However, the temperature profiles lacked the extensive isothermal zones commonly associated with commercially productive geothermal resources. The well-produced about 660 gallons/minute (pre-flash) at low wellhead pressure during a 3.5 hour artesian test after well stimulation. The well produced a low-salinity, 260 degree Fahrenheit fluid derived from porous sand horizons below the 13 3/8 inch casing shoe to a depth of 4,500 feet. Formation productivity was relatively low, with a carbonate hardness value of about 10,000 millidarcy feet and a productivity index of 2.5 gallons/minute per pounds per square inch. Computer simulation of the well performance indicated a productive potential of about 1.5 megawatts, net of parasitic, if the well was equipped with a downhole pump. If it is not used as a producer, IAE Trk-1 could be converted to an excellent injector well by perforating high porosity sands currently behind the cemented 13 3/8-inch casing.

Keywords: geothermal, geothermal exploration, geothermal drilling, geothermal well testing, Imperial County, Truckhaven, Iceland America Energy, Inc., Layman Energy Associates, Inc.

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EXECUTIVE SUMMARY

Introduction

The Truckhaven geothermal project is located in the northwestern portion of Imperial County, California, approximately two miles southwest of the small town of Salton City. The site is located in undeveloped desert land within the Ocotillo Wells State Vehicular Recreation Area, which is administered by the California Department of Parks and Recreation (CDPR).

The Truckhaven geothermal area was explored for geothermal resources by the energy industry in the late 1970s and early 1980s. This effort culminated in the drilling of a deep exploratory well by Phillips Petroleum in 1983, but this well failed to demonstrate commercial production. In 2001, Layman Energy Associates, Inc. (LEA) established a lease position in the area and subsequently completed geological and geophysical studies of the Truckhaven area with federal funding support. In December 2004, LEA signed an agreement with Iceland America Energy, Inc. (IAE) to cooperate on developing the Truckhaven geothermal project. IAE subsequently secured additional leasing rights and commenced planning for drilling an exploratory well. The well was targeted to intersect an elongate, west-northwest trending zone of higher temperatures and low resistivity indicated by prior exploratory work.

In May 2005, LEA was awarded a $700,000 grant from the Energy Commission's Geothermal Resources Development Account (GRDA) program to support drilling and testing of an exploratory well at Truckhaven. The Energy Commission subsequently approved LEA's request that project expenses incurred by IAE as project operator / developer be accepted as reimbursable expenses under the Grant Agreement. LEA is providing this Final Report to the Energy Commission in accordance with the terms of the Grant Agreement.

Project Purpose

The overall goal of the project was to prove that a commercially productive geothermal resource was present at the Truckhaven area and to stimulate development of additional geothermal resources in California.

In order to meet this goal, the project needed to accomplish several specific objectives, including obtaining the necessary permits; procuring all services and equipment; constructing the access road and wellpad; drilling an exploratory geothermal well to a depth of at least 6,000 feet; conducting downhole surveys of the well temperature and pressure; conducting a flow test of the well to demonstrate productive capacity; and evaluating and interpreting the results.

Project Results

The project achieved all of these objectives. All permits were obtained in August 2007. Wellpad construction was completed in September 2007. The IAE Trk-1 well was completed to a depth of 7,139 feet in December 2007 and geophysical logs were run. Downhole temperature and pressure surveys were conducted while the well was heating up in January-March 2008. A short-term flow test of the well was conducted in early March 2008. Test results for IAE Trk-1 were below expectations from the standpoint of reservoir temperature and permeability. While a maximum temperature of 350 degrees Fahrenheit (°F) was measured at 7,000 feet depth, the equilibrium temperature profile was only weakly convective and did not exhibit the significant isothermal intervals commonly associated with highly productive geothermal wells.

Log analysis indicated that the zone that contributes production to the well occurred at a relatively shallow depth and ranged in temperature from 225-280°F. This productive zone extended from the 13 3/8-inch casing shoe at 2,938 feet to a depth of 4,500 feet and yielded a 260°F mixed fluid derived from several discrete intervals with varying temperature. The productive intervals were correlated with sandstone layers with high porosity (18-29%). The low permeability zone in the well below 4,500 feet was associated with shale, siltstone, sandstone with low porosity (8-10%), and underlying granitic basement rocks. No fluid loss zones were encountered during drilling of IAE Trk-1, indicating a lack of permeable fracture zones in the well. This reinforced the importance of sand matrix permeability for production.

Results of a flow testing conducted in early March 2008 indicated that the IAE Trk-1 well was marginally productive. The flow test consisted of two short periods of artesian flow separated by injection of produced fluids back into the well. Coiled tubing operations were conducted to clean out the bottom portion of the well by jetting it with water and to stimulate flow by injecting nitrogen. Flow test duration was limited by the lack of an injector well and portable storage tank capacity. The combination of injection and coiled tubing stimulation appeared to have improved the well productivity. After stimulation, the productivity index improved from 1.9 to 2.5 gallons per minute/pounds per square inch (gpm/psi) and the formation permeability-thickness improved from about 7,000 to 10,000 millidarcy feet. These figures were at the low end of the range for operating geothermal fields. The well-produced about 660 gallons/minute (pre-flash) at low wellhead pressure during a 3.5 hour artesian test after well stimulation. Computer simulation of well performance indicated a productive potential of about 1.5 megawatts, net of parasitics, if the well was equipped with a downhole pump.

The produced geothermal fluid was a benign, low-salinity, neutral power of hydrogen (pH) sodium-chloride-bicarbonate (Na-Cl-HCO3) fluid with total dissolved solids of about 4,500 parts per million (ppm). Gas levels in the separated steam were quite high (10-11 percentage by weight), but were likely to decline to some degree with long-term production. If gas levels were to remain high, it could adversely impact plant efficiency for a flash plant facility. The gas levels were not likely to pose a problem for power plant efficiency if the resource is ultimately developed with binary plant technology, as would be expected with the low to moderate temperature resource intersected by IAE Trk-1.

The marginal productivity and fluid production temperature of the IAE Trk-1 well indicated that the Truckhaven geothermal resource may not be commercially viable. Additional exploratory work is required to identify a region of higher temperature and productivity before development of this resource can move forward. While the low salinity of the produced brine was favorable for development, it was not known if higher salinity fluids may be present elsewhere in the Truckhaven resource area.

The project team had two recommendations:

- Secure a suitable injection well for long-term testing of IAE Trk-1 to evaluate well performance and gas chemistry trends.
- IAE Trk-1 could be converted into an excellent injector well by perforating the cemented 13 3/8-inch casing below 2,000 feet. This would add 680 feet of net sand with an average porosity of 28.4 percent, and should significantly increase the well carbonate hardness (kh) and its injectivity. IAE Trk-1 and other wells drilled in the vicinity could provide injection support if a production wellfield was established at Truckhaven and a power plant was built in the vicinity.

Benefits to California

The total cost for drilling and testing of IAE Trk-1 was on the order of $7 million. The majority of this expenditure was directed to California firms that supplied materials, equipment and services to the project, providing income to California companies and employees. While IAE Trk-1 was not a commercially productive resource, the project has added significantly to the geological understanding of the area. The project results will hopefully be used by IAE and others to guide future exploratory work at Truckhaven, and may also help locate a productive resource.

Chapter 1: INTRODUCTION

1.1 Location and Access

The Truckhaven geothermal project is located in the northwestern portion of Imperial County, California, approximately 2 miles southwest of the small town of Salton City (**Figure 1**). The site is located in undeveloped desert land within the Ocotillo Wells State Vehicular Recreation Area, which is administered by the California Department of Parks and recreation (CDPR).

The project site is most easily reached from state highway 86 via the Imperial County landfill access road which intersects the highway about 3 miles south of the intersection with county road S-22. The landfill access road intersects Pole Line road about 2.5 miles west of the highway, and the project site is immediately west of the Pole Line road about 0.8 miles north of the landfill access road. The developed facility at the project site includes a driveway, wellpad and the Iceland America Energy, Inc. Truckhaven-1 well (IAE Trk-1), which was completed in December 2007. The wellsite is located in the northeastern quarter of section 1 in Township 11 South, Range 9 East.

1.2 Project Background

The Truckhaven geothermal area was explored by industry for geothermal resources in the late 1970's and early 1980's. Phillips Petroleum conducted geophysical surveys and temperature gradient hole drilling in the area, and drilled a deep production test well, Phillips Truckhaven-1. This well did not demonstrate commercial production. Further exploration efforts were stalled thereafter, presumably due to the well results and poor market conditions resulting from the decline in oil prices in the mid-1980's.

In 2001 market conditions began to improve and Layman Energy Associates, Inc. (LEA) secured leasing rights on 5 contiguous sections, or about 3,200 acres in the Truckhaven area. In 2003, LEA completed geologic, gravity and magnetotelluric resistivity studies of the area with partial funding provided by the U.S. Department of Energy's Geothermal Resource Exploration and Development (GRED II) program. The results of this work were summarized in a report submitted to the Department of Energy (Layman Energy Associates, Inc. 2006). In December 2004, LEA signed an agreement with Iceland America Energy, Inc. (IAE) to cooperate on development of the Truckhaven geothermal project. In 2005, IAE executed a lease with ProLogis Corporation for mineral rights on three sections formerly under agreement with LEA.

