Crump Geyser Exploration and Drilling Project

HIGH PRECISION GEOPHYSICS & DETAILED STRUCTURAL EXPLORATION AND SLIM WELL DRILLING

Final Report

United States Department of Energy – Geothermal Technologies Program

Award DE-EE0002835

Nevada Geothermal Power Company

With Contributions by:

Ormat Nevada, Inc.

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Executive Summary

The Crump Geyser Exploration and Drilling Project – High Precision Geophysics and Detailed Structural Exploration and Slim Well Drilling ran from January 29, 2010 to September 30, 2013. During Phase 1 of the project, collection of all geophysical surveys was completed as outlined in the Statement of Project Objectives. In addition, a 5000-foot full sized exploration well was drilled by Ormat, and preexisting drilling data was discovered for multiple temperature gradient wells within the project area. Three dimensional modeling and interpretation of results from the geophysical surveys and drilling data gave confidence to move to the project into Phase 2 drilling.

Geological and geophysical survey interpretations combined with existing downhole temperature data provided an ideal target for the first slim-hole drilled as the first task in Phase 2. Slim-hole 35-34 was drilled in September 2011 and tested temperature, lithology, and permeability along the primary range-bounding fault zone near its intersection with buried northwest-trending faults that have been identified using geophysical methods.

Following analysis of the results of the first slim-hole 35-34, the second slim hole was not drilled and subsequent project tasks, including flowing differential self-potential (FDSP) surveys that were designed to detail the affect of production and injection on water flow in the shallow aquifer, were not completed. NGP sold the Crump project to Ormat in August 2014, afterwards, there was insufficient time and interest from Ormat available to complete the project objectives. NGP was unable to continue managing the award for a project they did not own due to liability issues and Novation of the award was not a viable option due to federal award timelines. NGP submitted a request to mutually terminate the award on February 18, 2015.

The results of all of the technical surveys and drilling are included in this report. Fault interpretations from surface geology, aeromag, seismic, and gravity data sets are in good agreement, illustrating two or more major range-bounding faults and buried northwest trending faults. The intersections of these fault systems provide the primary targets for drilling.

1. Introduction

The Crump Geyser Exploration and Drilling Project – High Precision Geophysics and Detailed Structural Exploration and Slim Well Drilling ran from January 29, 2010 to September 30, 2013. Nevada Geothermal Power Company (NGP) continued to work with the Department of Energy past this date on a modification to the Statement of Project Objectives and Budget Justification. The Crump Geyser project was operated under a Joint Venture Agreement between NGP and Ormat Nevada Inc. (Ormat) from November 2010 until August 2014 when NGP sold the project to Ormat.

This project was intended to:

- Discover new 260°F and 300°F geothermal reservoirs in South Central Oregon.
- Create short term employment to explore and develop the geothermal power project.
- Create long term jobs in southern Oregon to operate the discovered resource.
- Demonstrate a combination of highly precise magnetic and gravity data and shallow seismic reflection/refraction to define fault structures in this geologic setting as a guide to targeting wells.
- Demonstrate sump-less drilling as a low-footprint drilling technology specially suited to environmentally sensitive areas.
- Demonstrate the innovative use of Flowing Differential Self-Potential (FDSP) to monitor the affects of well testing on a known low temperature shallow aquifer as a guide to exploration and resource management.
- Test a combination of electrical resistivity tomography with FDSP to co-interpret fluid flow and resistivity.

Phase 1 of the project was designed to collect and interpret multiple levels of magnetic field measurements, precision Bouguer gravity, detailed geologic mapping, and shallow seismic reflection to detail secondary fault offsets in a shallow basalt formation at Crump Geyser in southern Oregon. Temperature gradient well data would then be used to confirm which secondary faults host active hot water.

Work completed within Phase 1 includes the magnetic surveys (ATV-towed ground, boat and airborne), precision gravity surveys, and the gas-piston shallow seismic reflection survey. The data collected included magnetic, gravity, and seismic reflection surveys providing an unprecedented quantity of high resolution, high quality data over the geothermal prospect and surrounding areas. The majority of the collected data have been processed and incorporated into a three dimensional model. The analyses have identified new structures that have been mapped, as well as refined details gathered on previously known structures and geothermal features. Existing results from this effort were sufficient for targeting of slim-holes and identifying a slim-hole target for Task 6.1 in Phase 2.

Work completed within Phase 2 included the drilling of the first DOE funded slim-hole well 35-34 which was completed in October 2011. The drilling demonstrated an environmentally-friendly sumpless drilling method that could be applied to all geothermal exploration efforts worldwide.

Following analysis of the results of the first slim-hole 35-34, the second slim hole was not drilled and subsequent project tasks, including flowing differential self-potential (FDSP) surveys that were designed to detail the affect of production and injection on water flow in the shallow aquifer, were not completed. Immediately following the FDSP survey the surface electrode network was to be applied to an electrical resistivity tomography survey to provide another detailed geophysical data set to support future drill and reservoir operations.

After NGP sold the project to Ormat, there was insufficient time and interest from Ormat available to complete the project objectives. NGP was unable to continue managing the award for a project they did not own due to liability issues and Novation of the award was not a viable option due to federal award timelines. NGP submitted a request to mutually terminate the award on February 18, 2015.

The following sections describe the collection and interpretation of each data set and results from drilling slim-hole 35-34.

2. Results of Exploration Surveys

2.1 Magnetic Surveys

Ground Magnetic Survey 2005

Prior to the DOE award, a ground magnetic survey completed by NGP in 2005 provided the first very detailed look at the subsurface geologic structures at Crump Geyser (Figure 1). The data fit well with the surface geologic and fault model and confirmed that the strong NW and NE trending fault structures clearly visible in the surrounding topography are present beneath the sedimentary cover in the Warner Valley, as was expected. The structural interpretation of the data provides one important component of the local structural model of the hydrothermal system.

The dataset is characterized by strong NW trending magnetic discontinuities, offset or intersected by NE trending and less-prominent apparent NNW trending discontinuities, which are here interpreted as faults. The interpreted faults also correlate well with faults identified from surface topographic lineaments. Two key elements of this structural interpretation are important to highlight. First, the prominent NNE trending range front forming the western margin of Warner Valley appears to be composed of multiple (at least two) east-dipping, sub-parallel range front faults. Secondly, the area along the range front between Crump and Pelican lakes shows a high occurrence of intersecting NW trending faults that are closely associated with a prominent landslide/slump block (outlined hashed areas on the figures). The southernmost block occurs at a point where the NE trending range front (going from south to north) appears to assume a more NNE directed orientation. It is unknown whether fracturing associated with this block is constrained to the near surface environment or is also related to deeper structures, although its location suggests that the latter is possible. This interpretation identifies numerous fault targets between Crump and Pelican lakes along and immediately east of the range front, as well as fault targets further eastward toward the center and eastern portions of the valley floor. The highest priority fault targets are those areas in which the NW trending faults intersect the NNE trending range front – an area likely to be more highly fractured than areas to the south or immediately to the north.

Aeromagnetic Survey 2010

In March 2010 an airborne magnetic survey was flown over the Warner Valley to expand on the existing ground magnetic data, and to better define both the major and lesser, valley-centric fault structures hosting the hydrothermal system (Figure 2). The airborne survey provides the regional context for more detailed structure mapping from the ground surveys. The airborne survey was conducted by Edcon-Prj utilizing their ultra-light aircraft in order to cover a broad area of the valley floor and obtain very dense data coverage of the magnetic anomalies, especially in areas close to the range front. North-south primary survey lines were spaced at 100-meter intervals with west-east tie-lines spaced at 400 meters, and with an average terrain clearance of 123 meters. A total of 948 line-miles of aeromagnetic data was acquired. The flight path was recorded with a Trimble differential GPS navigation system. The data were corrected with respect to the base magnetometer and filtered to remove any identified noise, and leveled. Lastly, the data were reduced to the pole with an inclination of 65.58°, and a declination of 14.95°. Although some cultural noise was identified in the data, it was considered minimal, and no steps have been taken to do any deculturing of the data.

The dataset vividly shows the prominent NW, NE, and lesser and variably oriented structures believed to host the primary fluid pathways of the broader Warner Valley hydrothermal system. The dataset has provided insight into the prominent local structures that intersect the range front near the Crump Geyser area and are strong candidates for well targeting as is outlined elsewhere in this report. Generally, the dataset shows strong NW and NE structures which cross the entire valley, and are generally continuous with the surrounding surface topographic lineament trends (Figure 3). As noted in the discussion of the NGP ground magnetic survey, there is a higher incidence of NW and NNE fault intersections between Crump and Pelican lakes that is closely associated with the strongest heat anomaly (Figure 3). It is likely that the large landslide block immediately south of Crump Geyser is related to the intersection(s) of major through going faults, and the degree of rock fracturing in the vicinity will be much greater than areas to the north or south. The ground magnetic and the airborne magnetic surveys agree with each other well, corroborating the survey results and lending a high degree of confidence to structural interpretations from the datasets. While the aeromagnetic survey has provided unprecedented detail on the pattern of fault blocks within the valley, the actual depth to the top of the offset fault blocks is not known from this survey. The seismic reflection survey, discussed below, does provide a depth calibration to the valley-centric down-dropped fault blocks, which is important for well targeting and drilling designs.

USGS Ground Magnetic Survey 2009/2010

The USGS was allocated funds to expand upon their geophysical study of the Warner Valley to provide detailed ground (ATV-towed and Boat) magnetic coverage of primary interest areas in the vicinity of Crump Geyser. The surveys were carried out in two field sessions spanning the summers of 2009 and 2010. Figure 4 shows the map grids of the 2009 ground magnetic survey and the boat magnetic survey. Further processing of this data will be valuable for modeling the precise nature and orientation of specific key structures thought to control fluid flow in the Crump Geyser hydrothermal system. Lithologic and magnetic susceptibility data from core wells will be combined with these data to further pinpoint controlling structures at greater depths following drilling.

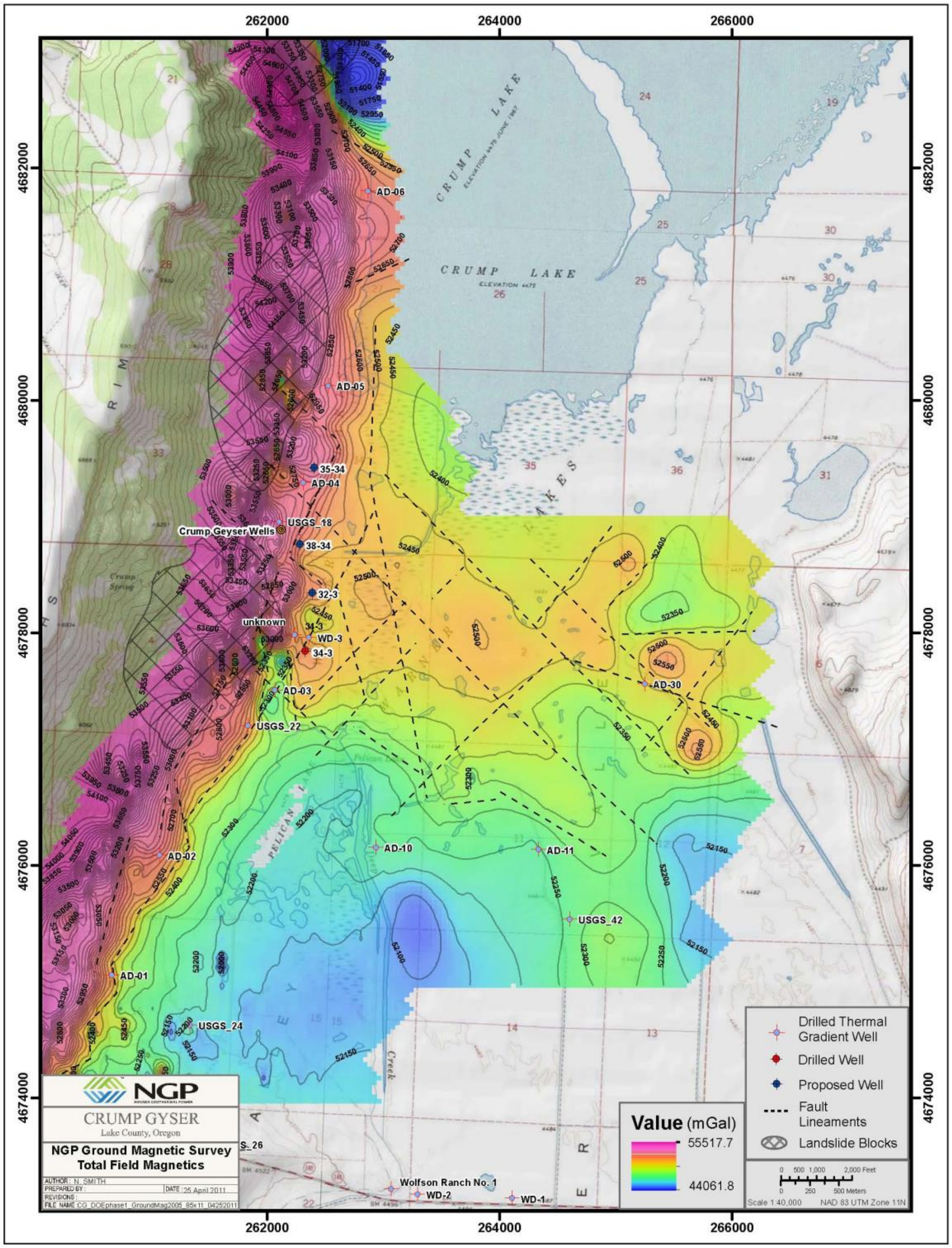

Figure 1. Map showing 2005 ground magnetic data and interpreted faults.

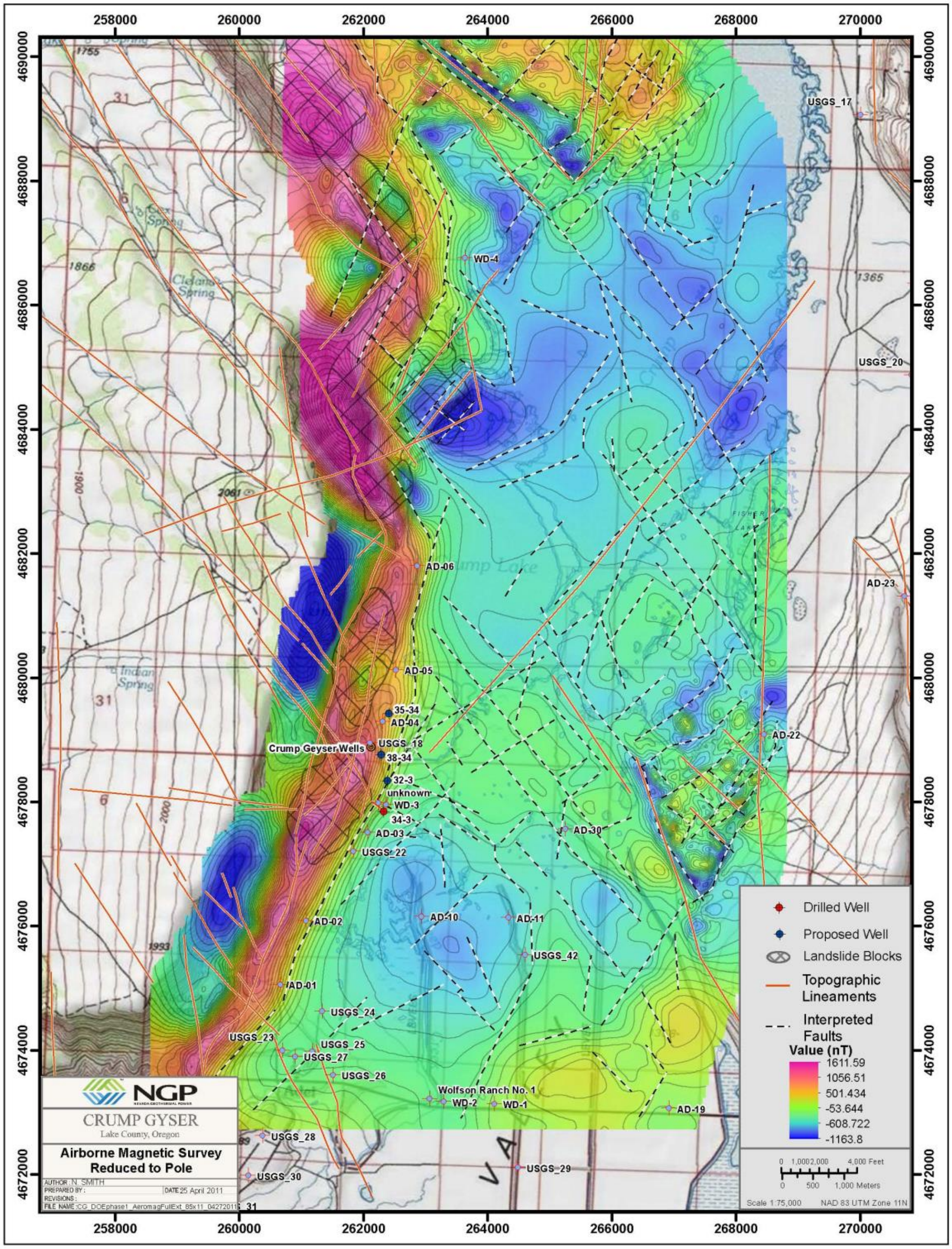

Figure 2. Map showing the full aeromagnetic survey coverage, and surrounding regional topographic lineaments.

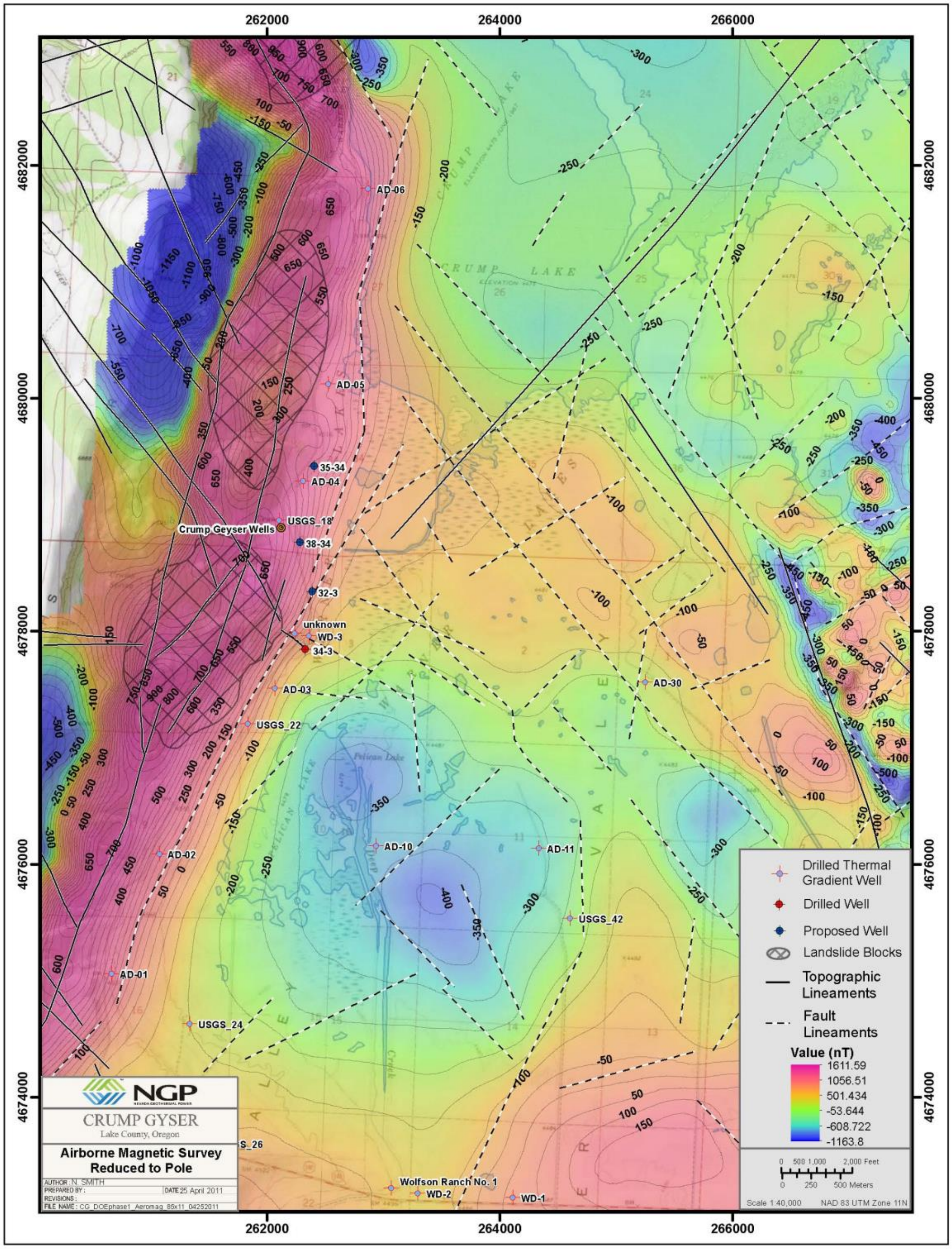

Figure 3. Airborne magnetic anomaly reduced to pole.

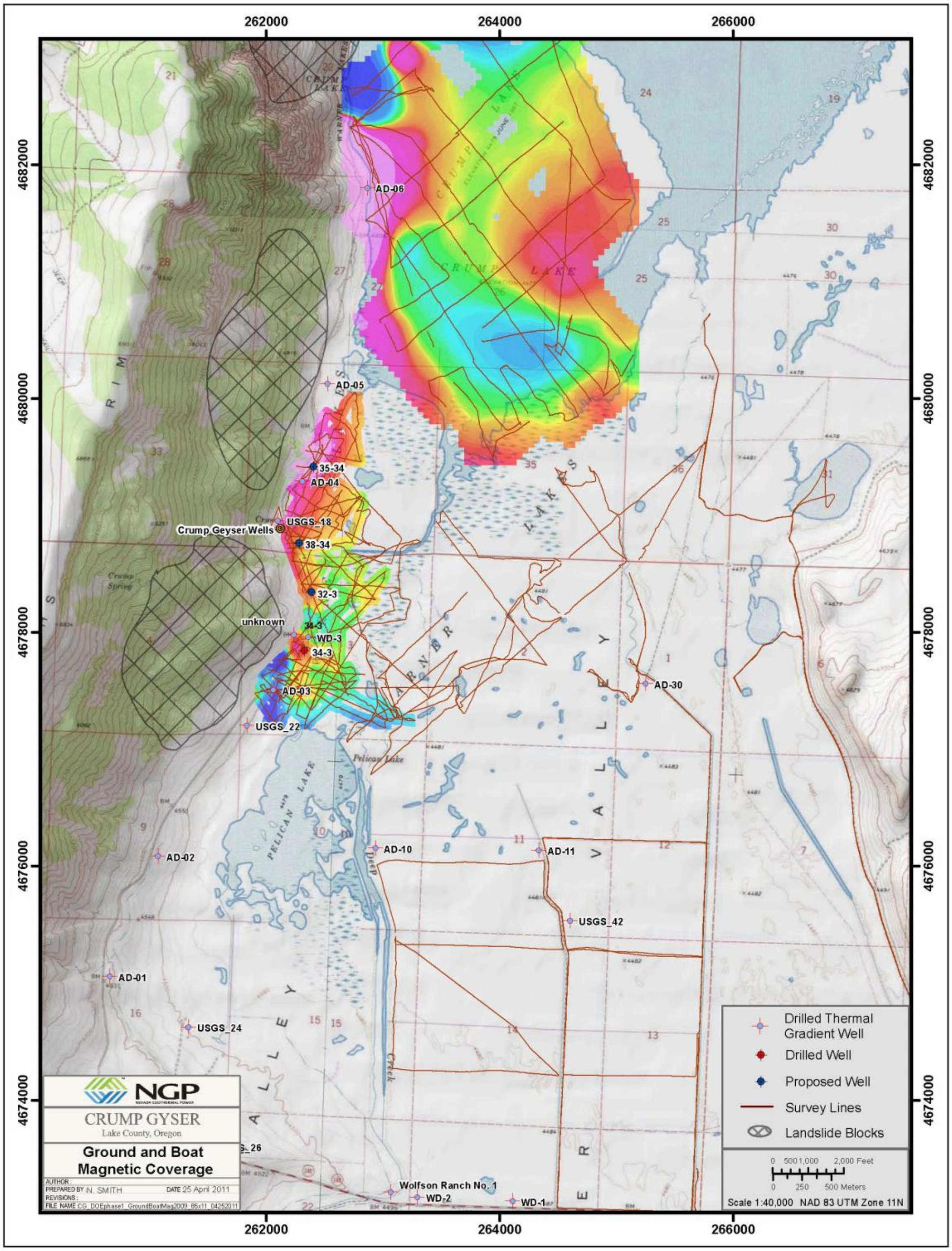

Figure 4. Map showing ground magnetic data collected in the vicinity of Crump Geyser, Oregon.

2.2 Gravity Survey

As a part of this DOE funded project, the USGS was allocated additional funds to expand upon their (already in progress) geophysical study of the Warner Valley to provide very detailed precision gravity surveys of the valley area immediately east of the Crump Geyser wells to complement their more regional data collection efforts. This survey resulted in 164 and 373 new gravity station during the summers of 2009 and 2010 respectively. All new gravity stations were tied to the base station at the Adel post office, which is in turn tied to the base station in Alturas, CA. The gravity stations were reached by car, ATV, and on foot for the detailed profile lines. The data were gridded using a minimum curvature method with 100m cell spacing and color contoured as shown in Figure 5.

Figure 5 shows the isostatic gravity anomaly in the vicinity of Crump Geyser, with the data points indicating the survey coverage in 2009 and 2010. The precision gravity profile lines were completed with station spacing of 30-100 meters and were designed to match exactly with the seismic reflection survey lines and cover the same region in which the ground magnetic surveys have been completed.

The isostatic and horizontal gravity maps reflect the strong influence of the NW and NNE structures in the Crump Geyser region. The isostatic (Figure 5) and complete Bouger (Figure 6) maps show a well-defined rapid transition eastward across the Crump fault from high to low gravity; this NNE-trending, range bounding fault is also prominent in the horizontal gradient (Figure 7). The interpretation of these results is in good agreement with those of the magnetic and seismic surveys, as described in Section 4. Integrated Analysis of Results & Conceptual Resource Model. Two larger gravity lows are located one south near Pelican Lake, and a lesser gravity low occurring at the north end of the basin beneath Crump Lake (Figure 6). These lows are not well defined in the regional isostatic map (Figure 5), but close station spacing better defines high gradient areas visible in the horizontal gradient map (Figure 7), which provide additional constraints for modeling and interpreting faults. A relative high gravity anomaly separates the lows immediately east of Crump Geyser and trends to the southeast, coinciding with the magnetic anomalies and indicating the presence of a relative basement or bedrock high. This intra-basin high is likely formed by the presence of significant through going faults bisecting the valley. The relative high fault block is also likely to be highly internally fractured (as evidenced by supporting magnetic and seismic data), and its relatively shallower depths are favorable for providing fluid upflow conduits to the surface springs or near surface environment. The primary interpreted faults align well with those interpreted from seismic data, lending confidence to the overall structural interpretation and slim-hole targeting, as described in Section 4. Integrated Analysis of Results & Conceptual Resource Model.

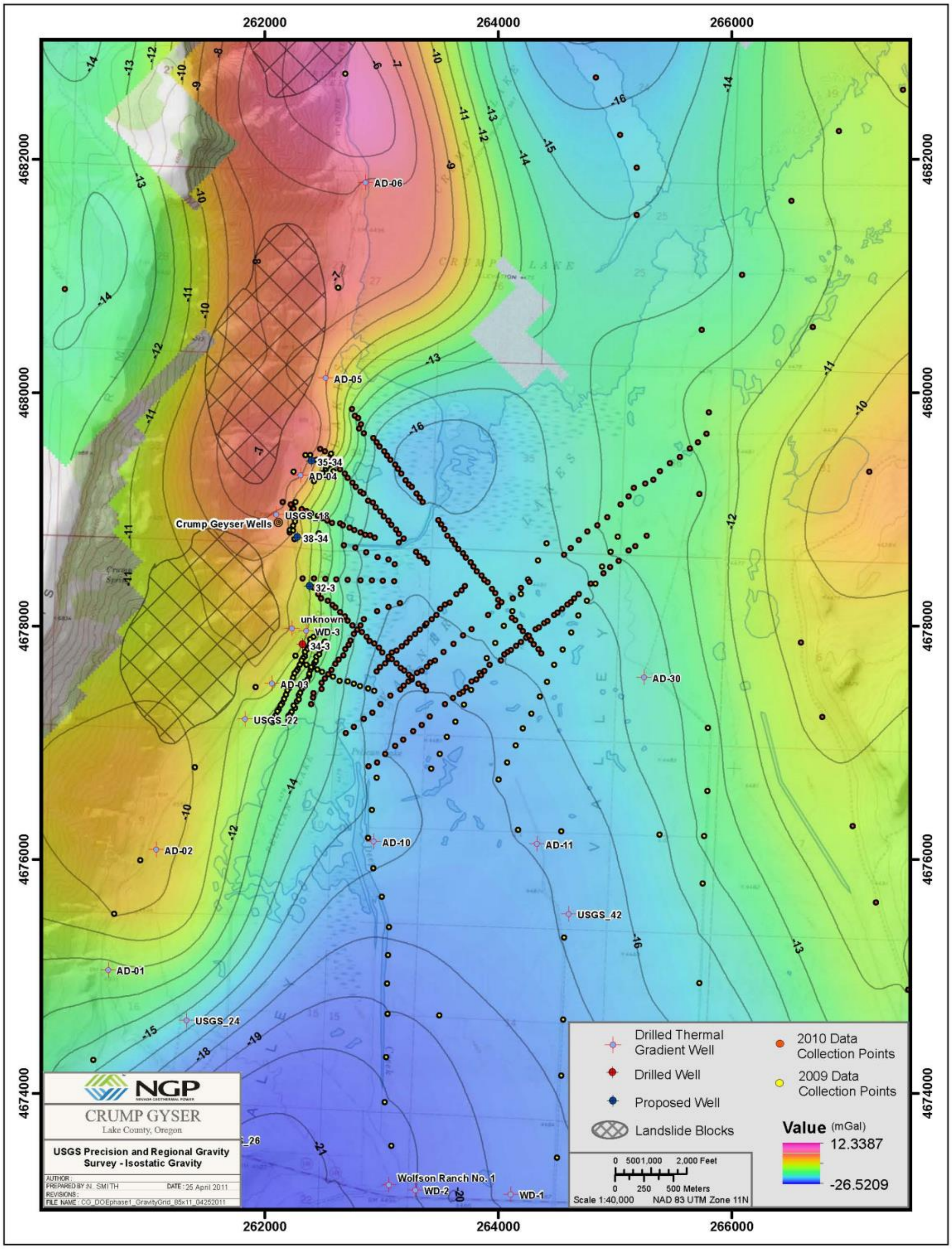

Figure 5. Map showing isostatic gravity data and station locations.

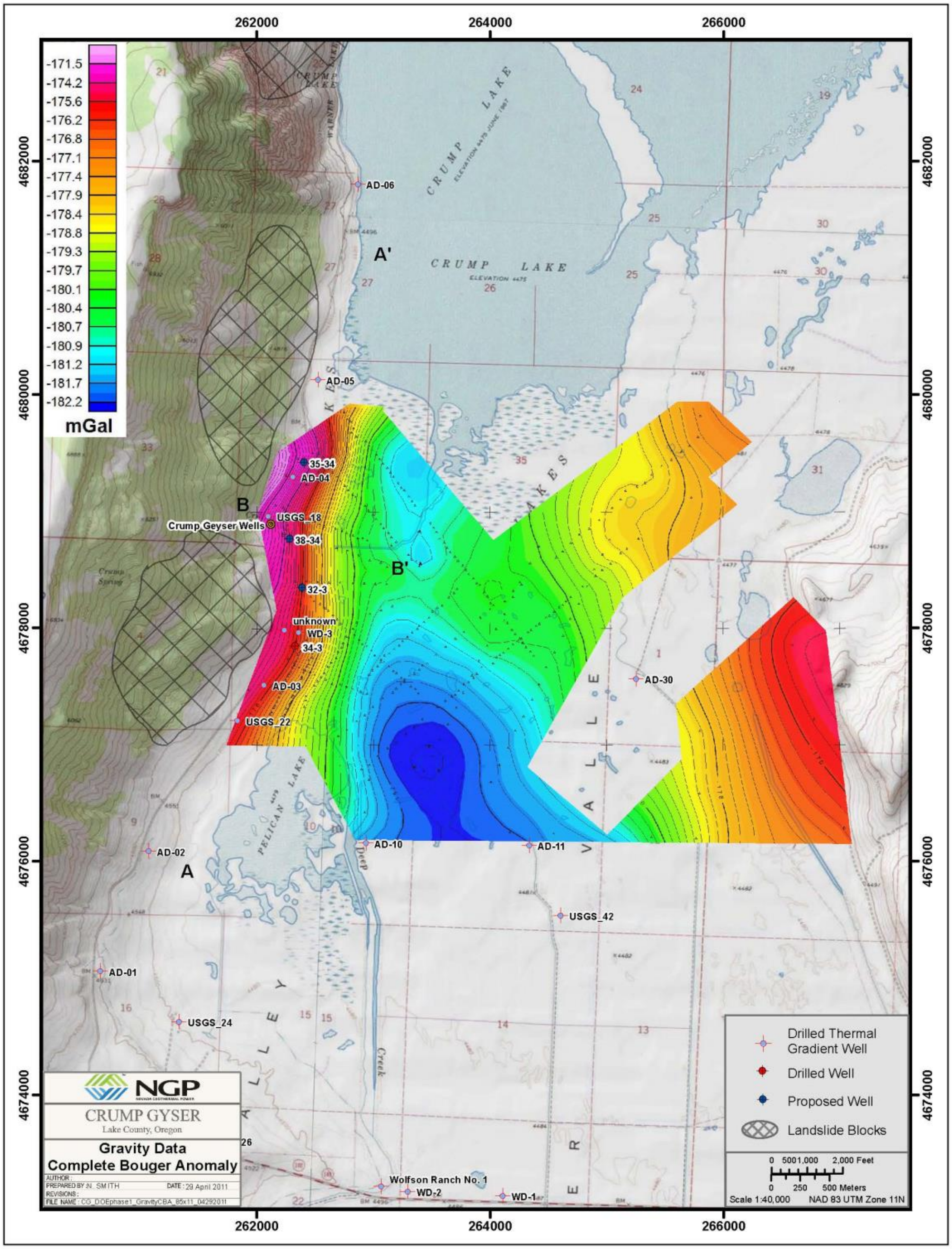

Figure 6. Map showing magnitude of the Complete Bouger Anomaly.