After reviewing existing geologic and geophysical data, IAE decided to drill an exploratory well on the ProLogis lease in the northwest quarter of section 1 in Township 11 South, Range 9 East. The well was designed to intersect an elongate, west-northwest trending zone of higher temperatures and low resistivity indicated by the results of the magnetotelluric survey and temperature gradient hole drilling.

Figure 1: Imperial County

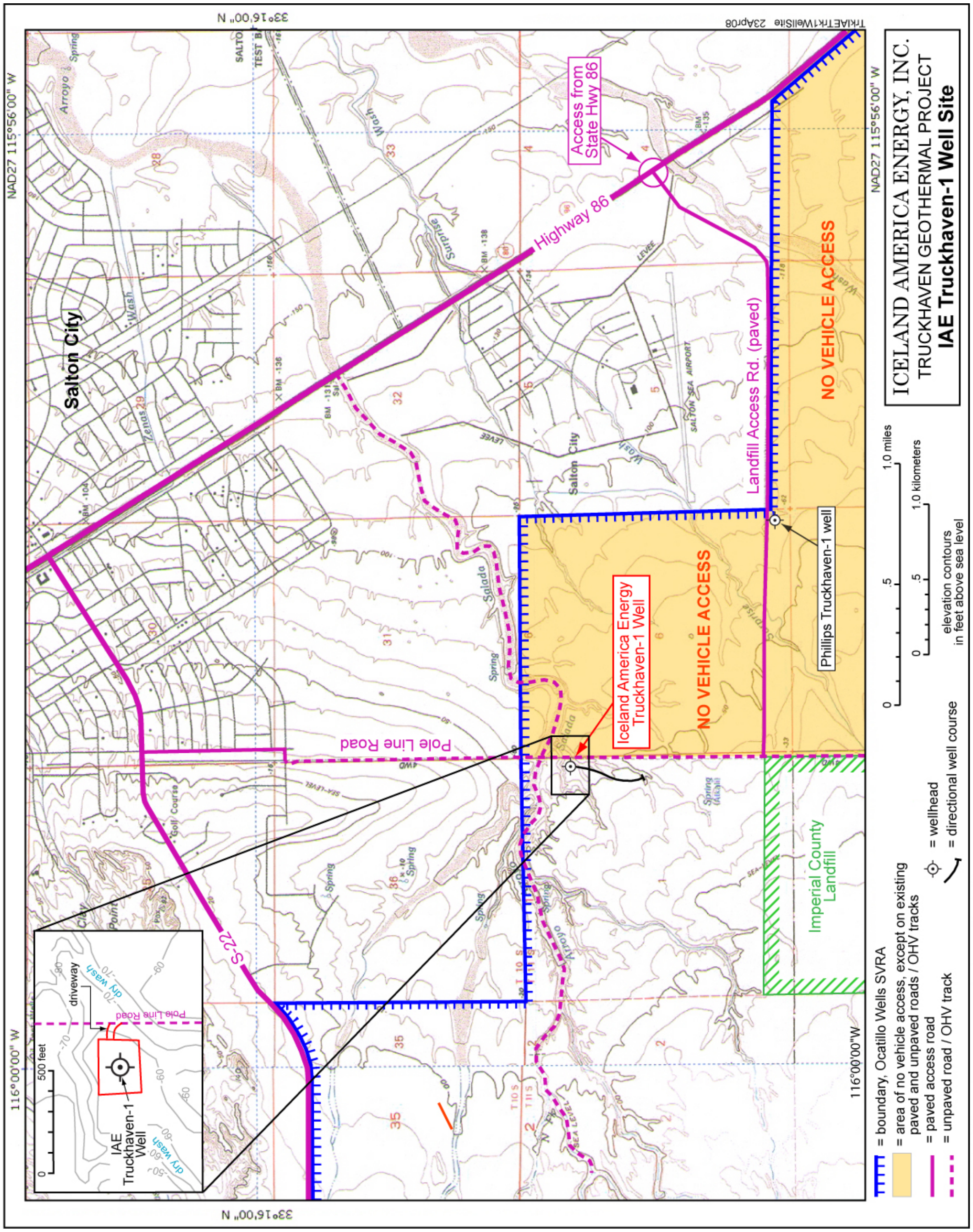

FIGURE 2. Map of access route to project site.

1.3 Energy Commission Involvement

In April 2004, LEA applied to the Energy Commission Geothermal Resources Development Account (GRDA) program to obtain grant funding to support drilling and testing of an exploratory well at Truckhaven. The Grant Agreement (grant number GEO-04-007) was executed by LEA and the Energy Commission in May 2005, and included $700,000 in grant funds to be provided by the Energy Commission for the project. The Energy Commission Project Manager subsequently approved LEA's request that project expenses incurred by IAE as operator / developer be accepted as reimbursable expenses under the Grant Agreement. This approval was provided after the Energy Commission reviewed a copy of the development agreement signed by LEA and IAE in December 2004.

The original grant application submitted to the Energy Commission by LEA included drilling of a small diameter "slim hole" to a depth of about 6,000 feet. The slim hole design was based on installation of 4.5-inch slotted liner in the intended production zone. LEA's development partner IAE subsequently decided to modify the drilling program to a full-sized production test well with 9 5/8-inch slotted liner in the intended production zone. This change was approved by the Energy Commission Project Manager, and the Energy Commission share of the project cost remained unchanged at $700,000.

LEA is providing this Final Report to the Energy Commission in accordance with the terms of the Grant Agreement.

1.4 Project Permitting

Though permitting costs are specifically not reimbursable to LEA under the Grant Agreement, securing the necessary permits for drilling and testing of the well was included as part of the Work Statement attached to the Grant Agreement. Permitting for the project was particularly challenging due to overlapping jurisdictions of multiple agencies. CDPR owns the surface rights to the land for the drillsite, for which the mineral rights have been leased by IAE from ProLogis. LEA secured a Right of Entry Permit from CDPR in August 2005, which was subsequently assigned to IAE by LEA in August 2007. LEA also secured a Conditional Use Permit from Imperial County in July 2005, which was subsequently assigned to IAE by LEA in June 2007. The last group of permits and approvals for the project were obtained by IAE in August 2007 and included the following:

- Bureau of Land Management, Right of Way
- California Division of Oil and Gas and Geothermal Resources, Drilling Permit
- Imperial Irrigation District, Encroachment Permit
- Imperial County, Building Permit
- Regional Water Quality Control Board, Waste Discharge Permit
- CDPR, archeological and biological monitoring permits; and
- CDPR, approval of operations plans

A final step necessary to allow drilling to proceed was registration of the drilling rig engines provided by the drilling contractor (Thermasource, Inc.) with the California Air Resources Board. Because of a delay encountered by Thermasource in obtaining compliant rig engines the necessary registration was not secured until mid-October 2007.

Chapter 2: PROJECT OBJECTIVE AND APPROACH

The overall project objective is clearly stated in the Work Statement included in the Energy Commission Grant Agreement: "*The objective of the project is to prove, via drilling and testing of an exploratory well, that the Truckhaven area hosts a commercially productive geothermal resource with benign produced fluid and gas chemistry. The results of the well would be used to facilitate development at Truckhaven of a large-scale power generation facility, as well as stimulate development of other geothermal resources in geologically similar flank areas of the Salton Trough*."

As a small firm, LEA's approach towards achieving the above objective was first to partner with IAE. This partnership insured that sufficient financial and technical resources were available to take the project to completion. IAE then took the lead role on the project as the operator and developer, while LEA provided project management and geoscientific analysis services as a consultant to IAE. As is the common practice adopted by geothermal developers, IAE contracted with numerous firms to procure the necessary equipment, services and materials to execute the project. Some of the key firms subcontracted by IAE to execute various phases of the project included, but are not limited to, the following:

Project management and geoscientific consulting (Layman Energy Associates, Inc.)

- Drilling supervision (InterAct PMTI)
- Drilling engineering and reservoir engineering consulting (GeothermEx, Inc.)
- Project permitting and compliance consulting (Environmental Management Associates, Inc.)
- Preparation of drainage and grading plan (Hale Engineering and Surveying, dba Tesco)
- Wellpad geotechnical investigation (Landmark Consultants, Inc.)
- Wellpad and access road construction and labor supply (Primo Construction Services)
- Drilling contractor (Thermasource, Inc.)
- Wellhead equipment supply (Rupple Marketing)
- Well casing supply (Mill Man Steel, Inc.)
- Well cementing services (Halliburton)
- Supply of bits, drilling mud, directional drilling services (Baker Hughes International)
- Vacuum / environmental services (Ancon Marine)
- Water supply lines / storage tanks (Rain for Rent; Denbeste)
- Diesel fuel supply (Sellars Petroleum)
- Rig monitoring / mud logging (Pason)
- Blow out preventers / casing accessories (Weatherford International)
- Temperature and pressure logging (Welaco)
- Geophysical logging (Schlumberger)
- Design of well test facility (JFPM, Inc.)

- Construction of well test facility (Performance Mechanical Contractors, Inc.)

During the course of the project, from the initial procurement stage through operations and site cleanup, LEA worked closely with IAE to manage project operations and coordinate the activities of this diverse group of contractors and suppliers. LEA and IAE also maintained close communications with the main surface management agency CDPR during field operations to keep CDPR informed of project activities and address any concerns.

Chapter 3: PROJECT RESULTS

LEA and IAE completed all the major tasks outlined in the Work Statement attached to the Energy Commission Grant Agreement. After all necessary permits were secured (as described above), the project moved forward quickly to completion. Wellpad and wellpad driveway construction commenced on 28 August 2007 was completed in mid-September. The IAE Trk-1 well was spudded on 16 October 2007 and completed on 18 December 2007. Injection testing of the well was conducted prior to release of the drilling rig. Static temperature and pressure surveys were conducted during January and February 2008. A short-term artesian flow test was conducted in early March 2008.

3.1 Summary of Well Completion and Drilling Operations

IAE Trk-1 was completed as a directional well to a total measured depth of 7,139 feet (**Figure 2**). The 20-inch casing was set and cemented back to surface at 447 feet, after cementing off a zone of artesian water flow (see below). The 17 ½-inch hole section of the well was drilled with heavy weight mud to maintain control of artesian water flow in this interval. The 13 3/8-inch casing was set and cemented back to surface at 2,932 feet. No zones of fluid loss were encountered during drilling of the 12 ¼-inch hole section, indicating that the well did not encounter permeable fracture zones. Slotted liner was hung inside the 13 3/8-inch casing at 2,856 feet and across the 12 ¼-inch hole section to 7,137 feet, just above the bottom of the well.

The directional work was completed in the 17 ½-inch hole section, with a kickoff point at 1,680 feet. The well was directed to the south-southwest (**Figure 3**) to intersect the geophysical target described above. The bottom hole location is 1,546 feet south and 238 feet west of the surface location. The total vertical depth of the well is 6,890 feet.

The well was completed in 62 days, as indicated in the drilling curve of **Figure 4)**. LEA has already provided to the Energy Commission a complete suite of daily drilling reports for IAE Trk-1 which include detailed descriptions of well operations. Penetration rates while drilling were generally quite good, except while drilling the 26-inch hole to 300-400 feet depth where soft formation clays resulted in balling of the drill bit. Despite the generally good penetration rates, drilling progress was hampered by the following problems encountered during operations:

- **Artesian water flow at ~600 feet depth**: A modest but persistent artesian flow of shallow groundwater was encountered while drilling the 26-inch hole at about 600 feet

Figure 2: Directional Well

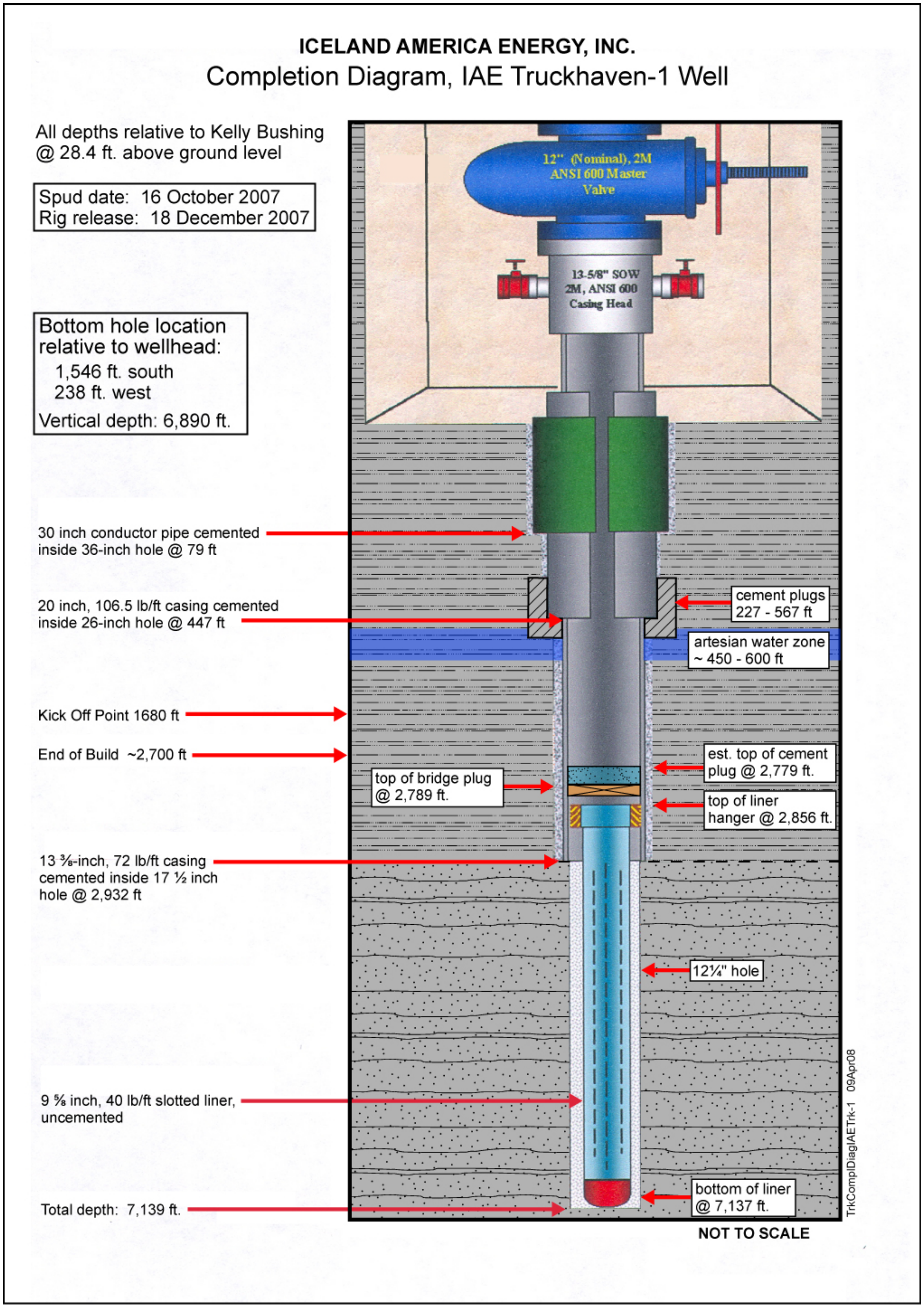

FIGURE 3. Diagram of well completion, IAE Trk-1 well.

Figure 3: Well Direction

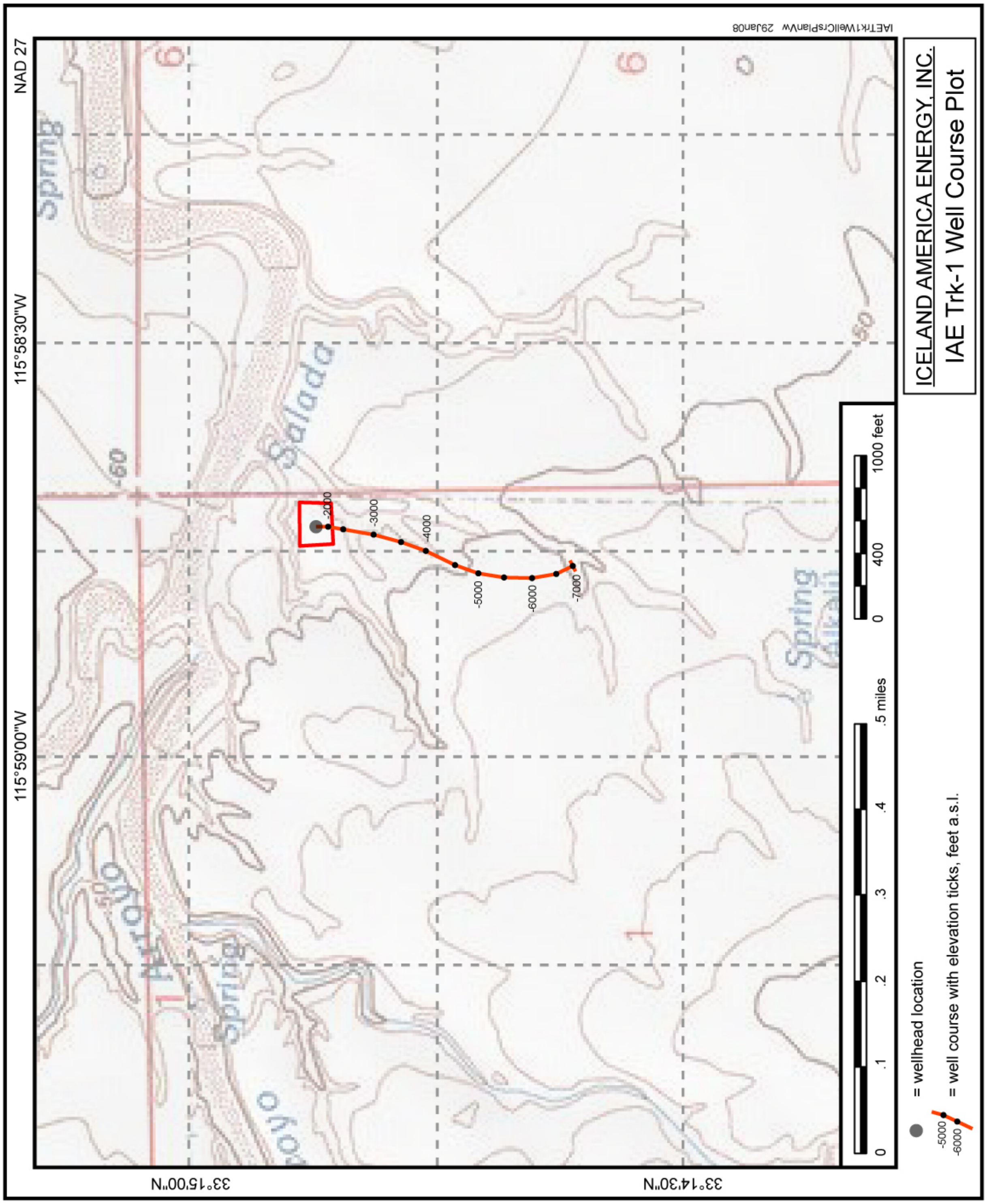

FIGURE 4. Map of directional well course plot, IAE Trk-1 well.