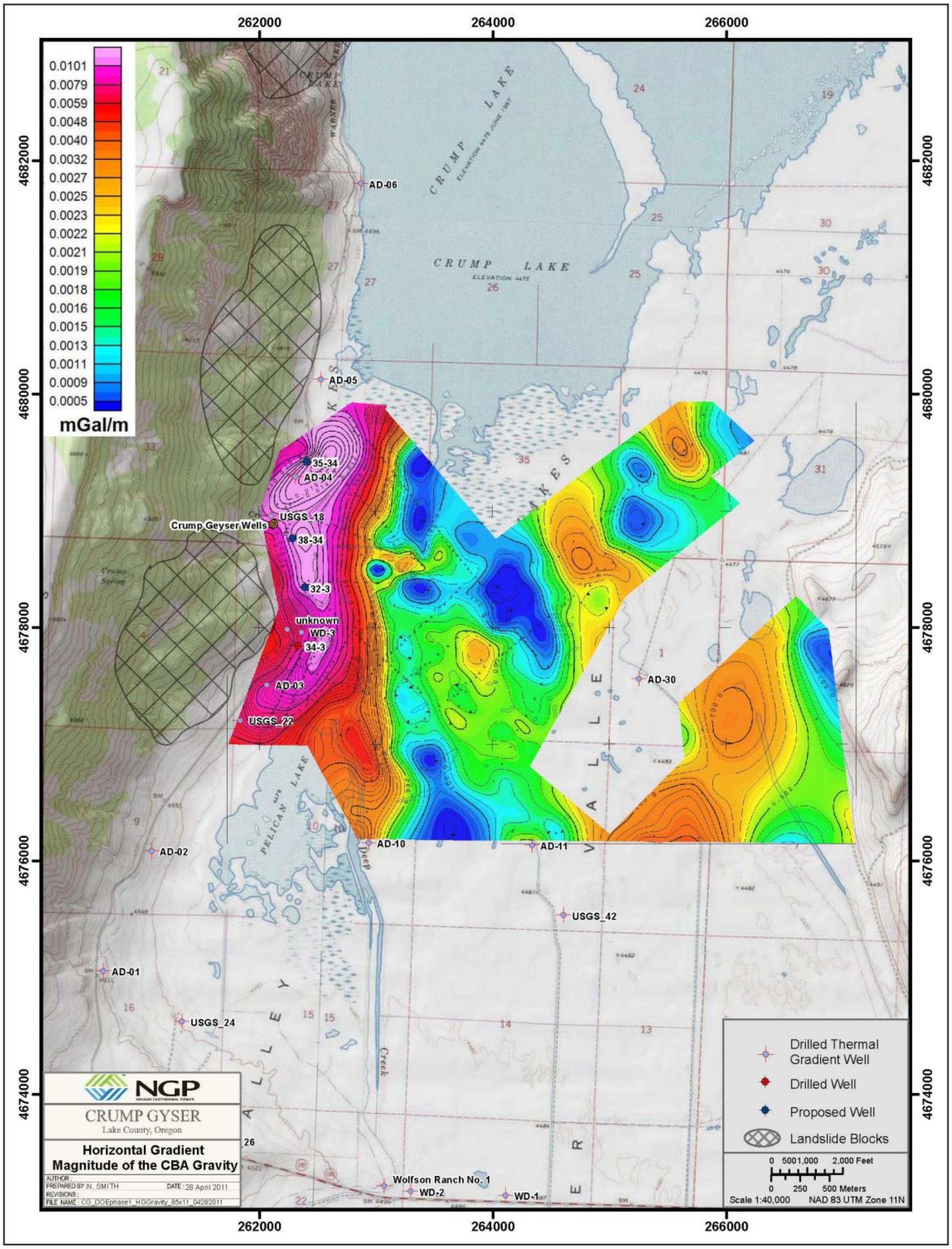

Figure 7. Map showing horizontal gradient magnitude of the Complete Bouger Anomaly.

2.3 Seismic Survey

Introduction

In the fall of 2010, Zonge Geosciences, Inc. (Zonge) conducted a two-dimensional (2D) seismic survey at the Crump Geyser geothermal prospect. The 2D seismic survey produced good seismic images to several thousand feet depth. Faults are readily identified and have been mapped across the prospect area. Sedimentary and volcanic layering were imaged and mapped.

The 2D reflection survey was completed collectively between Bird Seismic, Excel Geophysical, ExplorTech LLC, and Zonge. Bird Seismic performed the field data acquisition under the direction of Zonge personnel; reflection data processing was performed by Excel Geophysical, who specializes in high-end processing of shallow seismic data; and the interpretation was completed with ExplorTech in conjunction with the Zonge project geophysicist. All positioning of each source and receiver position was provided with RTK GPS survey data.

The primary objective of the seismic reflection survey was to map depth to the top of the basaltic bedrock as it is faulted off the mountain front on the west side of the project site. Additionally, the survey objectives were to image any associated structures such as faults and unusual topography on the top of the basalt. The lines were primarily located on the basis of structures identified from the prior aeromagnetic survey results (Figure 3). Prior to drilling, geologic information indicated that there could be (approximately) up to 1500 feet of undifferentiated alluvial sediments overlying the basalt beneath this project site – thickening eastward off the mountain flank. The 34-3 well showed that alluvium is actually very thin in this location, approximately corresponding with the Very Shallow reflector shown in the seismic images. The basic structure of the range front, and other associated, generally NW-trending faults have been modeled using airborne magnetic data. No borehole geologic information in the immediate area of the reflection survey was available for this project at the time of the survey. The target interface to image with the reflection survey was the alluvium / basalt contact. There is no indication of other rock formations overlying the basalt, other than discontinuous, indurated or semi-indurated beds and sand lenses within the alluvium and siliceous cinter deposits. The seismic reflection survey was designed to image the Qal / basalt contact as it drops to the east, in a series of anticipated normal faults.

In December 2010 and January 2011, Ormat drilled and logged the 34-3 exploration well at the location shown on Figure 7. It is a deviated well and a sonic log was acquired in the well. Based on the recommendation from the original seismic project report (December 2010).

Data Acquisition and Processing

The reflection survey was completed using a tight survey setup using 32.81-foot (10-m) source and receiver intervals. By using an equal S/R spacing allowed maximum fold to be achieved beneath the majority of the lines. A DigiPulse 250 impulsive, weight-drop source system mounted on a Polaris ATV was used for the source for this survey. It is a gas-charged seismic source that is capable of triggering the seismic system through a wireless connection. This is a unique, safe, and efficient seismic source. This system produced excellent quality seismic data here. Seismic data were collected with a static receiver geophone array configuration. The source accessed all the shot points and hammer blows were not necessary for this survey. The DigiPulse source produced good signal quality with repeatable content (i.e., frequency and amplitude). The data were recorded with a Seistronix EX-6 seismograph (capable of recording over 400 channels). Source points were positioned mid-way between the receivers (i.e., on the '*half-station*'). Changes in the source amplitude were adjusted in the processing sequence. Survey control for source points, receiver positions, and key monuments were acquired using a Leica System 1200 base and rover RTK GPS survey system. Survey data were acquired for points in Latitude and Longitude and converted to Universal Transverse Mercator (UTM) coordinates in meters. Survey data are in UTM Zone 11N coordinate system (meters). The survey datum was NAD1927. Figure 8 shows the survey layout.

After the data were acquired, the data were processed using a processing flow for high resolution 2D data. Refraction statics were utilized in the final processing. Field records were acquired in Seg-2 format with a 2.0-second record length, 2.0-millisecond sample rate, and all filters were out. The shot records were converted to 2D binned common-depth-point stacks (CDP). The seismic datum is 4600 feet above sea level and the replacement velocity was 5000 feet per second. The quality of the processed data is very good. The data from this site were typical of seismic data acquired in the basin and range province in the low-lying playas, where frequency content varies across an area. This is most likely due to variations in the ground surface that can influence the source signal. However, the data quality is more than adequate to produce good interpretations.

Time structure maps were produced on six seismic events. Depth conversions were done on the deepest two events, which have relatively stronger amplitudes. These stronger amplitude reflection events may be interpreted as the buried basaltic bedrock; however, until additional geologic and/or geophysical information calibrate and correlate with these seismic sections, the cause of these deeper reflection events is based on experience, to-date site information, and interpretation.

Following Ormat's drilling of well 34-3, Zonge conducted new depth conversions of the existing 2D seismic data and maps. NGP provided sonic log data from the recently drilled 34-3 well. Two time-depth curves were developed from the log data.

The interpretation and maps from the preliminary interpretation were used for a new analysis following the drilling of the 34-3 well. A sonic log was obtained in the new 34-3 well. The log was run over the full drilled depth (5,000 feet MD), but the well had casing run to 2557 feet (MD).

Since sonic log data are not available for the shallow part of the well, estimates of time to depth curves (velocity profile) for that part of the well had to be made. As a result of these uncertainties, two (2) time to depth curves were computed for this well in order to capture the range of likely velocity functions at this location. The first velocity model is a fast or high velocity estimate in which we projected the average velocity of the measured interval back to the surface. This is likely too fast for most of the area, but it does produce maximum depths to faults and horizons seen in the seismic data. A second slow or lower velocity estimate was made by projecting a smooth curve from 6,500 feet per second near surface to the actual measurements to cover the likely minimum depths of the faults and seismic horizons. Depth converted seismic sections and structure maps were created for both velocity profiles. Only the higher velocity conversions are included here for brevity. This velocity structure is likely to represent the deepest that faults would have to be targeted based on these data. Diminishing reflection quality with depth at the 34-3 site is likely due to noise associated with highly fractured and altered rock, as indicated by lithology logs and continuous drilling breaks. The lack of shallow sonic data and the discontinuous and noisy quality of the deeper seismic data make synthetic seismograms challenging to fully interpret, precluding better determination of the best velocity model.

Figure 9 shows the computed velocity profile and synthetic seismogram for the fast or high velocity model at 34-3. Figure 10 shows the relative depth difference in synthetic seismogram 34-3 well tie projected onto line L6 with the fast and slow velocity models.

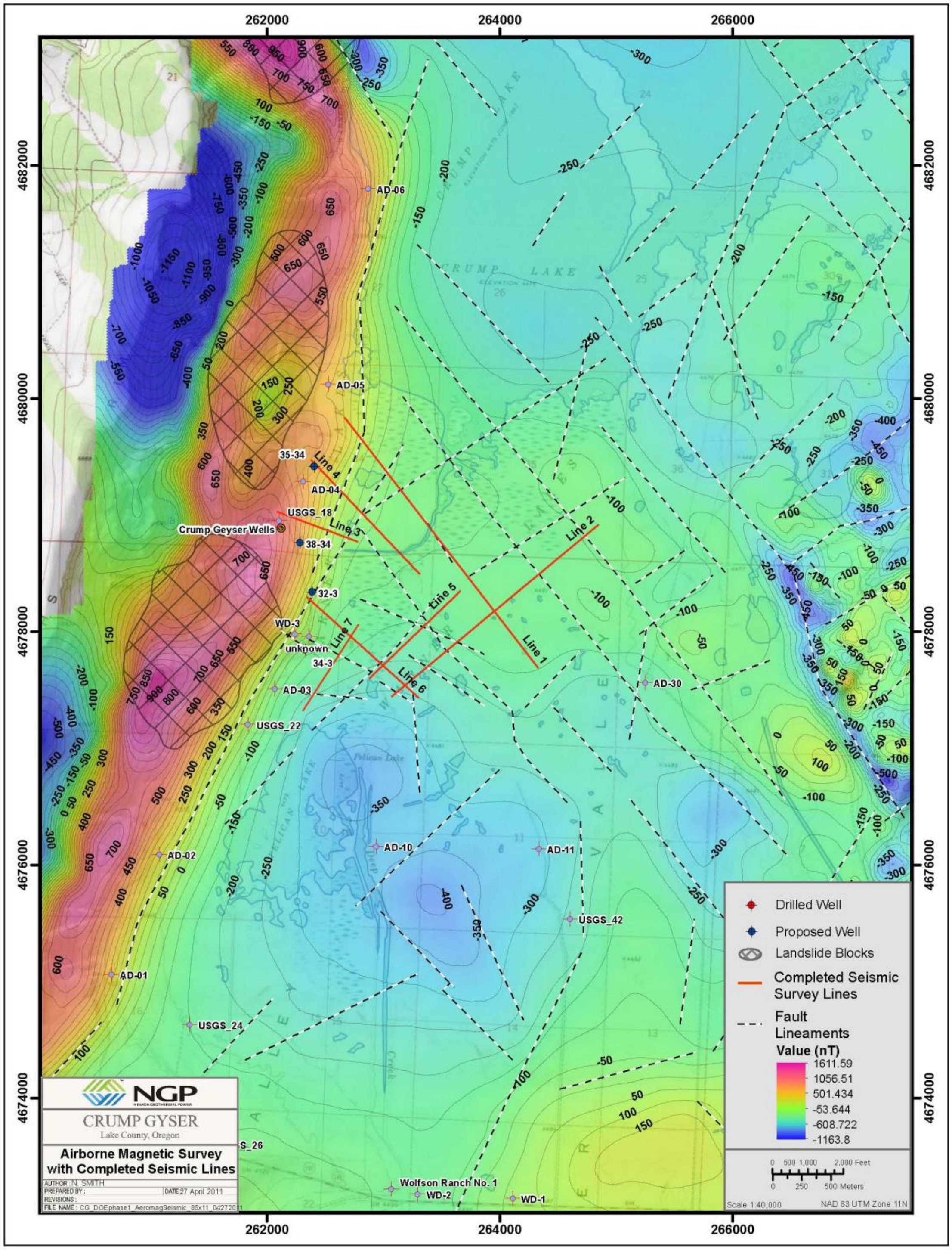

Figure 8. Map showing location of seismic survey lines and wells in relation to aeromagnetic RTP data.

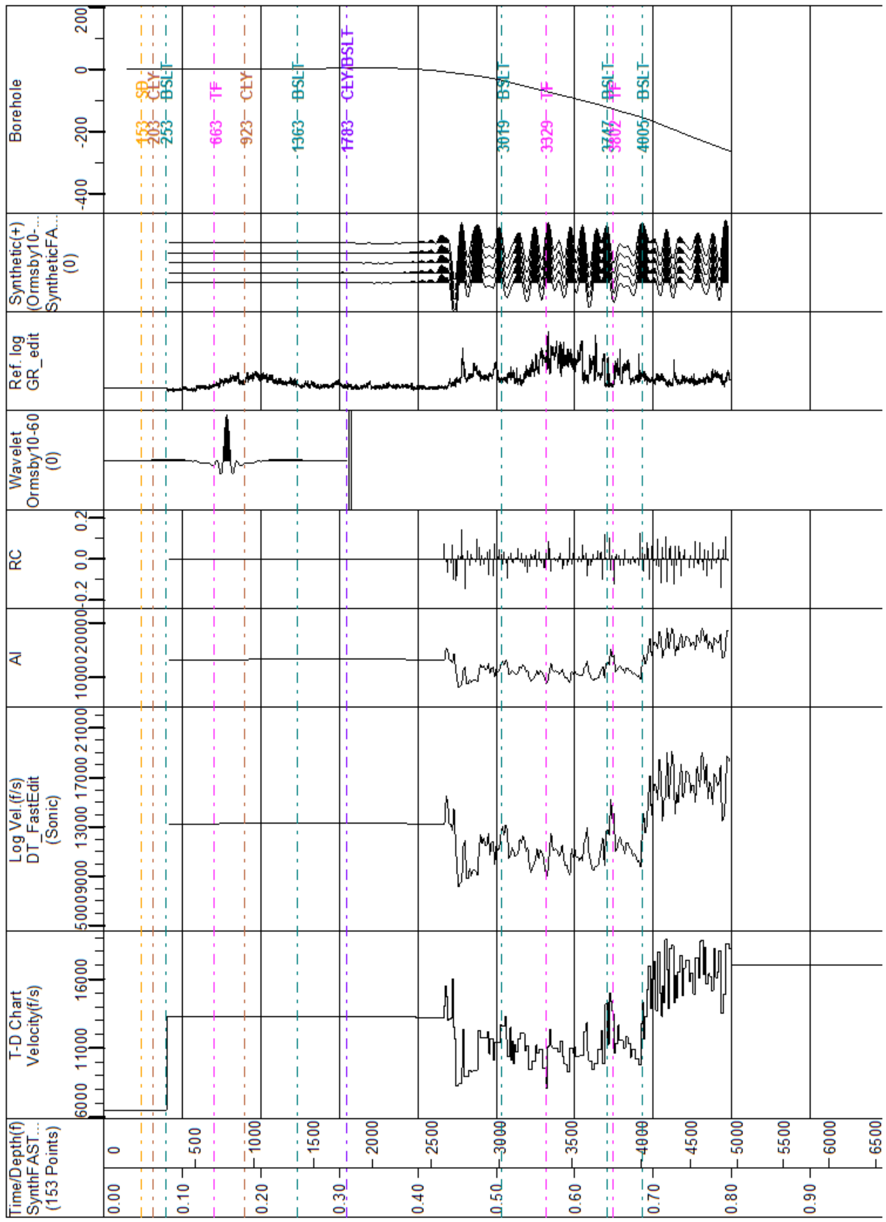

Figure 9. Crump Geyser 34-3 fast velocity model and synthetic seismogram

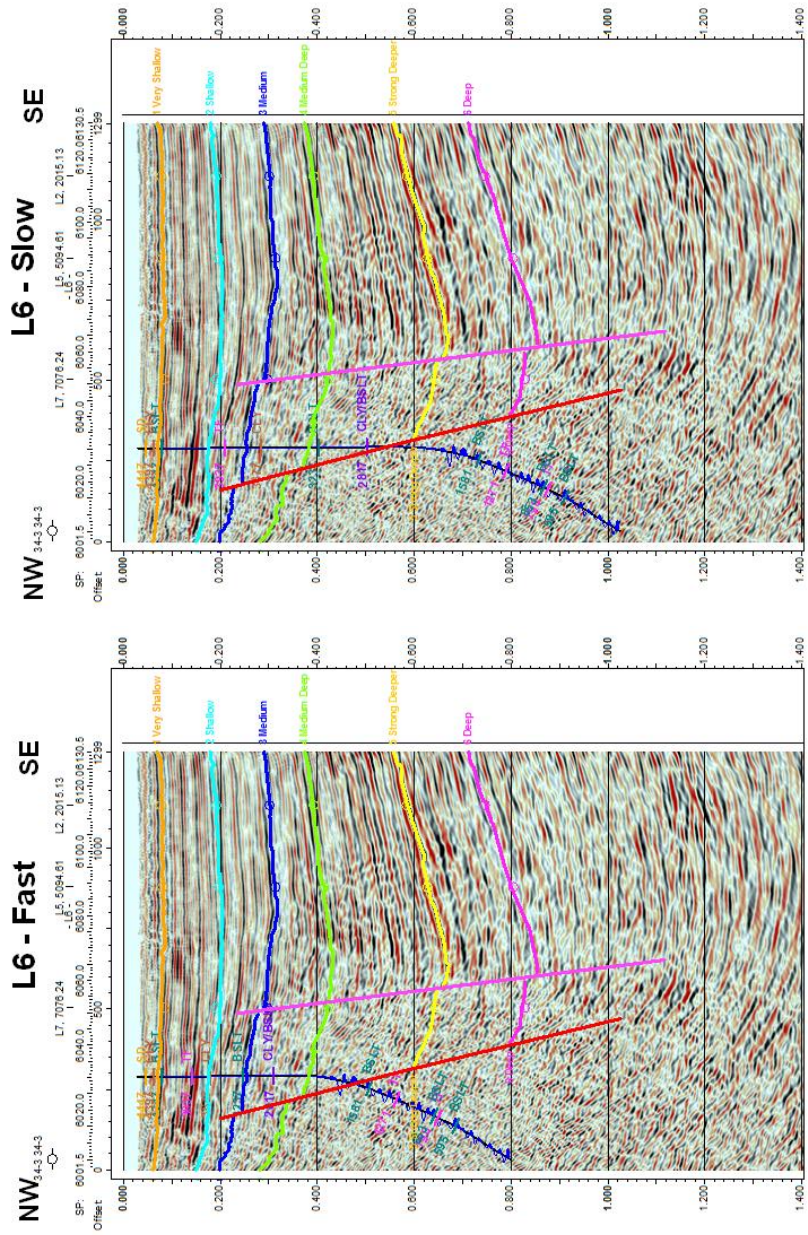

Figure 10. Fast and slow velocity model Synthetic Seismogram tie to Crump Geyser seismic line L6

Results and Interpretations

The seismic data are loaded into and were interpreted in a SMT/Kingdom seismic interpretation workstation. The two (2) velocity functions were used to depth convert both the seismic lines and the time structure maps. These were done using Kingdom processing features. This work resulted in two (2) versions of each seismic section and structure map. Figures 11-15 show the depth seismic sections for the fast or high velocity model. Until additional velocity information is collected, the high velocity model which assumes maximum well depths will be used.

Before the horizon picking was initiated, faults were interpreted on each of the seven seismic lines. Faults that could be correlated from line to line and that corresponded to the regional structural elements were utilized for structural mapping. These faults are shown in various colors. Observed faults that could not be readily correlated across the area (i.e., from line-to-line) are interpreted as black lines on the respective sections. Fault geometries and continuity were tested for each mapped fault using fault plane maps. Fault correlation will improve with future drilling results, and fault geometry calculations will also improve with better time to depth conversions following subsequent drilling. The red fault was definitely intersected by the 34-3 well, however, the well encountered multiple permeable fault zones, making it difficult to determine which correlates with the seismically defined red fault as shown in Figure 10.

After the faults were interpreted, six (6) seismic reflections from shallow to deep were interpreted. These horizons are identified with names based on increasing relative depth: Very Shallow (orange), Shallow (light blue), Medium (dark blue), Medium Deep (green), Strong Deeper (yellow) and Deep (pink). The two deepest events (Strong Deeper and Deep) have the strongest amplitudes, which may indicate a significant lithologic change. The Very Shallow event approximately coincides with the shallowest basalt occurrence in the 34-3 well. Future drilling leading to additional synthetic seismic modeling and better time to depth conversions will better define the specific lithologic changes that are represented by the seismic events.

Based on the velocity models, structure maps were made for each of these six horizons with fault polygons (dip directions indicated) along the interpreted fault traces. Two of these maps for the green horizon are shown in Figures 16 and 17. The green horizon was selected because it is the closest to the target depth for the proposed slim well. These two maps show two alternate interpretations for the faults based on the uncertainty of the seismic data. The first projects a northwest trending fault between seismic lines to account for apparent left-lateral fault offset between lines 3 and 6. The interpretation shown in Figure 16 requires significantly more lateral offset, while the interpretation shown in Figure 17 requires only a bend in the orange fault. Based on the other geophysical surveys, the Figure 17 interpretation is the preferred model with relatively small offset on the orange fault correlating well between both seismic lines. However, both maps are included to illustrate the relative uncertainty when using 2D seismic data and with limited drilling data.

Conclusions

The 2D seismic survey performed at Crump Geyser produced good seismic images to several thousand feet depth. The data are somewhat variable due to changes of surface conditions across the survey area, which can be expected on playa surfaces. However, the data quality is more than adequate to produce good stratigraphic and structural interpretations.

Faults are readily observed and have been mapped across the prospect area. Layering interpreted to be volcanic (basalt) was imaged and mapped at depth. Depth structure maps were produced on six seismic events. In order to improve time-to-depth conversions in the future, velocity data should be collected as additional wells are drilled on this prospect. In-situ velocity data obtained via acquisition of compensated sonic logs and/or check-shot surveys will be extremely helpful in evaluating the seismic results and refining the interpretations presented in this report for calibrated depth calculations (i.e., time-to-depth correlations and calculations not based on an average or assumed velocity function).

Properly designed 2D seismic surveys can be used to find and map faults in the prospect area. However, interpretation of faulting from 2D seismic data requires projection of faults from line to line, which is not always as accurate as desired between lines. 3D seismic surveying can be considered in order to accurately determine the positions of the faults across the area, and would be especially useful if basin stepping faults are found to be productive. The seismic interpretations provide additional evidence that multiple NNE faults bound the basin, and their intersections with NW faults provide likely targets for initial exploration drilling.

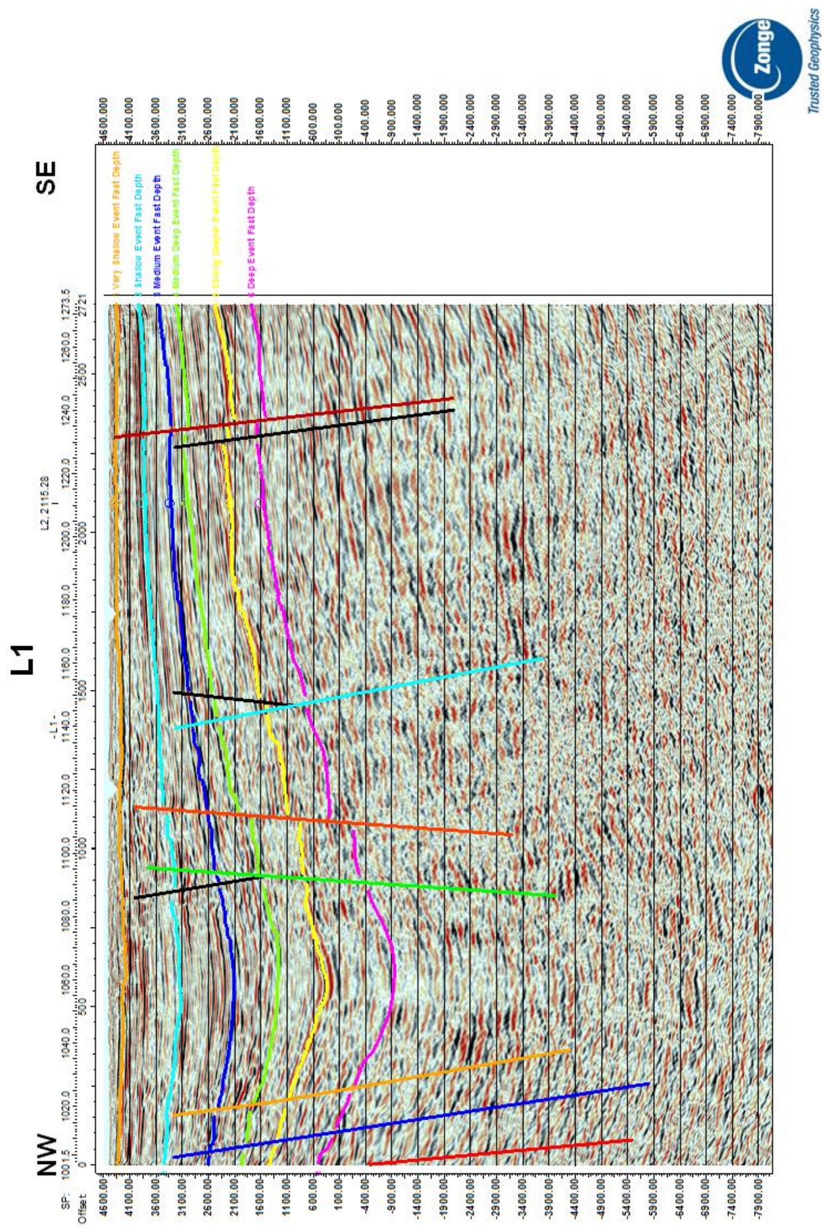

Figure 11. Interpreted fast model depth converted Crump Geyser seismic line L1

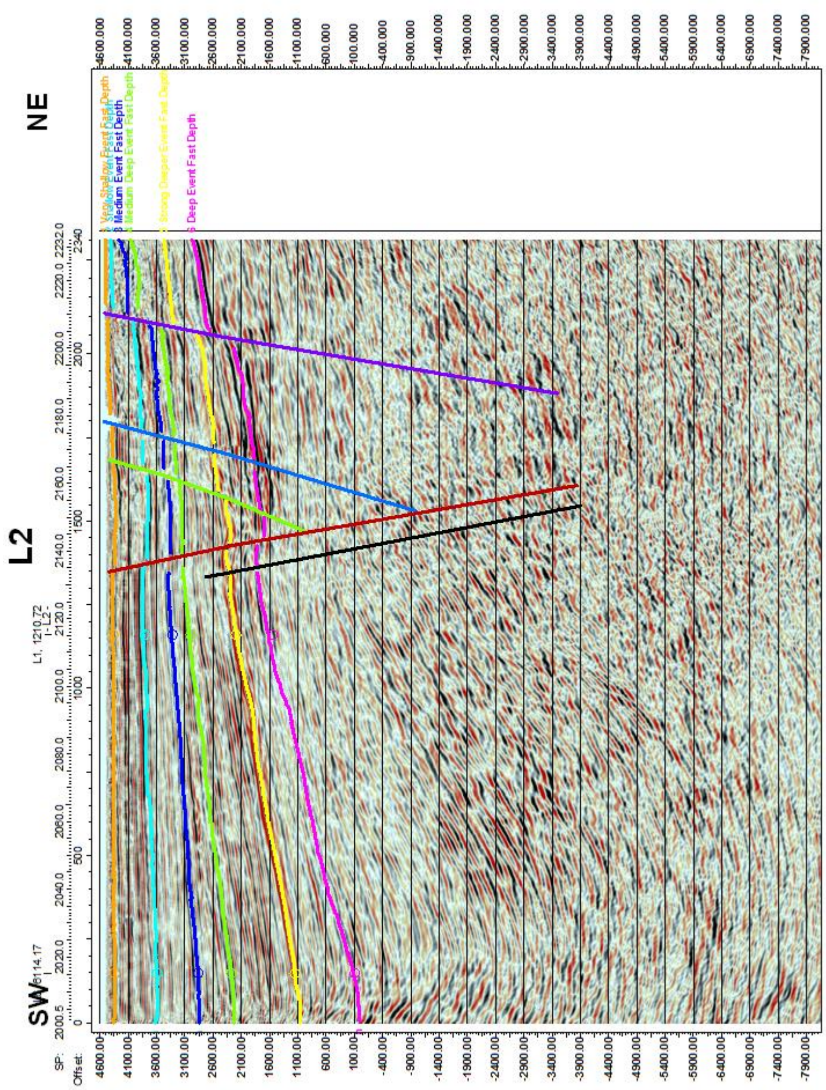

Figure 12. Interpreted fast model depth converted Crump Geyser seismic line L2

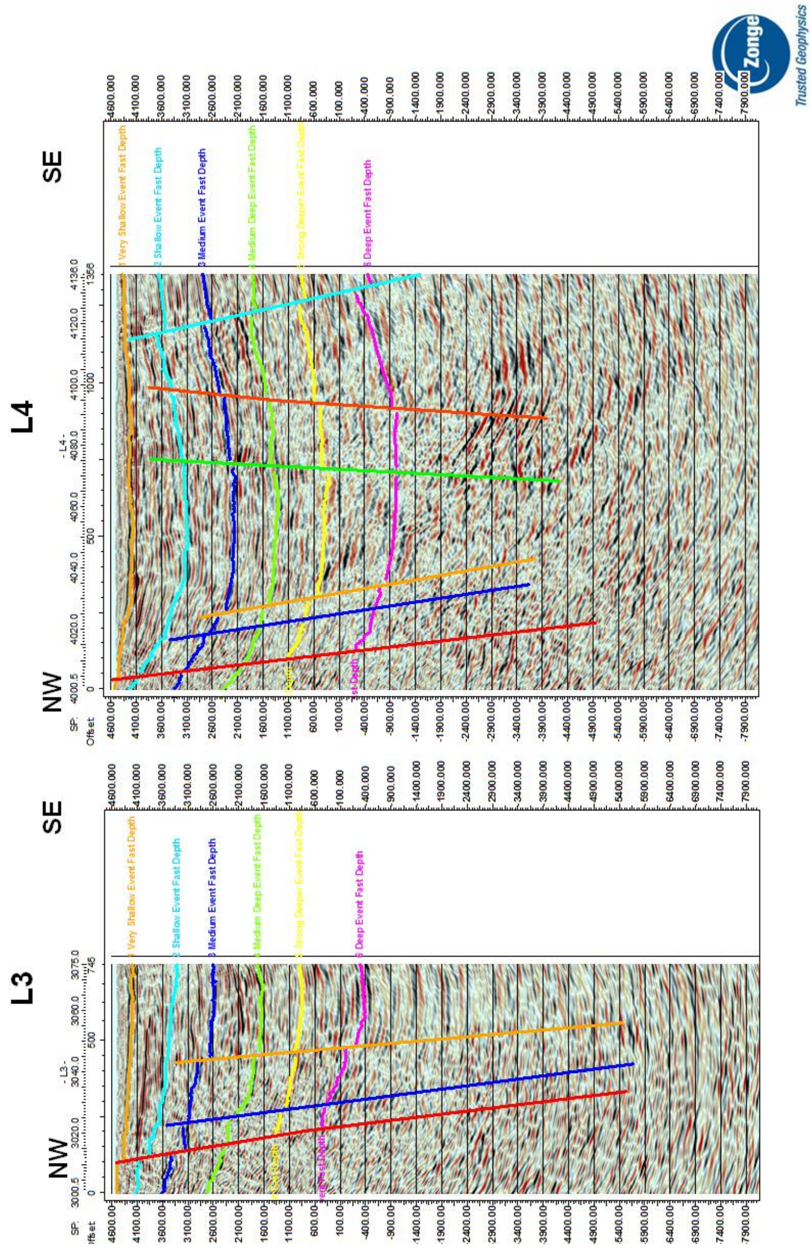

Figure 13. Interpreted fast model depth converted Crump Geyser seismic lines L3 and L4