Figure 4: Drilling Curve

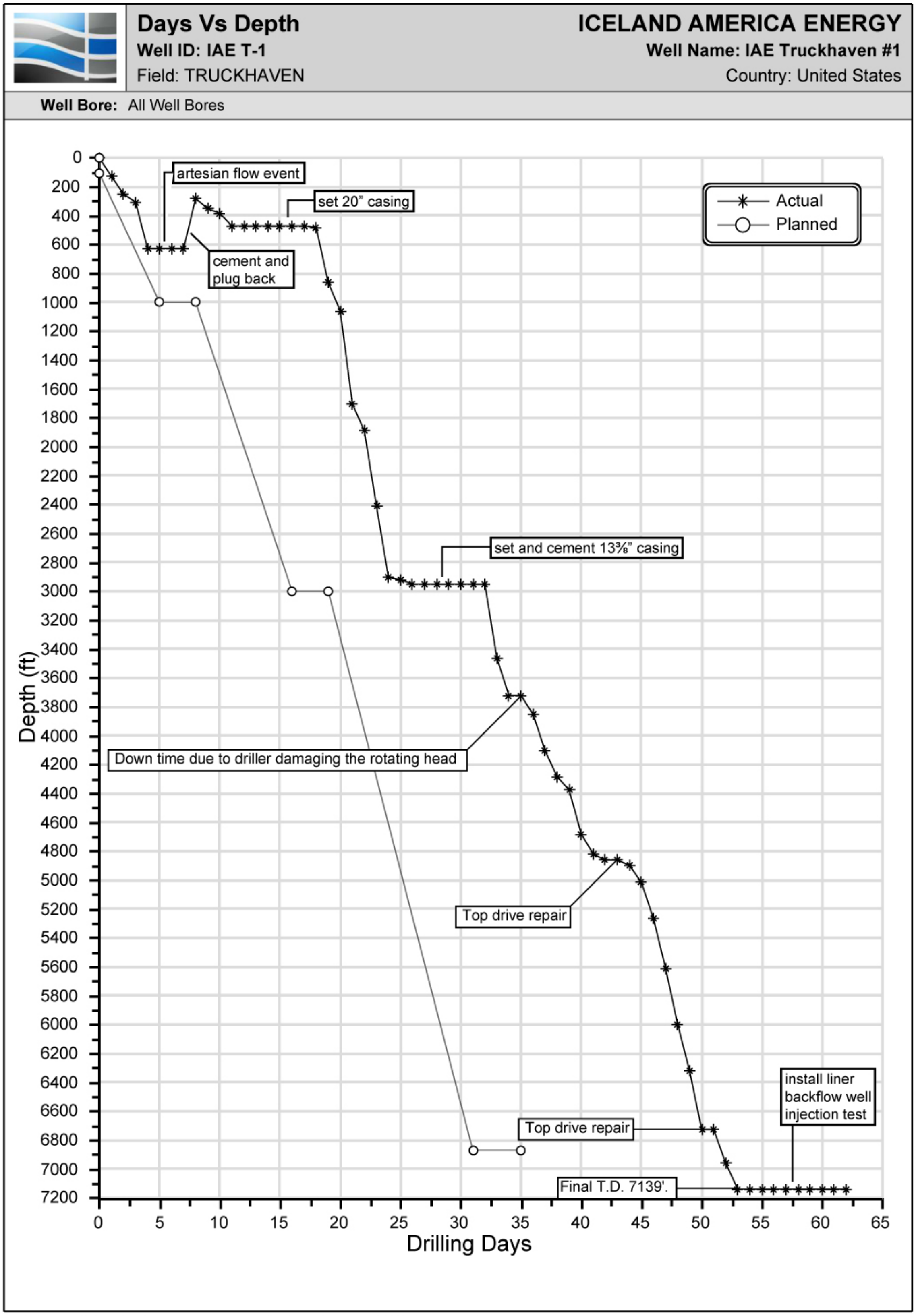

FIGURE 5. Plot of days versus drilling depth, IAE Trk-1 well.

Artesian flow at this shallow depth was not anticipated based on data available

As a result no special provisions for flow control were put in place for drilling the 26-inch hole to the planned depth of setting 20-inch casing at 1,000 feet. It is very uncommon to install blow out preventers on shallow 30-inch conductor casing strings, and such equipment is also difficult to procure. After an initial unsuccessful cement job, control of the artesian flow was accomplished by cementing off the zone with a second, larger volume cement plug using accelerants in the cement mix. The artesian flow continued for approximately two days and the produced water was stored in portable tanks. No leakage of the artesian fluid occurred outside of the wellpad perimeter. The second cement plug required re-drilling of a sidetrack hole from the top of the plug at about 250 feet to the final 20-inch casing point at 447 feet. This required re-drilling thorough soft clay formations, further slowing progress due to the low penetration rates.

- **Downtime for repairs of undersized top drive unit**: Thermasource provided a relatively undersized top drive unit relative to the size of the rig and depth of the well. This unit broke down on several occasions and had to be repaired.
- **Downtime for replacement of damaged rotating head**: While drilling the 12 ¼-inch hole, the driller inadvertently pulled the drill string up into the rotating head assembly and damaged the unit, which needed to be replaced.
- **General slow pace of operations due to new drilling rig and crews**: This was the first well drilled by Thermasource with this drilling rig, which had just been purchased by Thermasource after being refurbished by the seller. The drilling crews were also relatively inexperienced, and the combination of green crews and new equipment resulted in a generally slow pace of operations.

3.2 Wellbore Geology

IAE Trk-1 drilled through a sequence of clastic sedimentary rocks from surface to 6,700 feet depth, below which granitic basement was drilled to the total depth of 7,139 feet (**Figure 6**). The sedimentary sequence consists of poorly consolidated sands, silts, clays at shallow depths transitioning to more lithified equivalents (sandstone, siltstone and shale) at depths generally below 4,000 feet. Basement rocks penetrated were predominantly granitic rocks with minor amounts of schistose metamorphic rocks. The vertical depth of the basement contact was as predicted to within about 30 feet by the magnetotelluric resistivity survey modeling results (Layman Energy Associates, Inc. 2006).

Stratigraphic interpretation: The stratigraphic framework provided by Dorsey (2006) for the Anza Borrego region was used to interpret the stratigraphy of IAE Trk-1. Based on the relative abundance of sand and shale, a tentative stratigraphic interpretation of the clastic sequence encountered by the well is as shown in **Figure 5** and as summarized below:

Figure 5: Stratigraphic Interpretation

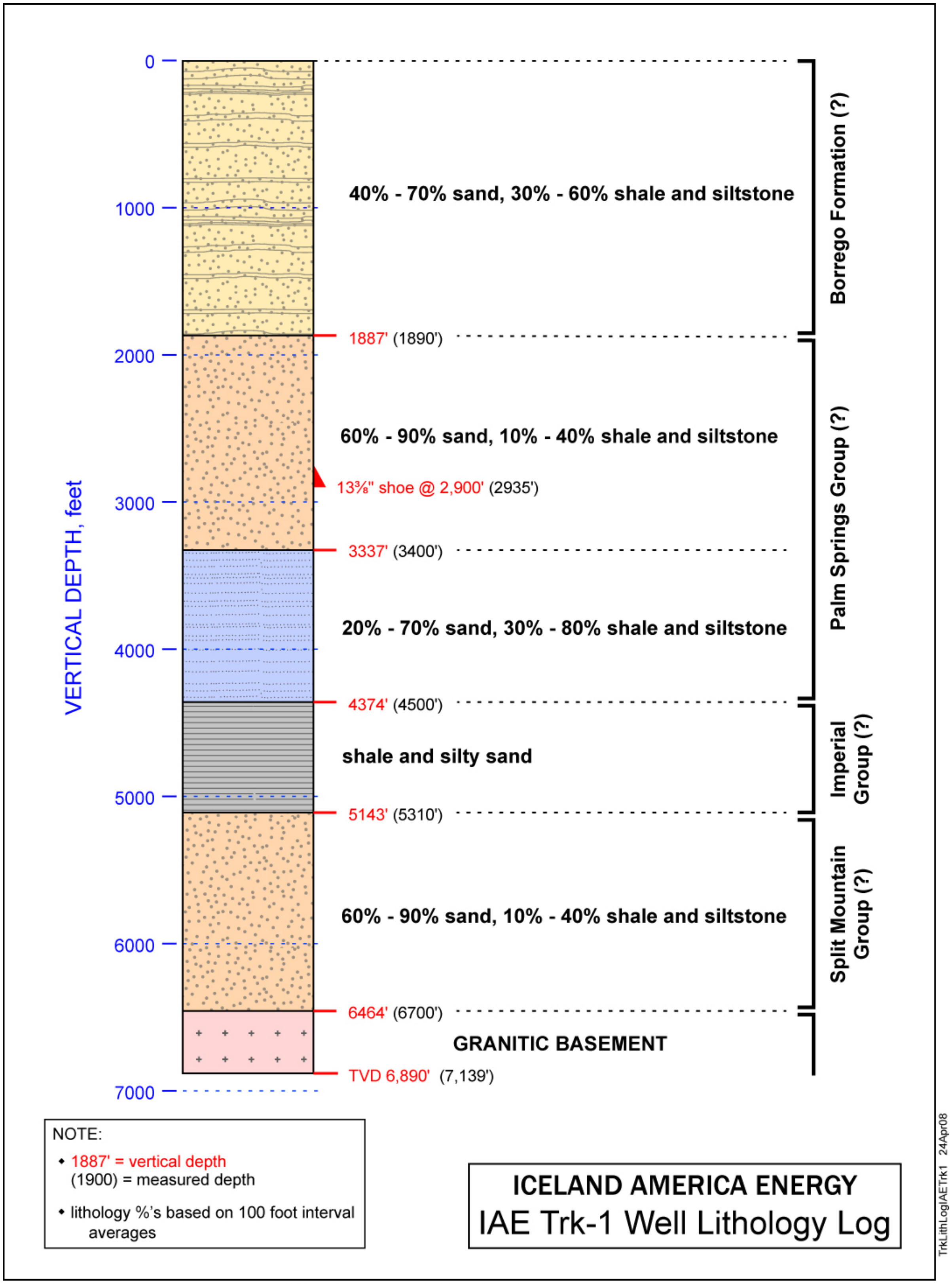

FIGURE 6. Summary of lithology encountered by IAE Trk-1 well.

- 0-1,890 feet: Plio-Pliestocene Borrego Formation (mixed sand, silt and clay)
- 1,890-4,500 feet: Pliocene Palm Springs Group (abundant sand)
- 4,500-5,310 feet: Pliocene Imperial Group (shale and siltstone)
- 5,310-6,700 feet: Plio-Miocene Split Mountain Group (abundant sand and gravel)

No fossils were identified in the drill cuttings that could potentially be used to confirm the above interpretation.

Reservoir sand analysis methodology: The absence of zones of loss of circulation and/or drill breaks during drilling of IAE Trk-1 indicates production from the well will be obtained from sand matrix permeability in the Plio-Pleistocene sedimentary section rather than from fractures. To assess reservoir characteristics in IAE Trk-1, Schlumberger geophysical log data collected in the 17.5-inch and 12.25-inch hole sections were reviewed in detail. The objective was to delineate sand abundance and sand porosity as primary indicators of potentially productive intervals in the well.

Gamma ray logs are used to distinguish potentially productive sands from impermeable, non-productive shales. Shales have high gamma ray response due to elevated levels of radiogenic potassium in clay minerals, while clean sands have low gamma ray response due to dominance by quartz which has low potassium content. The *density porosity log* is used to determine the porosity of individual sand layers, calculated from a measurement of the bulk density and an assumed "matrix" density (quartz sand grain) of 2.65 g/cc. The *neutron porosity log* measures porosity in effect by measuring the amount of water in the rock, whether in pore space or bound in clay. The neutron porosity log identifies "clean" sands with low clay content which have preferred production characteristics.

Mud log data was less useful than the Schlumberger logs for distinguishing sand layers because of extensive caving of unconsolidated sands into the wellbore from shallow depth. The sloughing of the shallower, unconsolidated sands often masked the lithologic signature from lower levels in the well.

Results of sand porosity and sand percentage analysis: Sand percentage and average sand porosity values were compiled for 100-foot intervals in IAE Trk-1 and plotted in **Figure 6**. The percentage sand plot supports the main lithologic boundaries identified on **Figure 5**. Sand porosity values decline gradually from 32% at 1,000 feet depth to 26% at 3,600 feet. Between 3,600-4,500 feet, sand porosities range between 15-20%. The lower sand-rich sequence (Split Mountain Group?) below 5,300 feet to the basement contact exhibits sand porosities between 8-10%. The main conclusions are summarized below:

- The most likely zone to contribute production to IAE Trk-1 extends from below the 13 3/8" casing shoe at 2,935 ft. to 4,500 feet depth. This interval includes about 820 feet of net sand thickness (52% sand) with 100' average sand porosity values ranging from 14-29%, and averaging 22.2% across the entire interval.

Figure 6: Sand Percentage and Average Sand Porosity Values

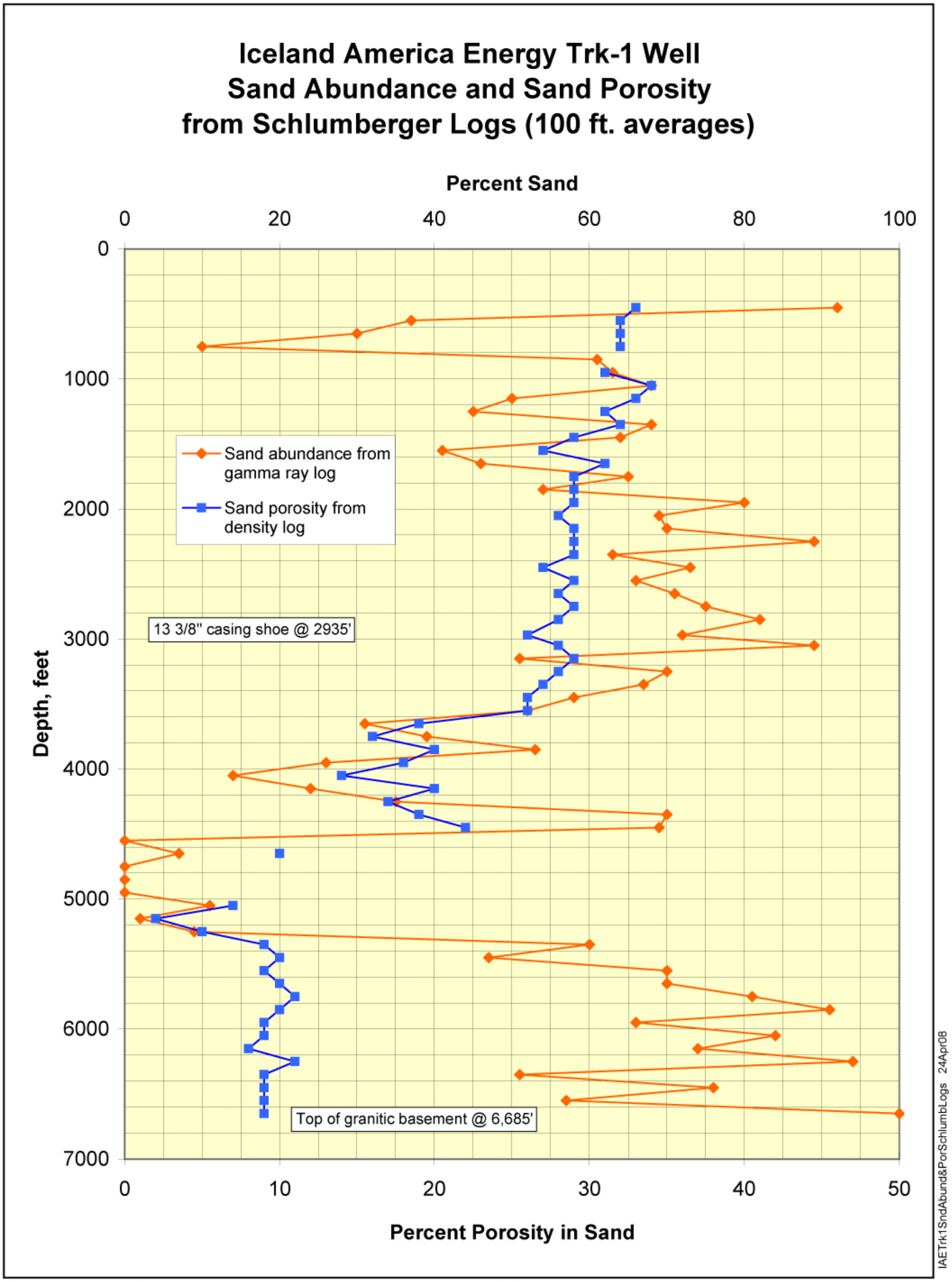

FIGURE 7. Plot of sand abundance and sand porosity, IAE Trk-1 well.

- Poor productivity is indicated between 4,500 feet and 5,310 feet, where the sedimentary section is dominated by low permeability shale and rare silty sands with low porosity (2-10%)
- Possible productive potential is present in a thick, sand-rich section between 5,310 feet and the top of the granitic basement at 6,685 feet. This section includes 1,081 feet of net sand (79% sand) with 100′ average porosity values ranging from 8-11%, and averaging 9.4% across the entire interval. While the porosity of these sands is relatively low, some of the sands are very "clean" (low clay content) and thus could potentially contribute to production.
- There are also abundant high porosity sands above the 13 3/8″ casing shoe at 2,935 feet. For example, the interval between 2,000 feet and the 13 3/8″ shoe contains 680 feet of net sand with an average porosity of 28.4%. While the temperature of these sands is low (see below), they are likely to have excellent characteristics for injection and could be accessed by perforating the cemented 13 3/8″ casing string.