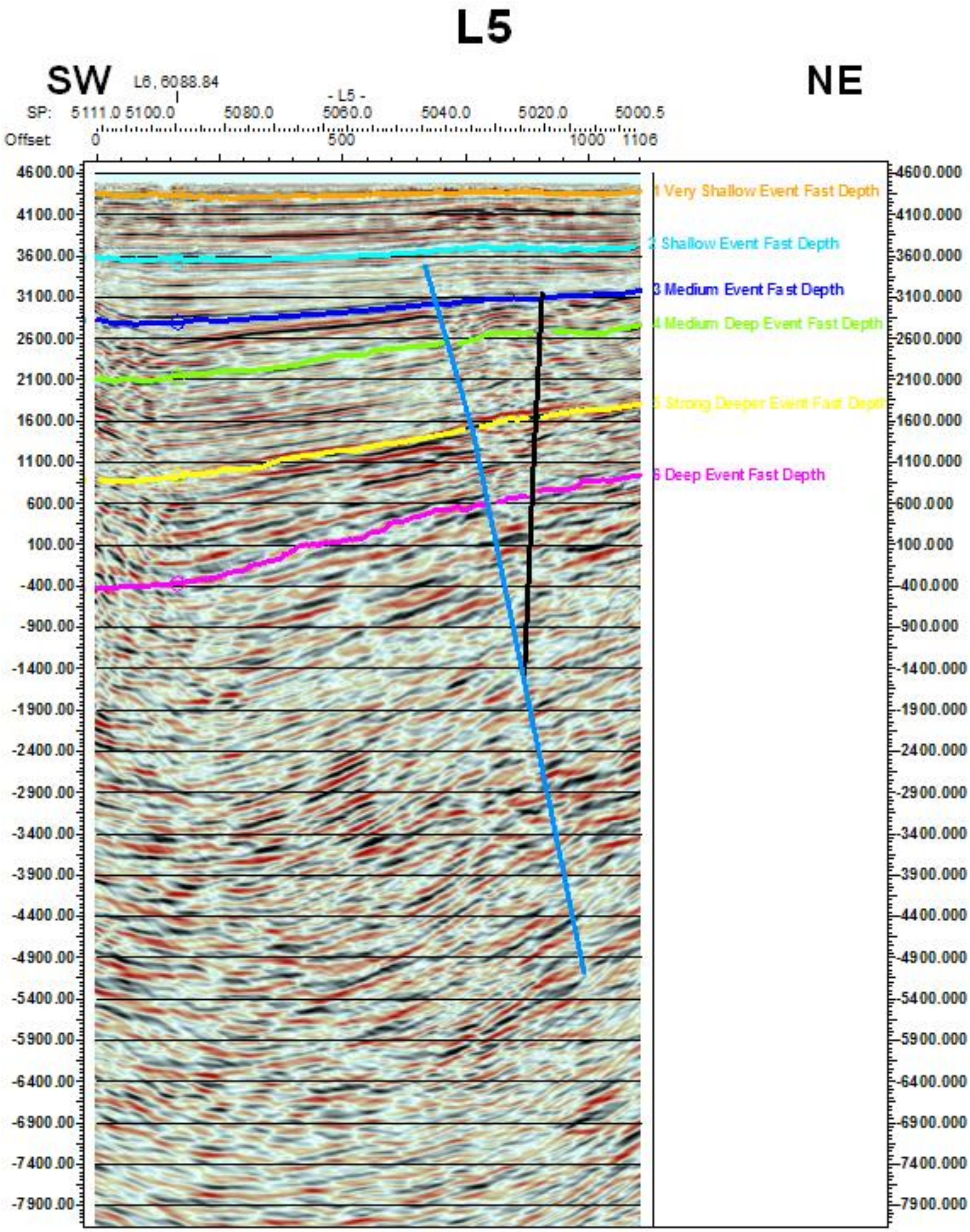

Figure 14. Interpreted fast model depth converted Crump Geyser seismic line L5

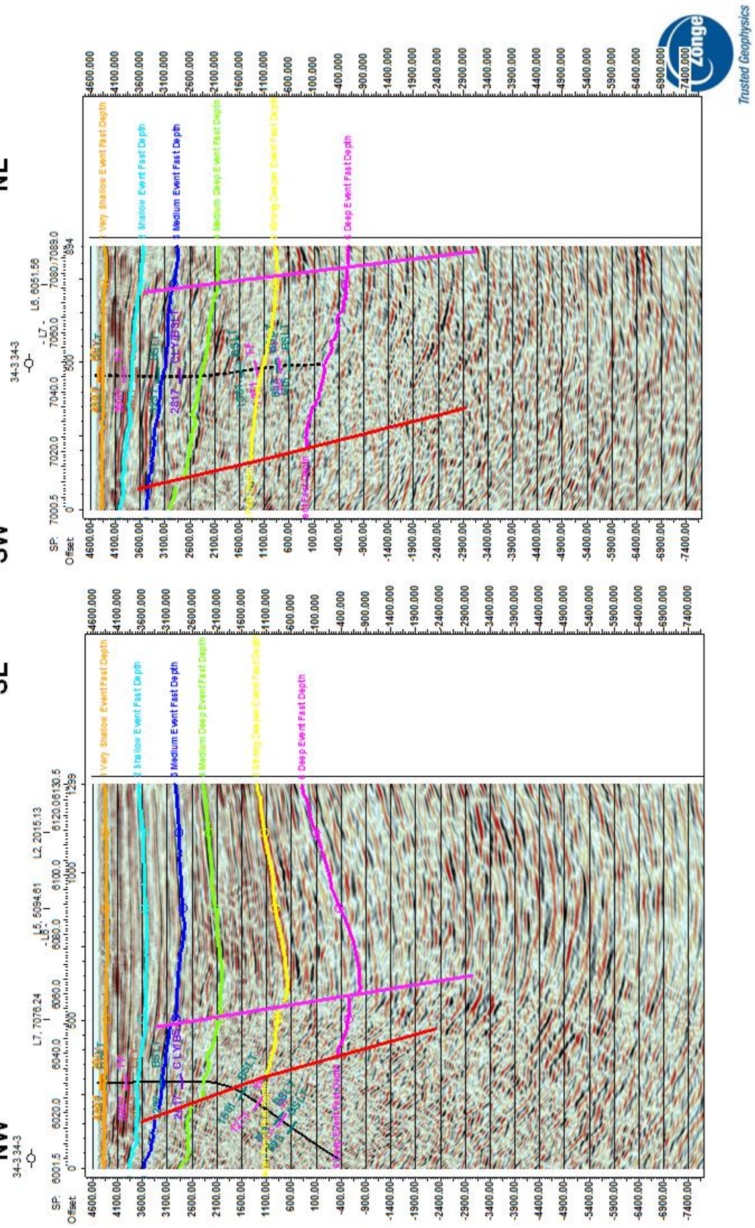

Figure 15. Interpreted fast model depth converted Crump Geyser seismic lines L6 and L7

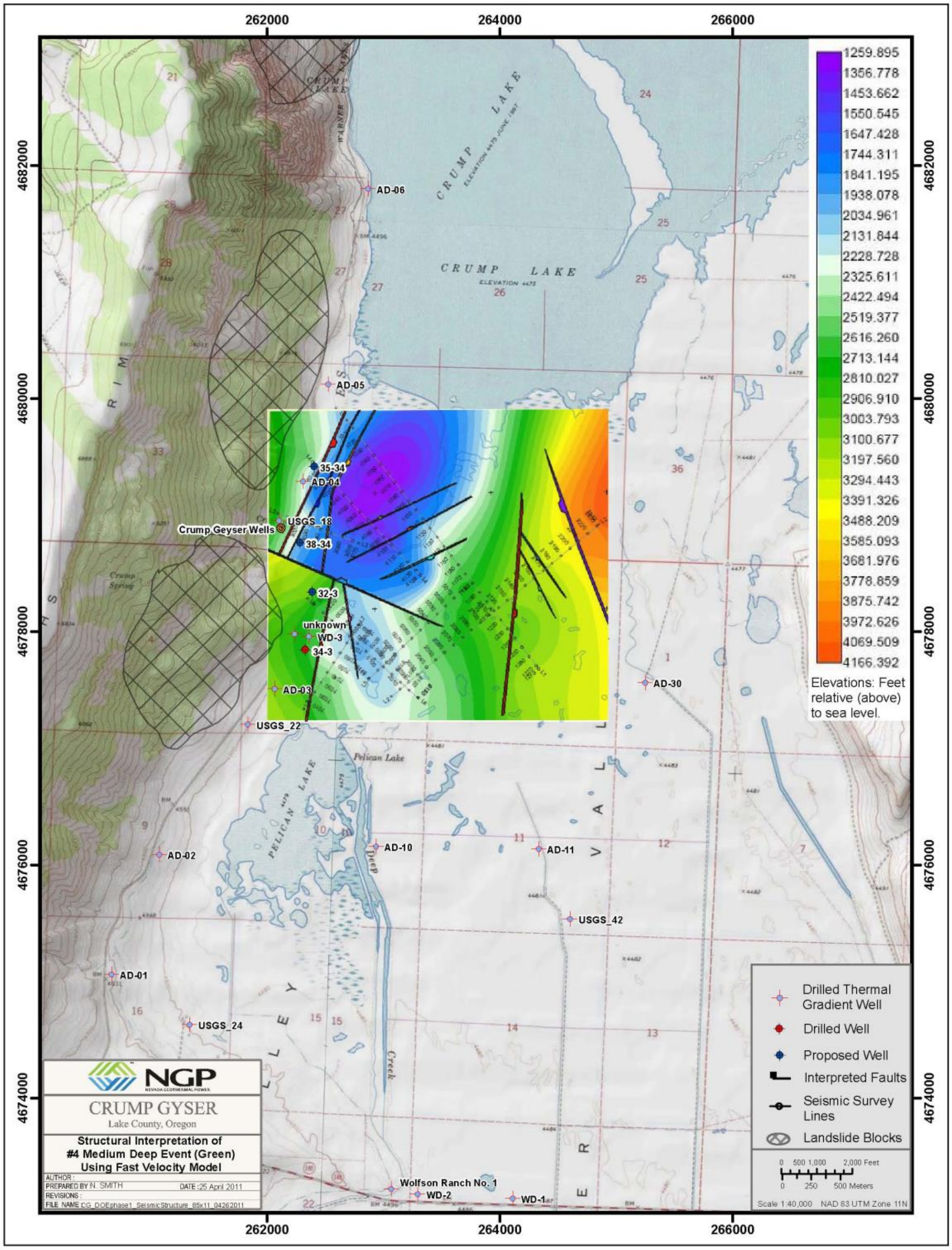

Figure 16. Structure map of Medium Deep event #4 (green) using fast velocity mod.

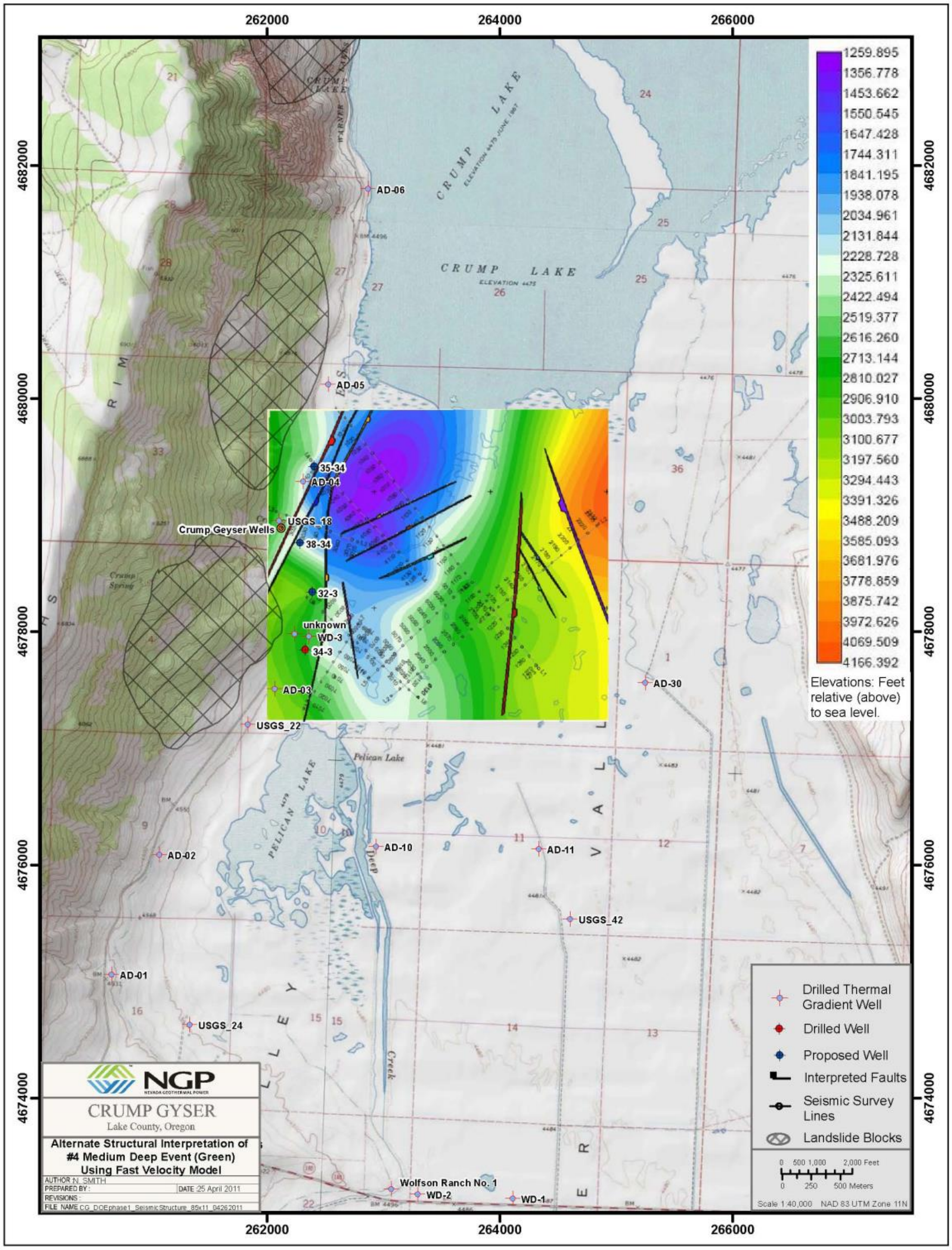

Figure 17. Alternate structure map of Medium Deep event #4 (green) using fast velocity

2.4 Resistivity Data

A 3-point schlumberger resistivity survey was completed in the vicinity of Crump Geyser by Premier Geophsyics in 2006 (Figure 18). A portion of the survey covered a broad area between the south end of Crump Lake and a mile south of the community of Adel, Oregon. The most important aspect to the results was the recognition of conductive anomaly nearly centered on and east of Crump Geyser. The low resistivity anomaly extends to approximately 1000 meters in depth, and covers approximately one square mile in areal extent. Because of the wide separation of survey points, the anomaly boundary is not well defined, but is clearly associated with the hottest springs, siliceous cinter and subsurface structures identified through the various geophysical surveys discussed previously.

The conductive anomaly coincides with an area between Crump and Pelican Lake interpreted to be a bedrock high cut by intersecting NNE and NW trending buried faults. The extremely high conductivity may be associated either with shallow warm fluid outflow in the near surface alteration, moderately deeper extensive clays or possibly hot geothermal fluids migrating upward in faults.

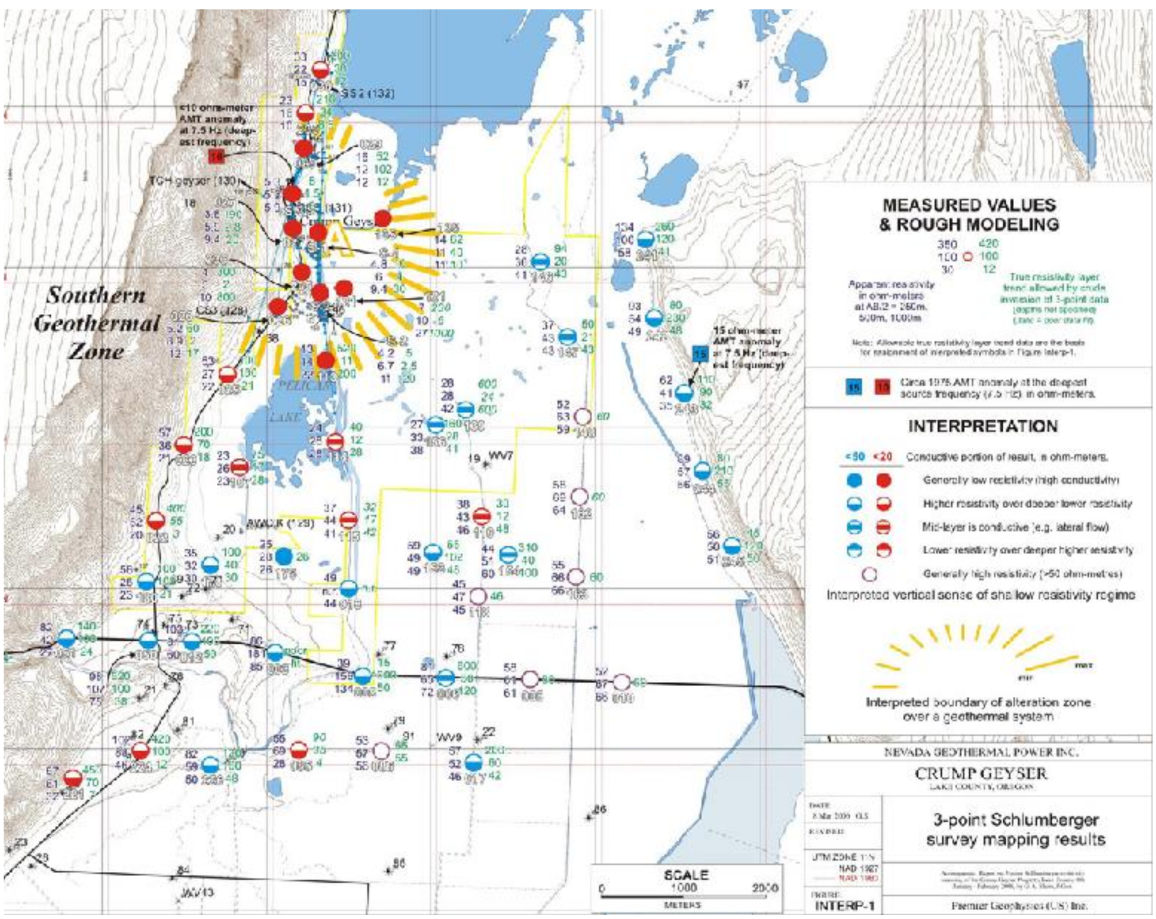

Figure 18. Map showing 3-point schlumberger survey results, highlighting the conductive anomaly near Crump Geyser.