Hydrothermal alteration: Binocular examination of drill cuttings indicates weak alteration of the sediments is present below about 3,500 feet depth where a commonly observed secondary mineral assemblage is greenish (smectite) clay + pyrite + calcite. No high temperature indicator minerals such as epidote were observed in the cuttings.

The basement rocks are strongly altered to a white, possibly kaolinitic, clay mineral in two discrete intervals: 1) from the basement contact at 6,700 to 6,725 feet; and 2) from 6,840-6,960 feet. While drilling through these zones the clay abundance in the drilling mud was high enough to significantly affect the rheological characteristics and require modification of mud chemistry to maintain hole cleaning properties. This alteration, while intense, does not extend into the overlying sediments at the basement contact and was not associated with fluid loss or other indication of permeability during drilling. These observations suggest that the alteration could pre-date deposition of the sediments and thus may have little significance for the currently active geothermal system at Truckhaven.

3.3 Wellbore Temperature and Pressure

Data on wellbore temperature and pressure in IAE Trk-1 was obtained via a series of pressure, temperature and spinner (PTS) surveys conducted by Well Analysis Corporation, or Welaco (**Figures 7**). Early stage PTS surveys were conducted in association with the backflow and injection test conducted on December 16-17, 2007 when the drilling rig was still on the location. These included both static and flowing surveys. Subsequently, static PTS surveys were conducted on the following dates: 17 January 2008 (30 days of heating after the rig was released); on 4 February 2008 (48 days of heating); and on 4 March 2008 (77 days heating; one day prior to flow testing). Flowing PTS surveys were also conducted during the flow test on 5 March 2007.

Figure 7: Pressure, Temperature, and Spinner (PTS) Surveys

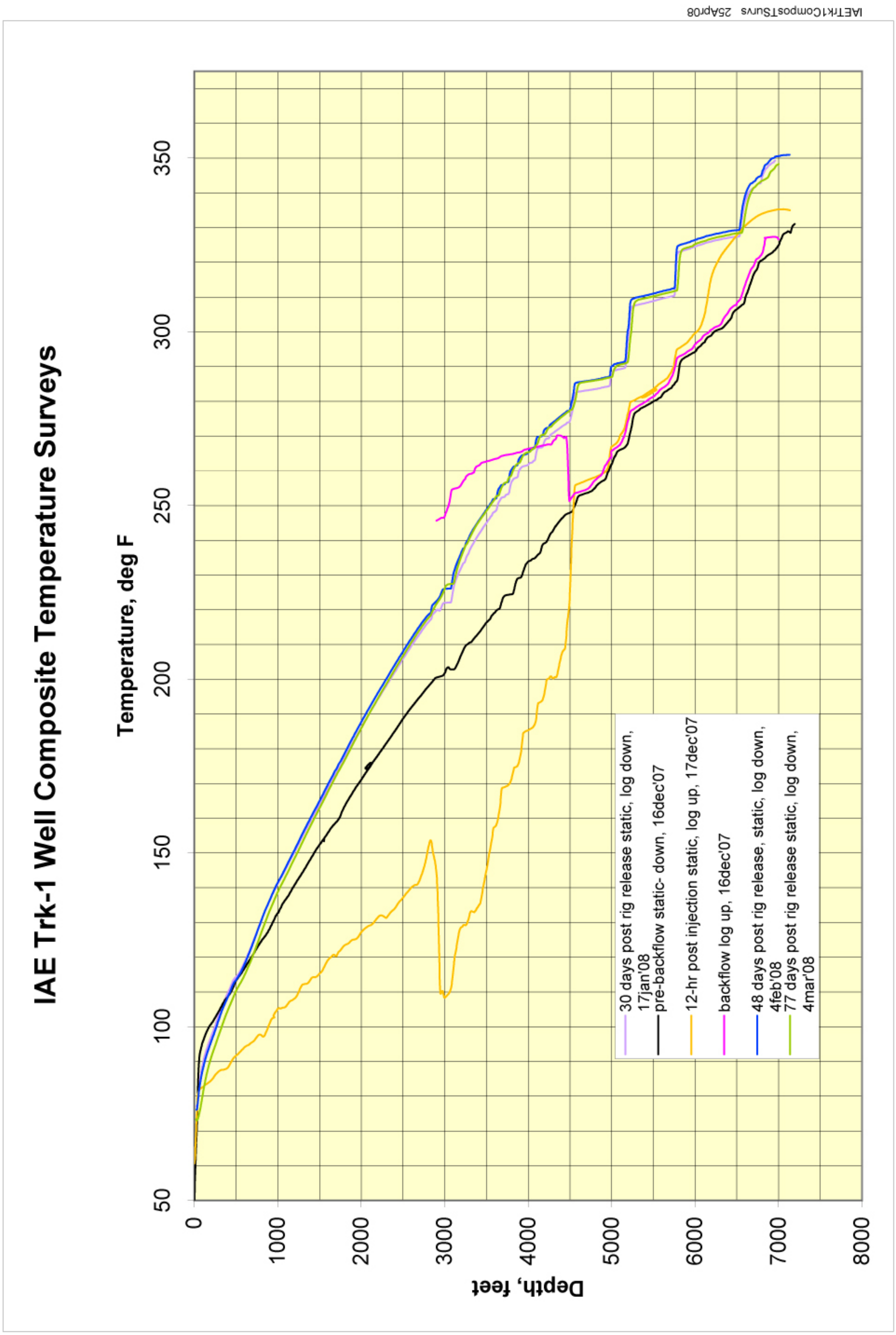

FIGURE 8. Plot of composite temperature surveys, IAE Trk-1 well.

Review of these PTS surveys suggests the following conclusions regarding the subsurface temperature and pressure at IAE Trk-1:

- The close overlap of the latest static temperature surveys on 4 February and 4 March 2008 indicate that the well had reached thermal equilibrium and had fully recovered from the cooling effects of drilling and injection testing.

  The fully heated static profiles indicate temperatures ranging from 225°F at the 13 3/8" casing shoe to 350°F at 7,000 feet depth.
- The overall form of the equilibrium static temperature profile is weakly convective, with thermal gradients decreasing with depth. Temperature gradients gradually decline from about 7°F/100 feet in the near surface to about 2°F/100 feet at a depth of 4,500 feet. The profile lacks extensive isothermal zone which are typically encountered in commercial productive, convective geothermal reservoirs.
- Below 4,500 feet, the static temperature profiles exhibit a series of "steps" which appear to represent isolated convective cells in the wellbore, rather than in the formation. This pattern is likely to reflect the fact that this lower section of the well is stagnant has not been fully cleaned out of drilling mud. This is supported by the fact that this lower interval did not accept or produce fluid during the flow testing (see below) and previous injection.
- The static pressure survey from 4 February 2008 (**Figure 8**) demonstrates artesian conditions are present in the reservoir zone below the 13 3/8" casing shoe. When shut-in, the well stands with pressurized water at the wellhead at 230 psia, and a hydrostatic pressure gradient extends from surface to the total depth.

3.4 Results of Injection Test, 16 December 2007

A short injection test was conducted of IAE Trk-1 on 16 December 2007 with the drilling rig still on the location. The objective of the test was to obtain a preliminary idea of the permeability of the formation below the 13 3/8" casing shoe. The 6-hour injection "step" test consisted of injecting at three successive rates (122 gpm, 197 gpm and 295 gpm) for two hours at each rate. The injection was followed by a 6-hour shut in during which the pressure fall-off was recorded by a pressure logging tool set at a stationary depth of 4,480 feet to record the pressure changes during and after the injection test. This depth for the pressure tool was chosen based on PTS data collected during a brief clean out (backflow) of the well conducted prior to injection, which indicated the majority of flow originated from near this depth.

Computer modeling of the pressure fall off data by GeothermEx indicates a rather low formation permeability-thickness (kh) value of 3,840 md-ft with positive skin of 1.4. A positive skin indicates that the permeability near the wellbore is lower than the average reservoir permeability. This suggests that not all the drilling mud was removed from the well prior to the injection test. The calculated productivity index (PI) for the well based on the injection rates and pressure drawdown data was 0.5 gpm/psi (gallons per minute per pound per square inch). Both the kh and PI figures subsequently calculated from flow test results (see below) are significantly higher than those from the injection test results, further supporting that drilling mud was still present in the well at that time.

A static temperature survey was conducted 12 hours after completion of the injection test on 17 December 2007. Comparison of this survey with another static survey conducted prior to the backflow of the well on 16 December (**Figure 8**) shows that the permeable interval in the well which accepted the injected fluid extends from the 13 3/8-inch casing shoe at 2,938 feet to 4,500 feet depth. This is supported by further comparison with the flowing temperature survey conducted during the backflow on 16 December (**Figure 8**). This survey shows that wellbore temperatures during the backflow were essentially unchanged below 4,500 feet compared to the static survey conducted prior to the backflow. This corroborates the indication of very low permeability below 4,500 feet.

3.5 Results of Flow Testing, 5-9 March 2008

A series of short flow tests of IAE Trk-1 were conducted between 5-9 March 2008. The duration of the flow tests was limited due to the combination of a lack of an injector well to dispose of produced fluid and permitting constraints which did not allow geothermal fluid to be stored in the drilling sumps. Thus all produced fluid was directed to a series of portable storage tanks and injected back into the well on completion of the test. Supervision of well test operations and analysis of well test data was conducted by GeothermEx, Inc.. A summary of the well test results is given below.