2.5 Thermal Gradient Wells and Exploration Well 34-3

During Phase 1 exploration, the project team uncovered historic drilling records for temperature gradient wells throughout the prospect area. These wells were previously unknown, and their data combined with the drilled 34-3 well supersede the TG wells planned for this project. Figure 19 includes temperature contours at 500 foot depth, active hot/cold springs, wells drilled to this depth, and proposed core wells under DOE project funding. The highest measured temperature is reportedly in the geyser well, though high shallow temperatures were also encountered to the south of 34-3. Several of the wells have a shallow high temperature that rolls over with increasing depth, indicating an extensive zone of outflow along the range front and that may also follow a stratigraphic contact (Figure 20). This outflow zone and its mixing with cool ground water will skew results of any additional shallow drilling.

Exploration well 34-3 was drilled prior to the discovery of the TG data. The well targeted the range bounding Crump Fault to search for temperature and permeability. Figure 21 shows the temperature logs for this well. The temperature of the well was lower than anticipated with a high temperature, shallow depth rollover that did not recover until near bottom hole. However, the well did encounter significant permeability and will be considered for an injection well. The evidence for permeability includes mud losses and lost circulation while drilling, a Formation Microimaging log (FMI) indicating dense fracturing, and sustained 1000 gpm flow during nitrogen lifting. Three possible explanations for the observed 34-3 temperature survey include 1) upflow is farther to the north along the same structures encountered in the well, possibly in concert with 2) a northwest-trending transverse structure that acts as a fluid barrier, or 3) that basin-stepping faults provide upflow and this well was targeted too close to the range front.

Permeability in the 34-3 well was encountered primarily in areas of dense, high angle fracturing (e.g. Figure 22). The tracks on the right half of Figure 22 are interpretations of FMI logs and relate to fracture and bedding orientations. The highly fractured zone at 4150’ depth corresponds with an abrupt change in bedding dip (pink dots). This zone also corresponded with drilling breaks and lost fluid (Figure 22) as well as a change in temperature (Figure 21). This zone provided much of the permeability during the flow test, although others zones contributed (Figure 21). No spinner surveys are available to quantify how much flow each zone contributed. Also, at least two zones of lost circulation are behind casing. If this well is used for injection, these zones may be perforated to improve injectivity.

Water chemistry samples were collected during the 34-3 flow test. However, these samples have significant drilling mud signatures and are not representative, despite pumping more than 10 well volumes. Samples are not available from the previously drilled exploration wells.

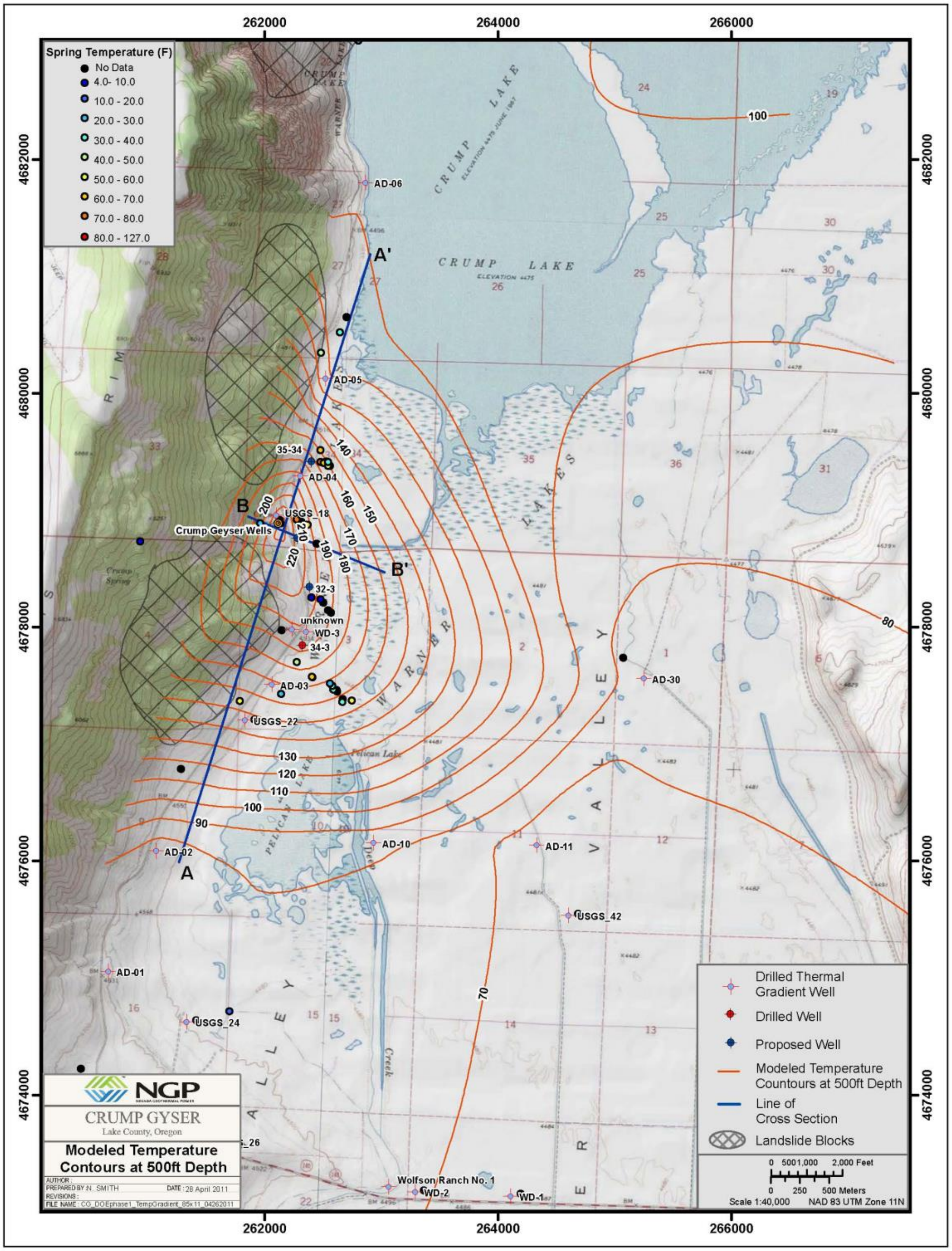

Figure 19. Map of 500 foot depth temperature contours, springs, existing wells and proposed core well locations.

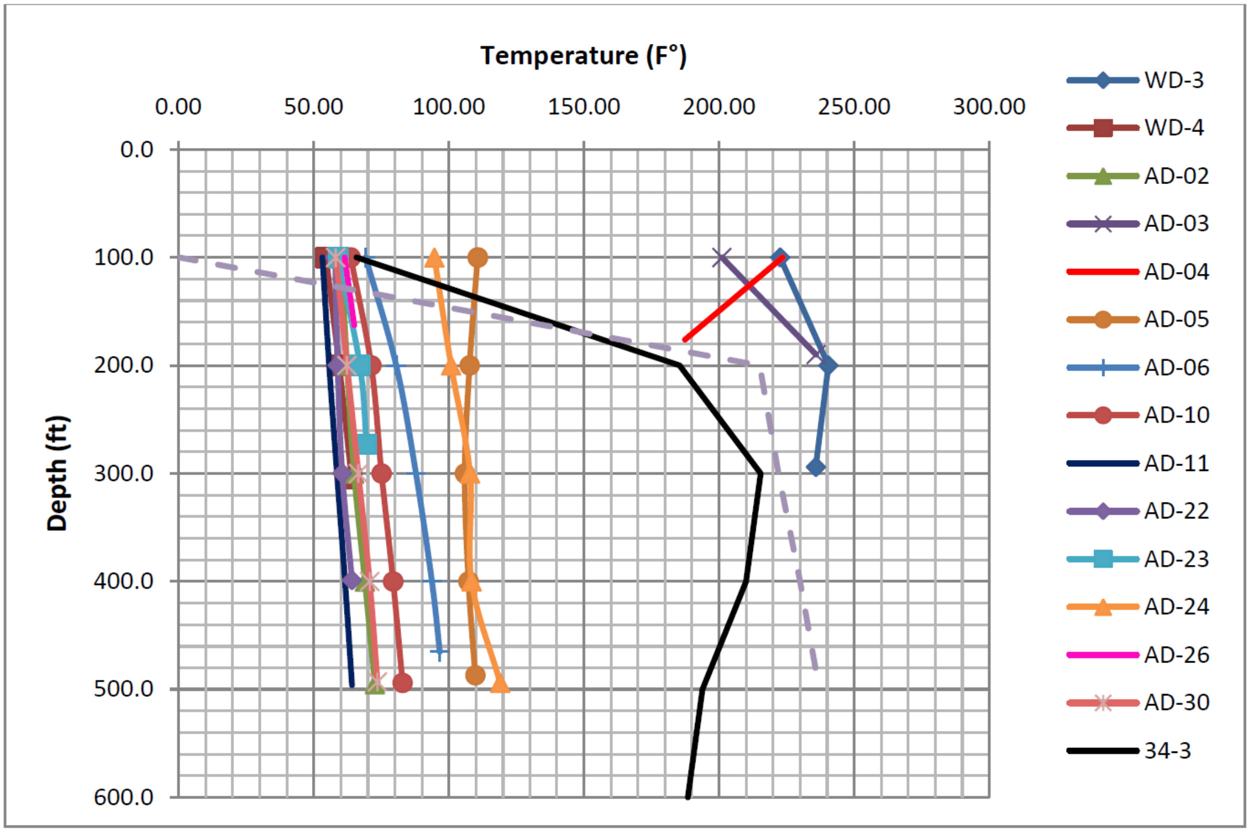

Figure 20. Temperature vs. depth plot for shallow wells surrounding Crump Geyser. Locations shown on maps throughout the text. Note that the geyser well is dashed because the data are sparse and uncertain (Peterson, 1959).

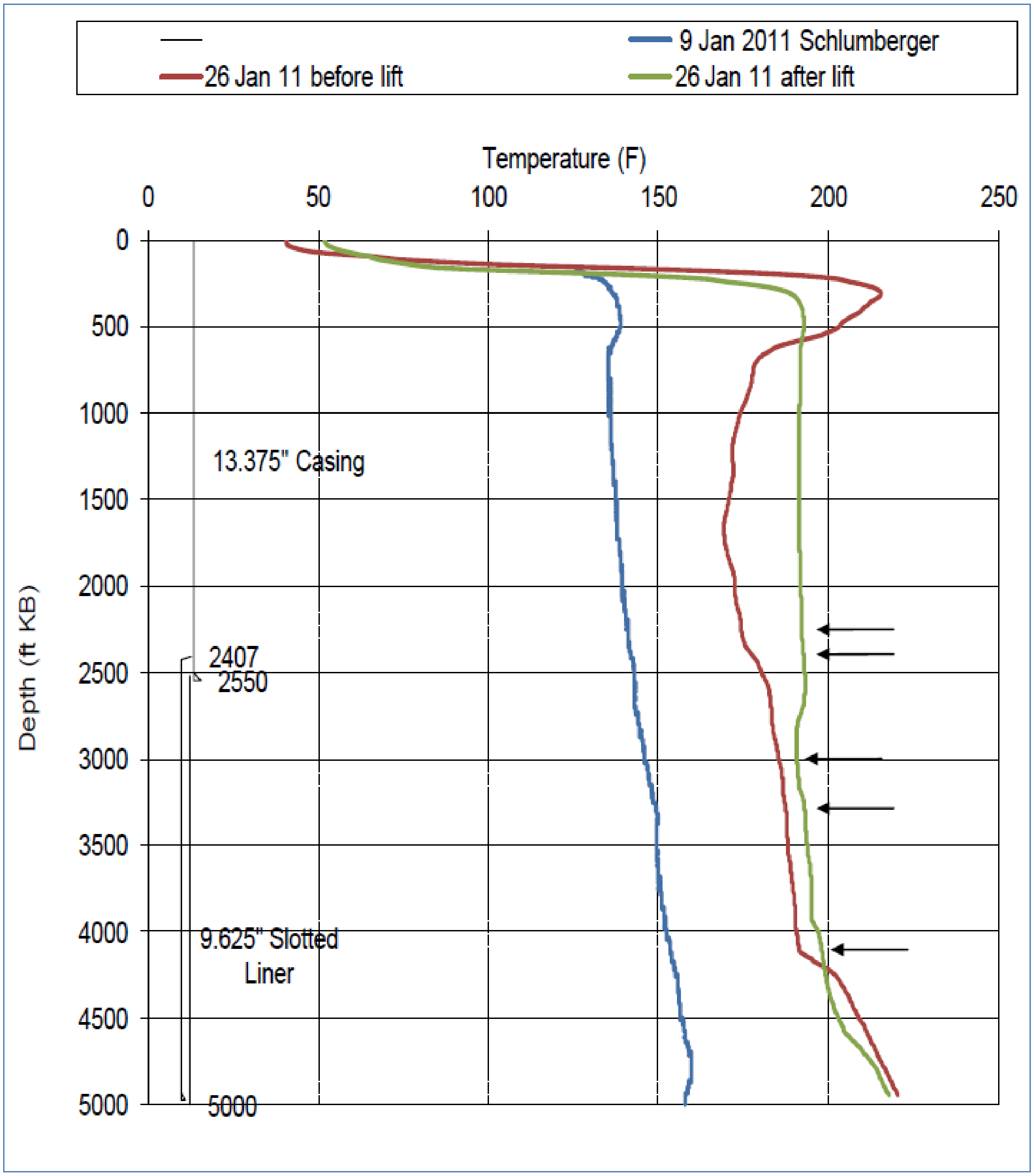

Figure 21. Well 34-3 temperature-depth curves. Arrows indicate permeable zones. The upper two zones behind casing were not tested.

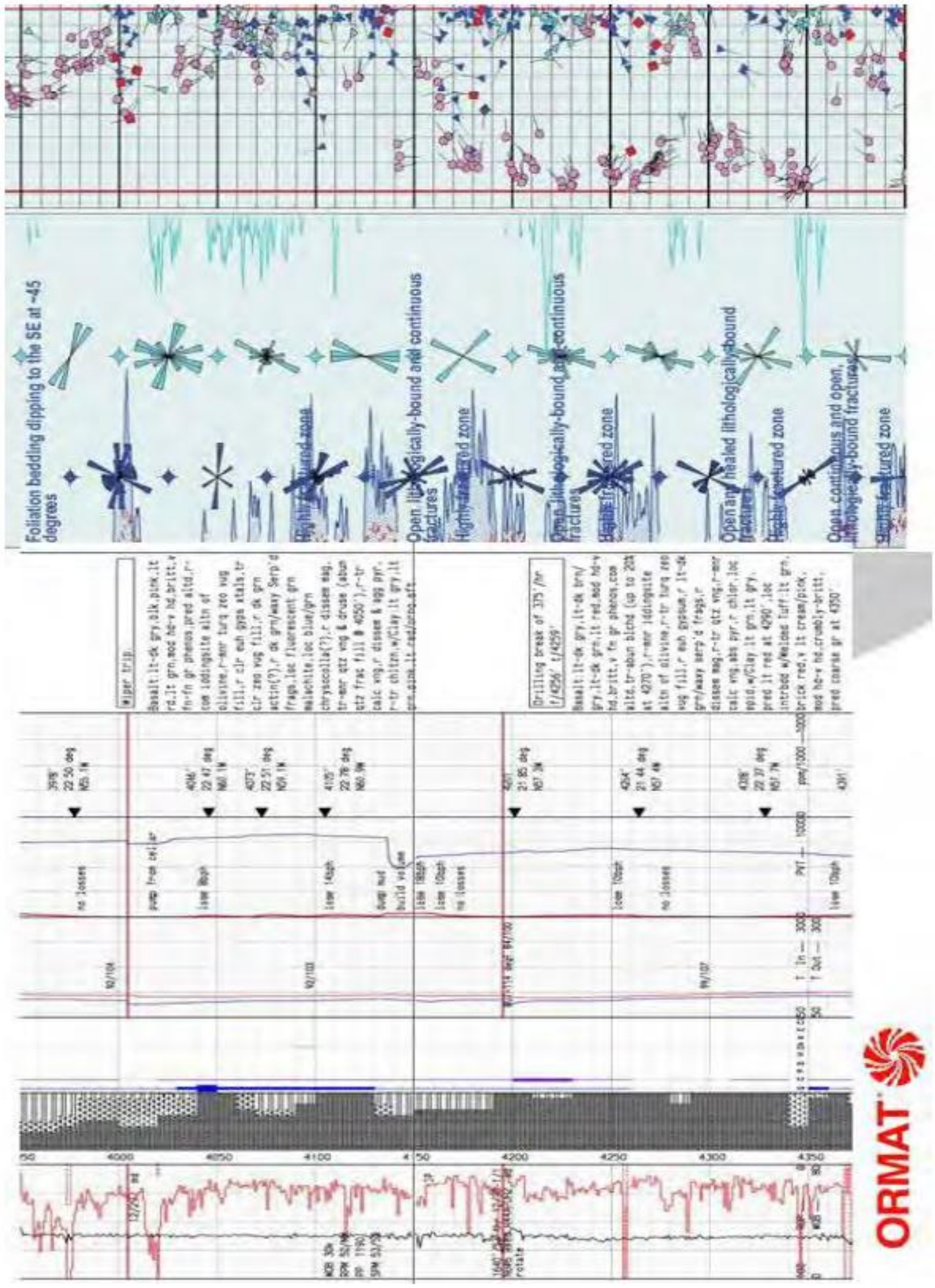

Figure 22. Sample section of 34-3log with drilling rate, lithology, mud temperatures, mud losses, deviation, lithologic description, fracture, and orientation logs. Pink dots on orientation log are bedding. Red and blue symbols are fracture orientations. Note the major change in structural dip at approximately 4100'.