Well test layout: The test facility consisted of a flow line from the wellhead to an elevated atmospheric flash tank, which was in turn connected via a flow line to the "regulating" tank, one of 20 Rain for Rent storage tanks each with 500 barrel (bbl = 21,000 gallon) capacity. The tanks were all interconnected at their base via a manifold system and valves which allowed produced fluid to be transferred to successive tanks as they were filled during the test. Steam was vented from the top of the atmospheric flash tank during testing.

Figure 8: Static Pressure Survey

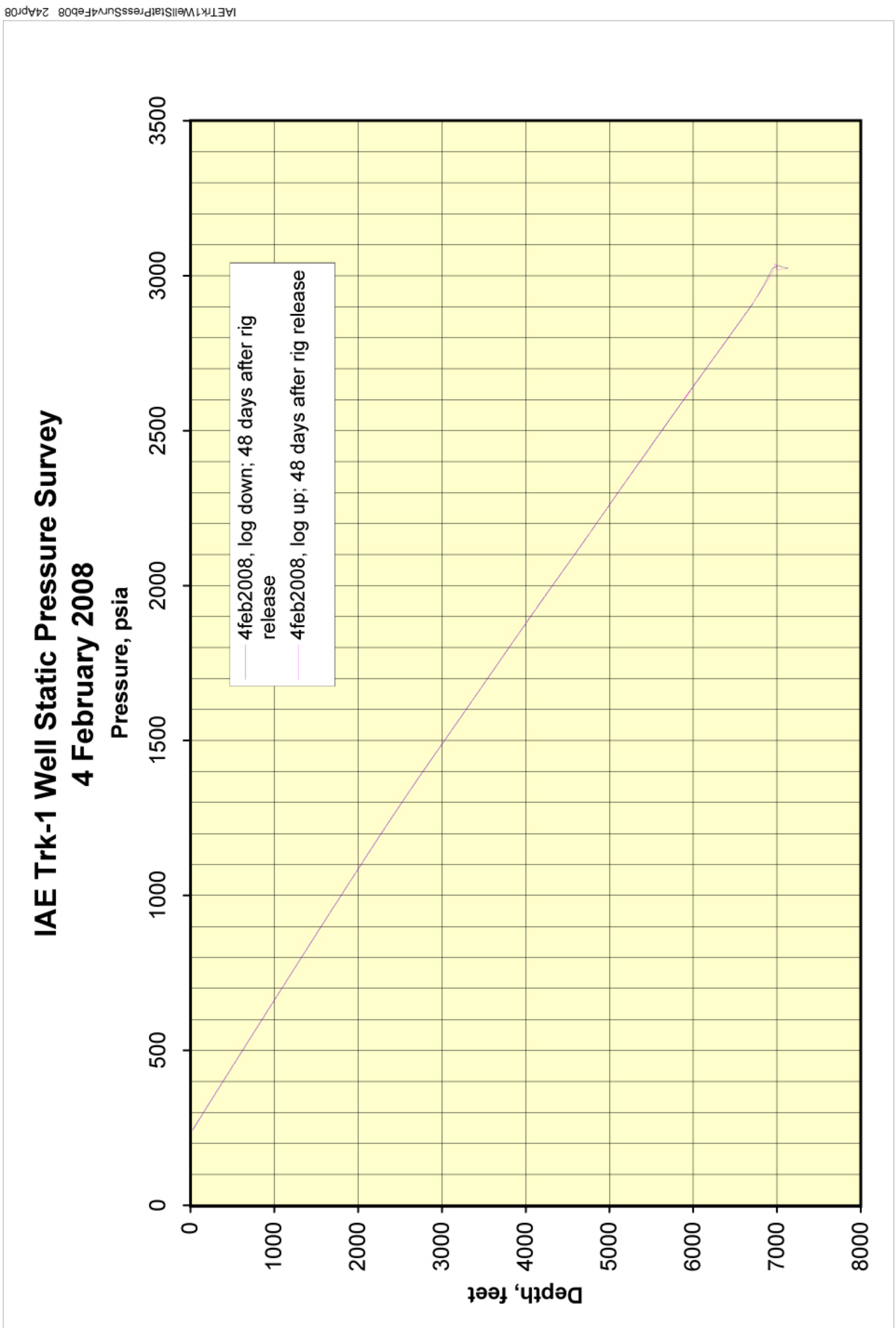

FIGURE 9. Plot of static pressure survey, IAE Trk-1 well, 4 February 2008.

Flow test stages: The flow testing of IAE Trk-1 was conducted in the following stages:

- 5 March 2008: A 12-hour artesian flow test was conducted which produced about 10,000 bbls of fluid nearly filling the 20 storage tanks. Samples of produced fluid and gas were collected for geochemical analysis during this test, which was followed by a 12-hour pressure build up survey. As described above, the result of this test are presented in detail herein.
- 6-8 March 2008: About 9,000 bbls of produced fluid from the initial artesian test was injected back into the well over a 33-hour period. Approximately 1,000 bbls were retained in the storage tanks for clean out operations (see below)
- 8 March 2008: A 4.5 hour flow test was conducted while cleaning out the interval from 4,500-6,700 feet depth by jetting high pressure water into to the well with a Halliburton coiled tubing unit (CTU).
- 8 March 2008: A 1.5 hour flow test was conducted while injecting nitrogen into the well using the Halliburton CTU.
- 9 March 2008: A 3.5 hour artesian flow test was conducted and shut in when all storage tanks were full This was followed by a 12-hour pressure build-up survey.

After completion of the final artesian flow test on 9 March and the subsequent build up survey, all produced fluid was injected back into the well with the exception of fluid produced during the CTU clean out operation. This latter fluid was assumed to be contaminated with drilling mud and other solids and was transported later to a designated landfill.

Results of initial artesian flow test on 5 March: Key parameters measured for the 12-hour artesian flow test on 5 March 2008 included flow rate, flow line temperature and wellhead pressure. The flow rates reported represent the amount of flashed liquid entering the storage tanks and do not include the steam vented from the atmospheric flash tank. Due to the relatively low temperature of the produced fluid (about 260°F upon entering the 13 3/8-inch casing- see below) the flash percentage at atmospheric pressure is 5%. Thus the flow rates plotted were low by about 5% and are thus conservative.

Prior to opening the well the shut-in pressure was 219 psig. Upon opening the well to flow the wellhead pressure quickly dropped to about 22 psig and the well flowed unassisted at a rate of about 750 gpm. The flow rate and wellhead pressure both declined over subsequent hours and appeared to stabilize at about 13 psig and 470 gpm toward the end of the test. The flow line temperature stabilized at about 240°F.

Results of a downhole pressure-temperature-spinner (PTS) survey conducted during the 5 March artesian flow were plotted and the static and flowing temperature surveys (4 March and 5 March respectively) were compared. The static and flowing surveys are identical below 4,500 feet, indicating zero flow from below 4,500 feet. The spinner surveys show a major fluid entry between 4,400-4,500 feet at 280°F, with additional shallower and cooler entries centered near 3,450 feet and 3,150 feet. The shallower entries are also indicated by the declines in flowing temperature observed at these depths, reflecting the lower formation temperature at the shallower depths. The “net” temperature of the mixed fluid entering the 13 3/8-inch casing shoe is about 260°F, as described above.

Comparison with Schlumberger logs indicates that these productive zones correlate with sand-rich intervals with high sand porosity (**Figure 6**). The sand porosities range from 18-22% for the main productive zone at 4,400-4,500 feet and from 27-29% for the shallower productive zones. The sand above 4,500 feet is very clean with low clay content as indicated comparison of neutron and density porosity logs. The low permeability “no-flow” zone below 4,500 feet includes intervals of shale and siltstone and sandstones with relatively low porosity, generally between 8-10%.

After shut-in of the flow test, a pressure build up survey was conducted with the logging tool set at the depth of the major productive interval at 4,500 feet. Downhole pressure at the end of the test period was 1,769 psia and had increased to 2,018 psia after 15 hours of buildup post shut in. At that time the well had not yet fully recovered to the pre-flow test static pressure of 2,060 psia at this depth.

GeothermEx conducted pressure transient analyses on the buildup data to calculate the formation permeability-thickness (kh) values, and indication of flow capacity. A Horner plot analysis yielded a kh value of 5,990 millidarcy-feet (md-ft) while a computer model curve fitting analysis yielded a kh value of 8,154 md-ft. These numbers are higher than the 3,880 md-ft kh value determined from the injection test results, presumably reflecting some cleaning up of the well and breakdown of drilling mud in the formation. A productivity index (PI) for the well of 1.9 gpm/psi was calculated based on the average pre-flash flow rate of about 560 gpm.

Results of final artesian test on 9 March after well stimulation: The combination of injection and coiled tubing stimulation work appears to have improved the productivity of IAE Trk-1. During the final 3.5 hour artesian flow test on 9 March the well-produced an average of about 630 gallons/minute (corrected to pre-flash flow of 660 gpm) at low wellhead pressure. While this is higher than the average pre-flash rate from the initial test of 560 gpm, the flow rates cannot be directly compared due to the shorter duration of the final test and the resulting lesser flow rate decline compared to the initial test. However, the productivity index and permeability-thickness factors for the well clearly increased post-stimulation. After stimulation, the productivity index improved from 1.9 to 2.5 gpm/psi and the formation permeability-thickness improved from about 6,000-8,000 millidarcy-feet to 9,600-10,800 md-ft.

Despite the improved well performance post-stimulation, the productivity of IAE Trk-1 still appears to be at the low end of the range for operating geothermal fields. The observed kh value of about 10,000 md-ft in IAE Trk-1 compares to commercially productive wells producing from sand matrix reservoirs in Imperial County similar to Truckhaven (e.g. Heber) which typically exhibit kh values in excess of 40,000 md-ft. The low reservoir kh in combination with the relatively low temperature of the produced fluid at 260°F suggest that IAE Trk-1 is a marginal producer. This conclusion is supported by the PI value of 2.6

gpm/psi, which is clearly at the low end of the range of PI values observed in operating geothermal fields.

Chemistry of well discharge: Two sets of samples were collected of produced brine and steam from the initial artesian flow test on 5 March 2008. The first set was collected about midway through the 12-hour test period and the second set was collected just prior to shut-in of the well. The samples were collected and analyzed by Thermochem, Inc. Separated brine and steam samples were collected using a portable separator apparatus connected to the flowline between the wellhead and the atmospheric flash tank.

The analyses of the two brine samples are generally quite similar, though the second sample had slightly higher salinity possibly reflecting cleanout of the well. The produced geothermal fluid is a benign, neutral pH, low-salinity brine with total dissolved solids content of about 4,500 ppm (parts per million). The fluid can be characterized as a Na-Cl-HCO3 water based on the dominant ions in solution. This benign fluid should pose no significant challenges to exploitation.

Application of various chemical geothermometers to the two brine analyses yield temperatures higher than the "net" 260°F fluid produced by IAE Trk-1. These include quartz conductive (297-313°F); Na-K-Ca (367-371°F); and K/Mg (289-293°F). This disparity could indicate higher temperatures are present elsewhere in the Truckhaven geothermal area.

The analyses of separated steam indicate high levels of total non-condensable gas in both samples (10.9-11.4% by weight). The dry gas is dominated by carbon dioxide (79 vol%), methane (16 vol%) and nitrogen (4.5 vol%), with trace amounts of hydrogen sulfide, ammonia, hydrogen and argon. The levels of hydrogen sulfide at 11-13 ppm by weight in the steam are quite low compared to other developed geothermal systems

The high total gas content in separated steam is likely to decline to some degree with long-term production. If gas levels were to remain high, it could adversely impact plant efficiency for a flash plant facility though a flash plant is unlikely with the low fluid production temperature from IAE Trk-1. If a binary system is installed the high gas content would be less significant as the produced fluid would be kept under pressure and the gas maintained in solution.

The relatively high nitrogen levels in steam may be the result drilling and injection operations conducted in prior to well completion in December 2007. Air is forced back into the resource during drilling and also with injection fluid that has been in contact with air. The oxygen is very reactive and will usually not make it back to the surface while the more inert nitrogen will only decline after long term production of the well.

Inferred generation capacity of IAE Trk-1 under pumped flow conditions: GeothermEx performed a numerical simulation of the well's performance if equipped with a downhole pump. The calculation was based on the input assumptions and assumed conventional pump technology is installed, i.e. line-shaft pumps with a maximum setting depth of 1,500 feet. The results of the simulation indicate a productive potential of about 1.5 Megawatts, net of parasitics (MW net).

For the above calculation, the partial pressure of the gas in the total well discharge was modeled at 188.5 psia using the Thermochem geochemical analyses. As described above, it is likely that the gas levels in the well discharge will decline after sustained production compared to levels measured during the short-term artesian flow tests. Lower gas partial pressure would reduce the potential for gas break-out during pumped flow and increase the estimated power output of the well above 1.5 MW net.

Chapter 4:
CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The IAE Trk-1 well was completed by Iceland America Energy, Inc on 18 December 2008 to a total depth of 7,139 feet. Test results to date for IAE Trk-1 are below expectations from the standpoint of reservoir temperature and permeability. While a maximum temperature of 350°F was measured at 7,000 feet depth, the equilibrium temperature profile is only weakly convective and does not exhibit significant isothermal intervals commonly associated with commercially productive geothermal wells.

The zone that contributes production to the well occurs at relatively shallow depth and ranges in temperature from 225-280°F. This productive zone extends from the 13 3/8-inch casing shoe at 2,938 feet to 4,500 feet depth and yields a 260°F mixed fluid derived from several discrete intervals with varying temperature. The productive intervals are correlated with sandstone layers with high porosity (18-29%). The low permeability zone in the well below 4,500 feet is associated with sandstone with low porosity (8-10%), shale, siltstone, and underlying granitic basement rocks. No fluid loss zones were encountered during drilling of IAE Trk-1, indicating a lack of permeable fracture zones in the well. This reinforces the importance of sand matrix permeability for production.

Results of a flow testing conducted in early March 2008 indicate that the IAE Trk-1 well is marginally productive. The flow test consisted of two short periods of artesian flow separated by injection of produced fluids back into the well and coiled tubing operations conducted to: a) clean out the bottom portion of the well by jetting with water; and b) stimulate flow by injection of nitrogen. Flow test duration was limited by lack of an injector well and portable storage tank capacity. The combination of injection and coiled tubing stimulation appears to have improved the well productivity. After stimulation, the productivity index improved from 1.9 to 2.5 gpm/psi and the formation permeability-thickness improved from about 7,000 to 10,000 millidarcy-feet. Nonetheless, these figures are at the low end of the range for operating geothermal fields. After well stimulation, the well-produced about 660 gallons/minute (pre-flash) at low wellhead pressure during a 3.5 hour artesian test. Computer simulation of well performance if equipped with a downhole pump indicates a productive potential of about 1.5 Megawatts, net of parasitics.

The produced geothermal fluid is a benign, low-salinity, neutral pH Na-Cl-HCO3 fluid with total dissolved solids of about 4,500 ppm. Gas levels in separated steam are quite high (10-11 weight %), but are likely to decline to some degree with long-term production. If gas levels were to remain high, it could adversely impact plant efficiency for a flash plant facility. The gas levels are not likely to pose a significant problem for power plant efficiency if the resource is ultimately developed with binary plant technology, as would be expected with the low to moderate temperature resource intersected by IAE Trk-1.

4.2 Commercialization Potential

The marginal productivity and fluid production temperature of the IAE Trk-1 well brings into question the commercial viability of the Truckhaven geothermal resource. Additional exploratory work is required to identify a region of higher temperature and productivity before development of this resource can move forward. While the low salinity of the produced brine is favorable for development, it is not yet known if higher salinity fluids may be present elsewhere in the Truckhaven resource area.

4.3 Recommendations

The following steps are recommended regarding the assessment and planned utility of the IAE Trk-1 well:

Long-term testing: It would be desirable to secure a suitable injection well to allow long-term testing of IAE Trk-1. Long term testing on the order of weeks or months would determine whether: 1) the well performance would improve with additional flow and clean out of drilling mud; and 2) high gas levels observed in steam during the short term artesian tests would decline over time.

Conversion of injector well: IF IAE Trk-1 is not used as a production well, it could be converted into an excellent injector by perforating the cemented 13 3/8" casing below 2,000 feet. This would add 680 feet of net sand with an average porosity of 28.4%, and should significantly increase the permeability-thickness factor for the well. Should a production wellfield be established at Truckhaven and a power plant built, IAE Trk-1 and other wells drilled in the vicinity could provide injection support for the project.

4.4 Benefits to California

The main benefits to California of the drilling and testing of the IAE Trk-1 well can be described as follows:

Benefit to California businesses: This total cost for drilling and testing of IAE Trk-1 was on the order of $7 million. The majority of this expenditure was directed to California firms which supplied materials, equipment and services to the project. California firms which contracted with IAE for this project include but are not limited to the following entities, listed along with the service provided:

- Project management and geoscientific consulting (Layman Energy Associates, Inc.)
- Drilling supervision (InterAct PMTI)
- Drilling engineering and reservoir engineering consulting (GeothermEx, Inc.)
- Geochemical sampling and analysis (Thermochem, Inc.)
- Project permitting and compliance consulting (Environmental Management Associates, Inc.)
- Preparation of drainage and grading plan (Hale Engineering and Surveying, dba Tesco)
- Wellpad geotechnical investigation (Landmark Consultants, Inc.)

- Wellpad and access road construction and labor supply (Primo Construction Services)
- Drilling contractor (Thermasource, Inc.)
- Wellhead equipment supply (Rupple Marketing)
- Water supply lines / storage tanks (Rain for Rent)
- Vacuum / environmental services (Ancon Marine)
- Water storage tanks (Denbeste)
- Diesel fuel supply (Sellars Petroleum)
- Temperature and pressure logging (Welaco)
- Design of well test facility (JFPM, Inc.)
- Construction of well test facility (Performance Mechanical Contractors, Inc.)
- Disposal of drilling waste (Western Environmental)
- Pipes and fittings (Bakersfield Pipe and Supply)

Advanced knowledge of Truckhaven geothermal resource: While IAE Trk-1 did not prove a commercially productive resource at Truckhaven, it has added to the significantly to the geological understanding of the area. Results of this well will hopefully be used by IAE and others to guide future exploratory work at Truckhaven, and perhaps help to locate a productive resource.

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