3. Integrated Analysis of Results & Conceptual Resource Model

Interpretations of geological, geophysical, and drilling data have been combined in GIS databases and in a comprehensive 3D model using the Leapfrog Geothermal software package. Both models have enabled the team to rapidly view and adjust interpretations considering all datasets simultaneously. The orientation of fractures in the seismic data along with those measured by FMI in the 34-3 well have been incorporated to predict likely permeable fracture locations and orientations at depth. These fracture orientations have been used to guide 3D contouring of known temperatures (Figure 25 and Figure 26).

The existing datasets have identified that the general vicinity of the Crump Geyser area is highly faulted, and those faults appear to be well defined. The potential is high for many of the faults or fault intersections within the network to be productive, hence, the next logical step is to better define the moderate depth temperature distribution along the range front, which will provide valuable insight as to which faults or sets of faults are the primary fluid upflow conduits. The proposed drilling targets are designed to test for permeability and elevated temperatures along the range front at moderate depths (~2500') to complement the interpretation of shallow TG results and the location of surface hot springs. In addition, downhole fluid samples will be collected for water chemistry analyses.

Figure 23 and Figure 24 illustrate the same interpretations but are overlain on horizontal gravity and aeromagnetic data, respectively. There is particularly good agreement at the range front, and the northwest trending fractures correlate well between several interpretations. A large fault, the highest downhole temperatures, and all of the known hot springs occur at the range front, leading Ormat to conclude that drilling an intermediate-depth well here is the next logical step. Three dimensional temperature contours as shown in Figure 25 and Figure 26 are necessarily ambiguous because only one deep well exists. The current interpretation is that fluids preferentially migrate along the range front fault in the shallow section, as illustrated by the highest closed contours in both figures. Upflow is thought to be north of the 34-3 well and moving up the range front fault. The 3D contours agree with this interpretation. There may also be a thin stratigraphically-controlled outflow zone around 300 foot depth, but data are not distributed sufficiently to fully model this feature. Because this shallow outflow is not of commercial temperature and is probably variably mixed with shallow ground water, the project manager does not think drilling additional shallow wells will be valuable. The shallow outflow will be better defined as a byproduct of drilling deeper exploration wells. The highest value to finding a commercial resource will be the 3D temperature structure provided by drilling intermediate depth (~2500 feet) wells.

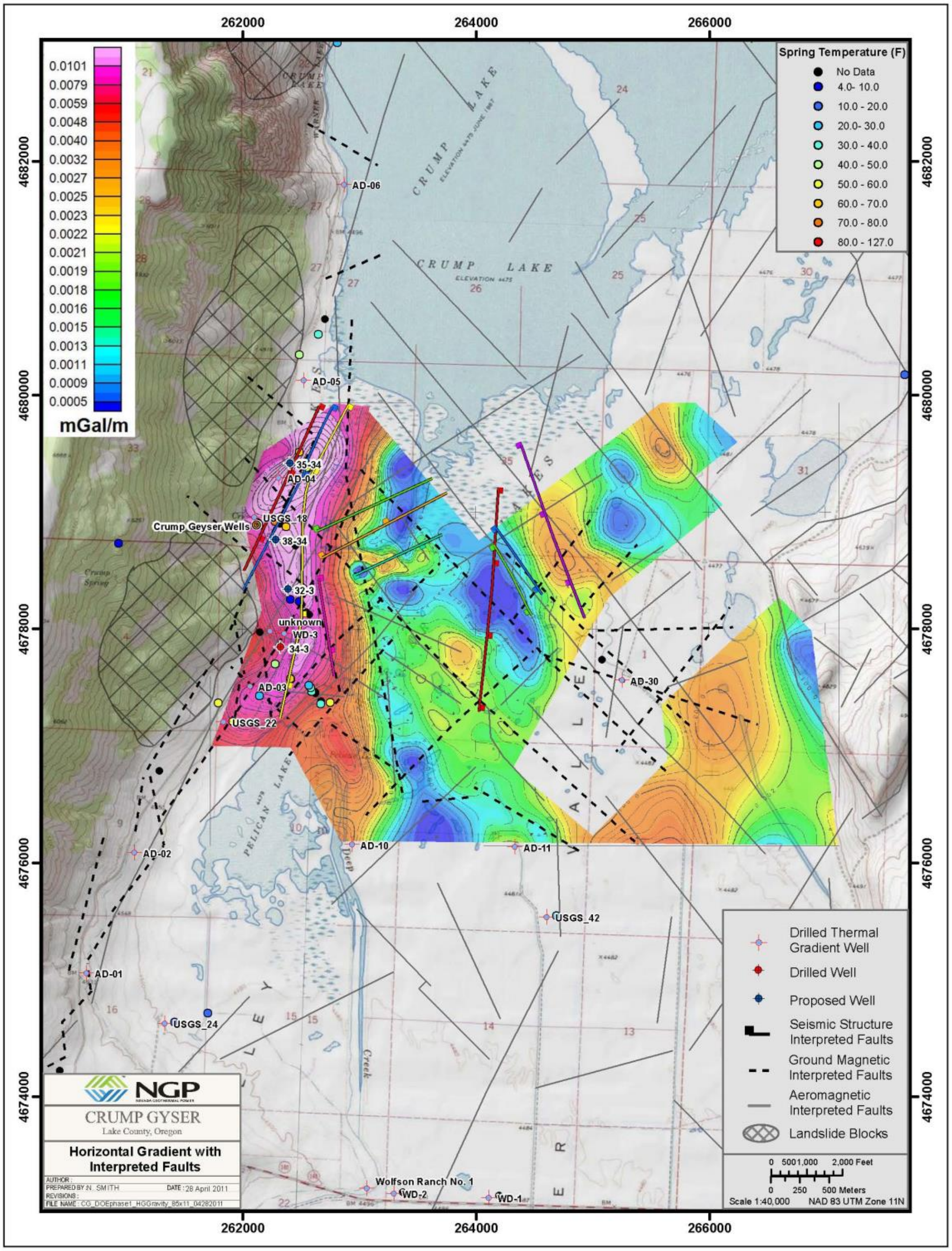

Figure 23. Map of multi-dataset interpretation overlain on horizontal gradient magnitude of the Complete Bouger Anomaly.

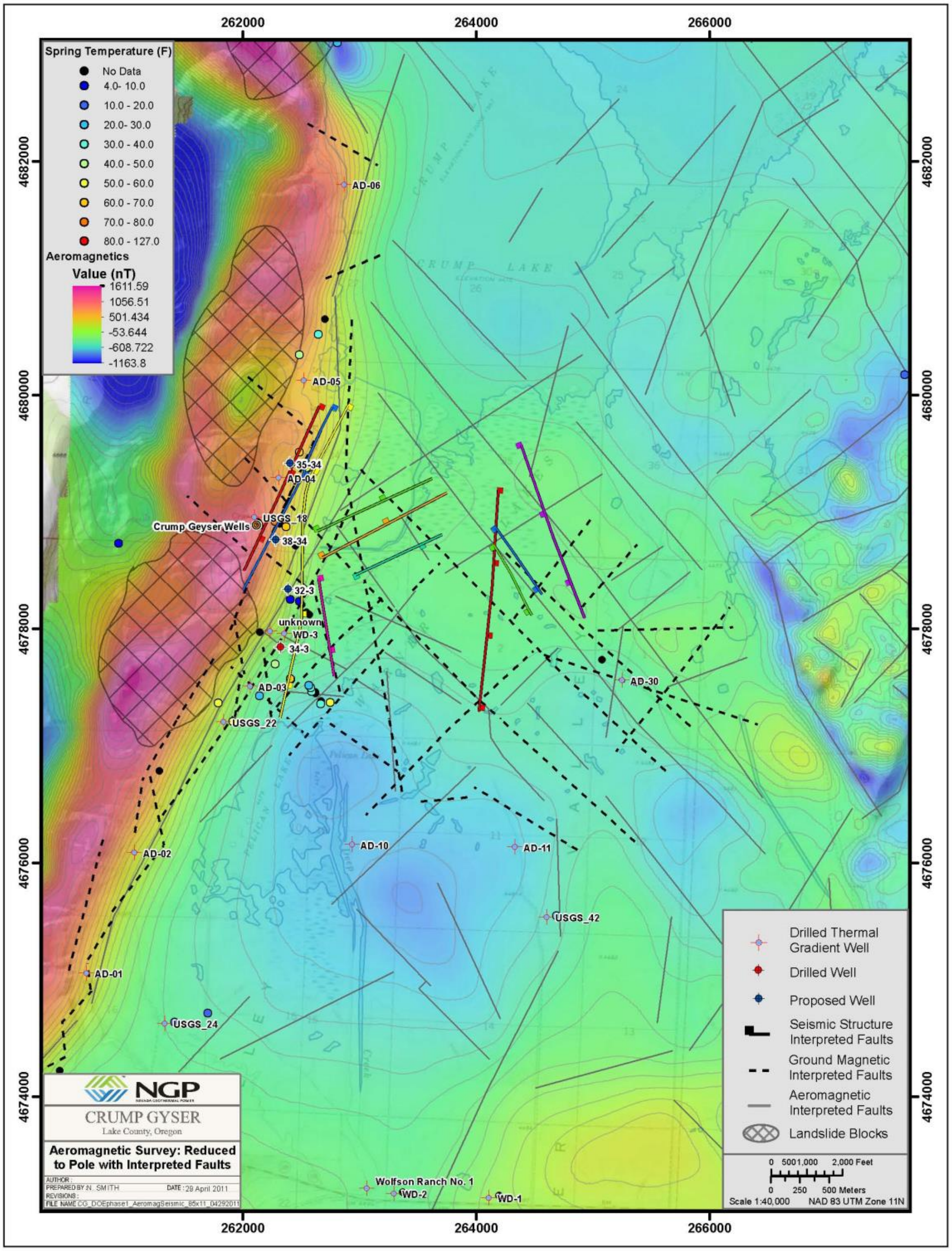

Figure 24. Map of multi-dataset interpretation overlain on color contours of aeromagnetic data, reduced to pole.

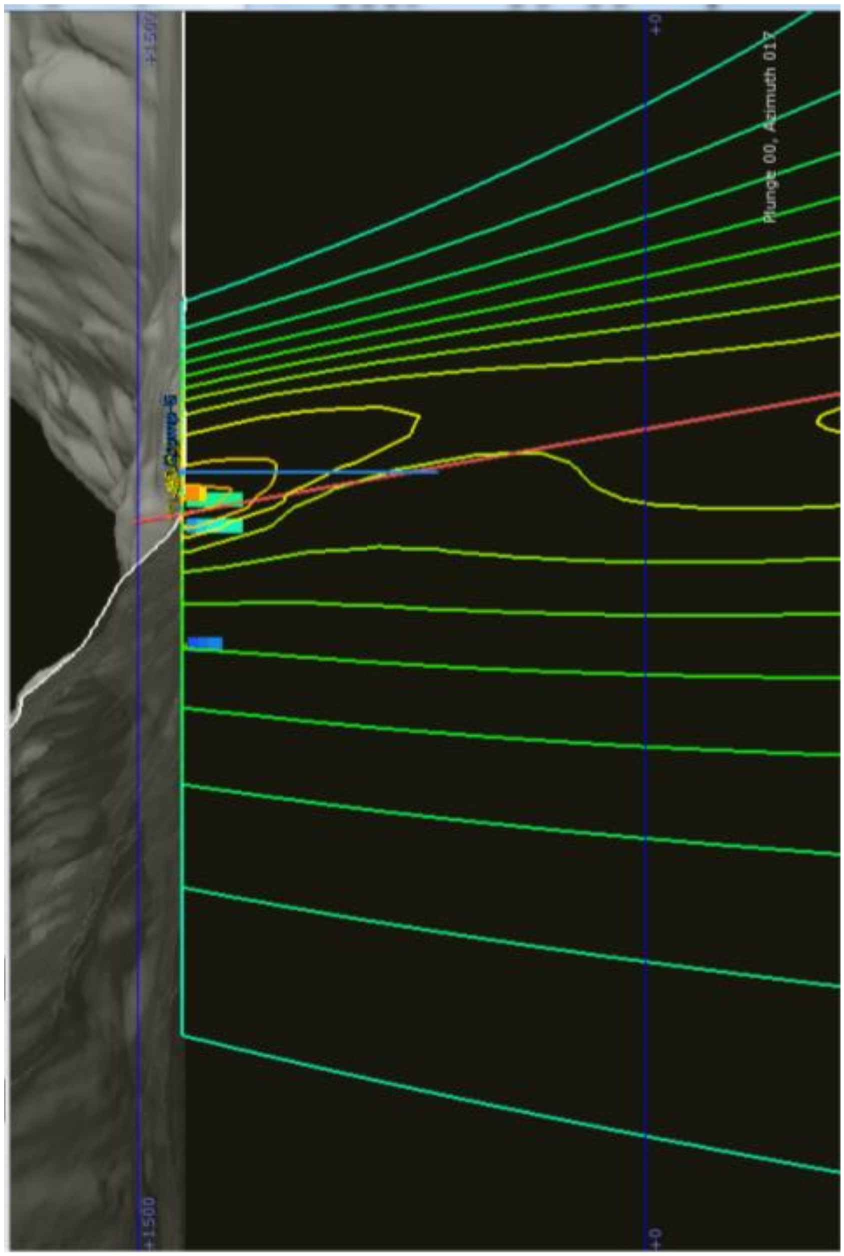

Figure 25. Section view of 3D model looking NNE parallel to interpreted fracture system (red). Contours are from 100 F (blue) to 200 F (orange) in 10 F increments. Planned 38-34 well is in blue. No vertical exaggeration. Elevations in meters relative to sea level. Location B-B' on Figure 19.

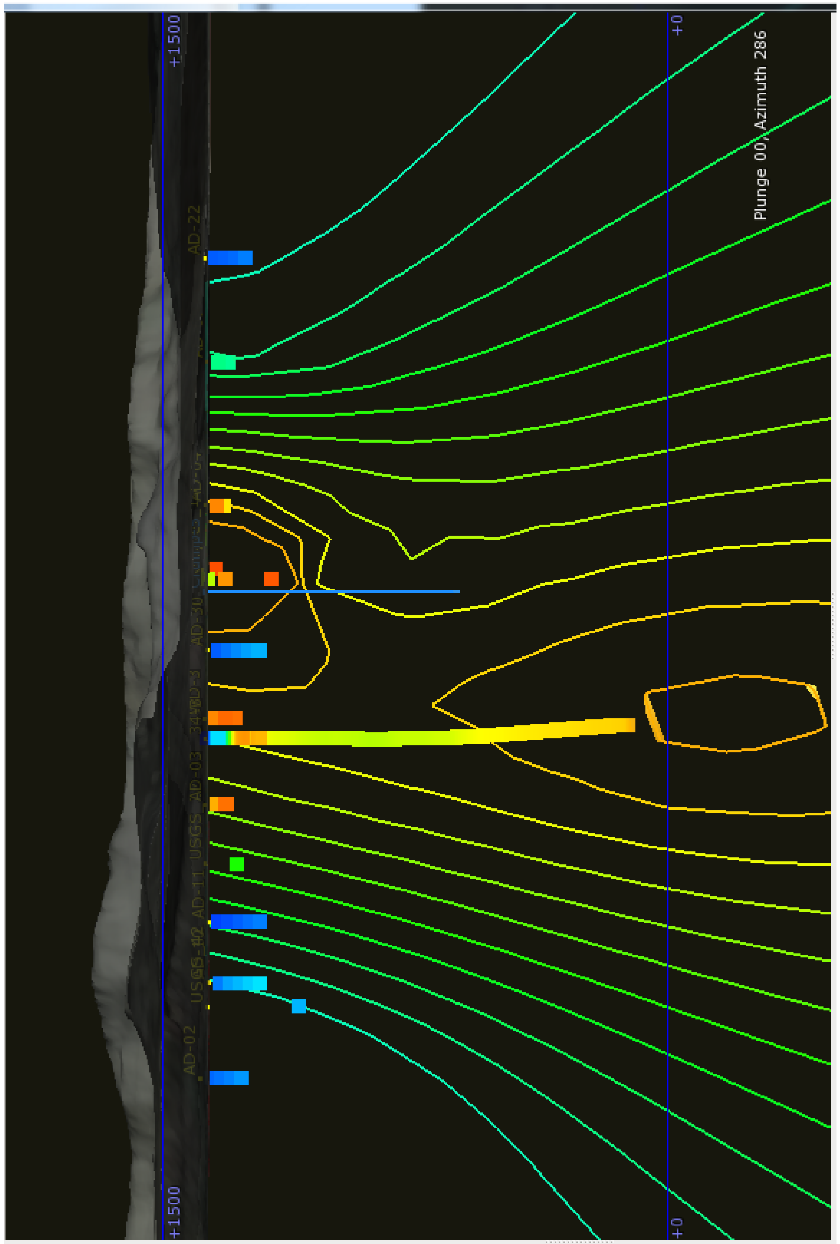

Figure 26. Section view looking WNW perpendicular to fracture system with contours on fracture plane. Contours are from 100 F (blue) to 200 F (orange) in 10 F increments. Planned 38-34 well is in blue. Thick colored lines are wells for control. The deep well is the recently drilled 34-3. The temperatures below the planned 38-34 are unknown, but this area has the highest shallow temperature. No vertical exaggeration. Elevations in meters relative to sea level. Location A-A' on Figure 19.

4. Drilling History

Ormat and Nevada Geothermal Power have drilled three exploration wells at Crump Geyser (Figure 27). The wells targeted the range-front fault on the east flank of the Warner Mountains. Well 34-3 was a full size well and encountered a shallow outflow zone, reaching 245 °F at 350’ before rolling over. The core well 38-34 was drilled ~3000’ to the north of 34-3 and again encountered a shallow outflow zone, reaching 250 °F at 370’ before rolling over and gradually building to 260 °F at 3050’. 35-34 was targeted an additional 2000’ north of 38-34 with the goal of stepping beyond the zone of shallow out-flow rollovers seen in the previous wells.

35-34 was the slim-hole drilled under subtask 6.1 of the DOE award. More information about the drilling program and results of this week are detailed through the rest of Section 4.

A program of shallow direct-push holes was completed concurrent with drilling 35-34, to collect shallow temperature data and evaluate whether a basin-stepping structure east of the main range-front may be channeling geothermal fluids. 10 holes were pushed to an average of 90’ depth before encountering an impermeable natural barrier. The temperature data for these holes show that the hottest shallow temperatures are confined to the range front (Figure 28). Direct-push sites 10, 19, and 16 are markedly hotter than the rest and are the three closest holes to the range front, suggesting that there is not a hot shallow system in the basin-stepping structure, or it is being masked by impervious lacustrine sediments and the shallow, cool fresh water aquifer in areas away from the range front.

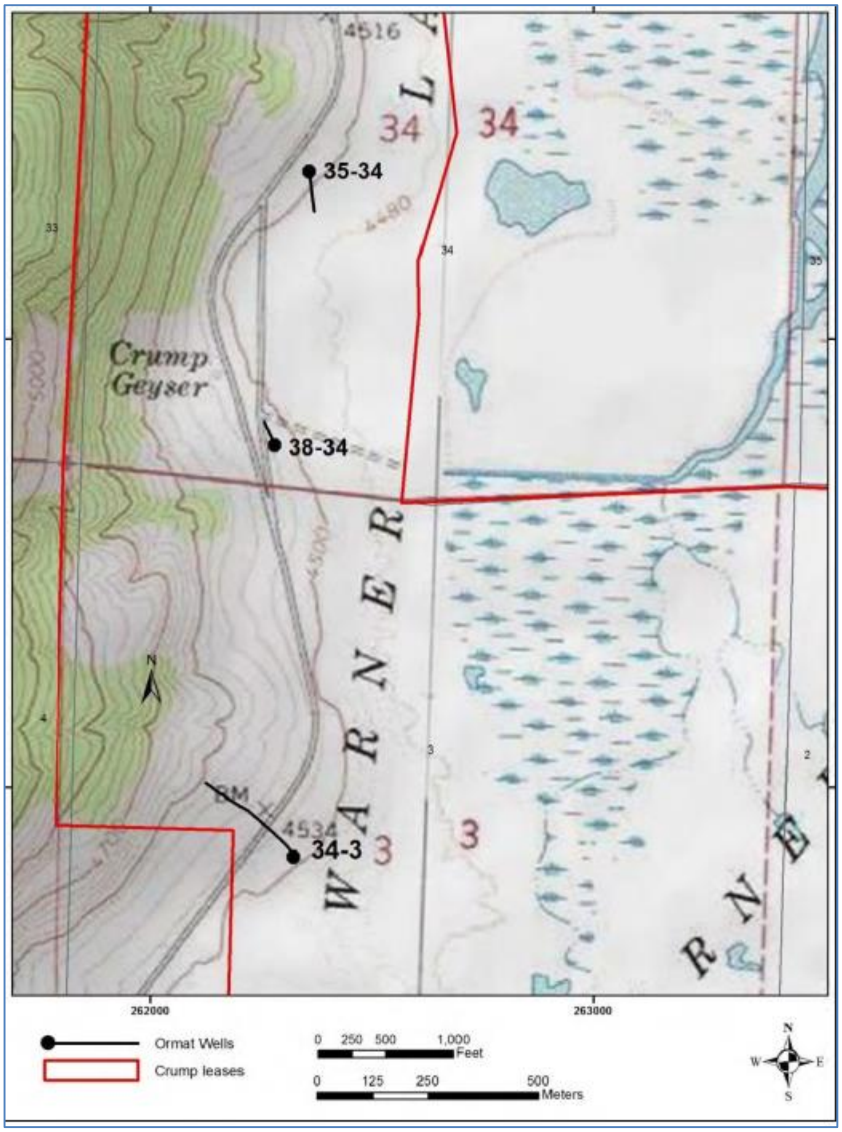

Figure 27. Crump Geyser Well Locations

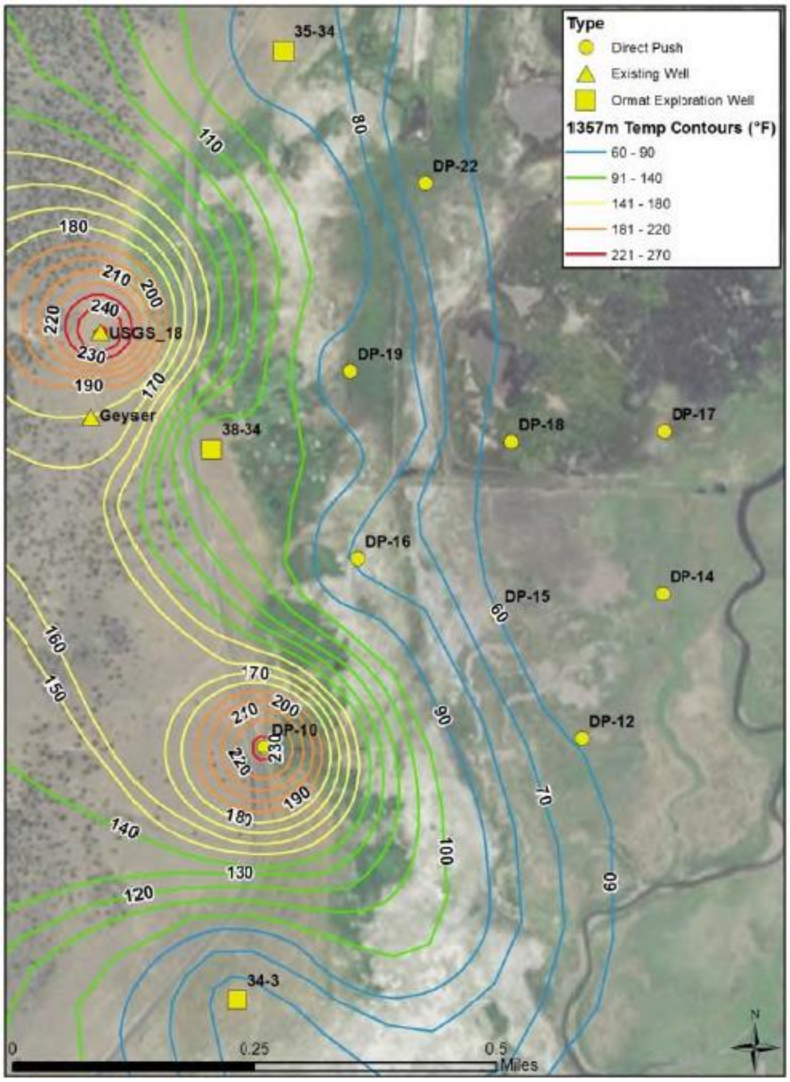

Figure 28. Map of direct-push wells showing temperature contours at 40 ft. depth below the valley floor (1357 meters above sea level).

4.1 34-34 Well Completion

The well was conducted on a 100ft by 100ft pad, using sumpless configuration. It required 33 days to drill the well. The 4-1/2-in cemented casing to 305ft took 2 days. The well was corded. HQ from 307 to TD, 3400ft, in 31 days.

The 35-34 well completion consisted of:

- 4-1/2 surface casing cemented from surface to 305 ft KB
- 2 3/8 J55 VFJ surface tubing from surface to 3395 ft KB
  - Blank 0-2861 ft
  - Slotted 2862-3395 (Slotted 0.25*2.5-IN, 12/ft)

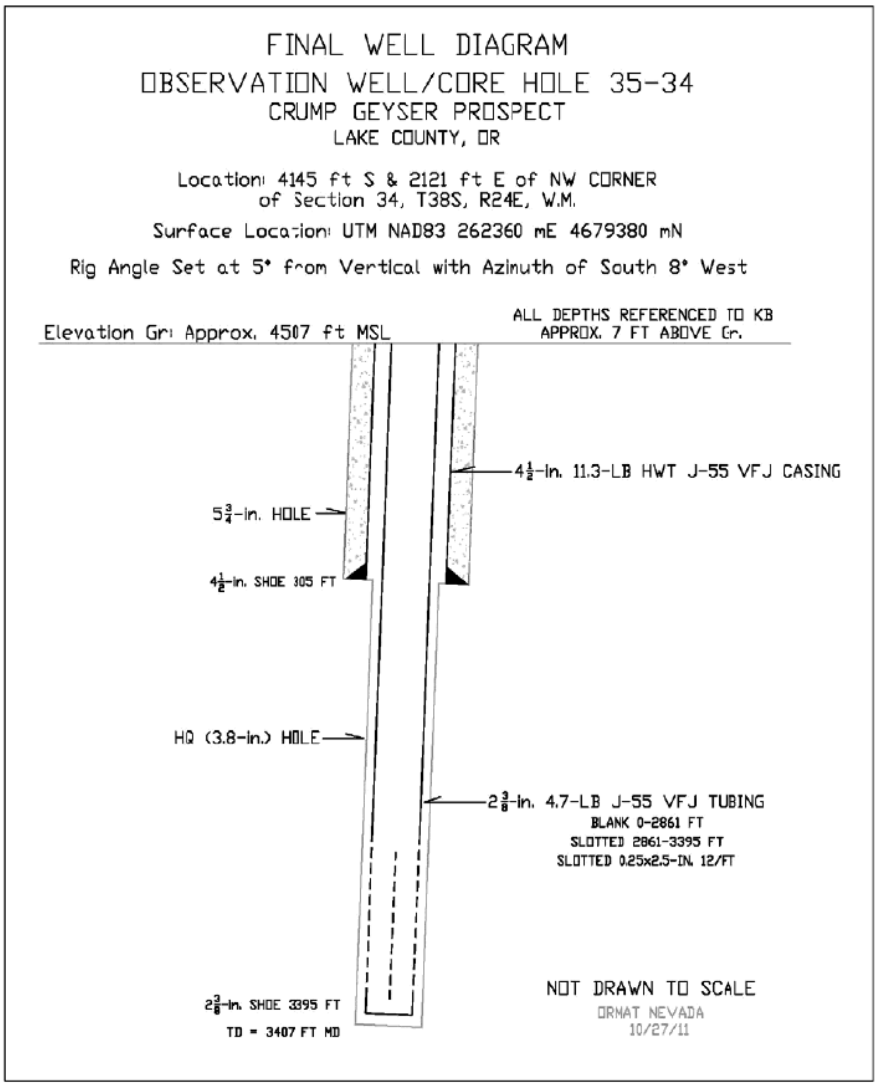

Figure 29. 35-34 Well Diagram

4.2 Sumpless Drilling

The 35-34 drilling program utilized sumpless drilling. All drilling mud and cuttings were contained in a series of lined troughs, with no discharge to the ground surface or bodies of water. At the conclusion of drilling, the remaining solids (non-toxic drilling fluids and cuttings) were disposed of according to Oregon Department of Environmental Quality (DEQ) regulations by hauling to a DEQ-permitted landfill following appropriate analytical testing.

4.3 Temperature Profiles

Core hole 35-34 encountered a conductive thermal gradient without experiencing the significant rollovers seen in the other wells (Figure 30). The well only experienced a small 1°F roll-over and isothermal zone from 200-400 feet before quickly returning to a steady build-up of temperature. The conductive gradient continues to TD, reaching a bottom-hole temperature of 265°F at 3400 feet, whereas large diameter well 34-3 encountered a shallow outflow zone, reaching 245°F at 350 feet before rolling over sharply Temperature gradients retruned to positive at around 1600 feet, increasing from 170°F to 220F at 4760 feet. 38-34 reached 250°F at 370 feet before rolling over and gradually building to 260°F at 3050'.

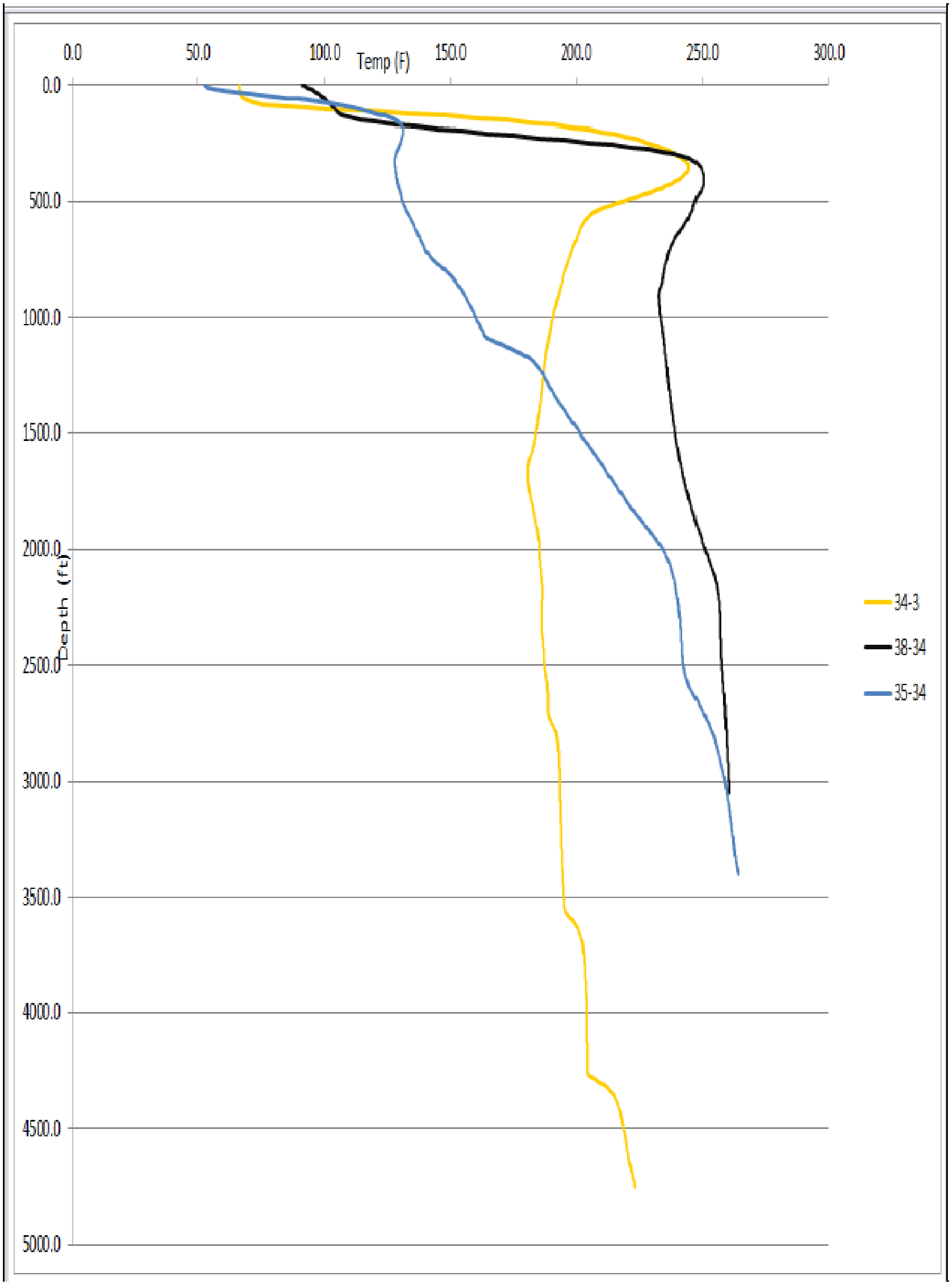

Figure 30. Temperature Profile of Crump Geyser Wells

4.4 Lithology

The lithologies encountered by 35-34 were similar to the previous wells and consisted entirely of volcanics. Alternating units of basalt, andesite, tuffs and pyroclastic debris flows occur throughout the well. The most significant fracture occurred from 2900 – 2905'and had an undulating near vertical orientation. This fracture was open and lined with clear to white needle like micro crystals of selenite and the well began lightly flowing upon encountering the fracture. Another significant fracture was at 3362' this fracture was open and lined with euhedral gypsum & calcite and cut the core at an angle of around 64°.

4.5 Image Log Structural Analysis

Upon completion of 35-34 before casing was set, an acoustic image log was collected by Tiger Energy Services for structural analysis. The analysis of the bottom half of the log (2800-3400') has been completed by Schlumberger and the fractures identified within the wellbore are quite numerous. In addition variation in dip azimuth among the fractures is very high, however the most common orientation for continuous fracturing is NW-SE, dipping to the NE (Figure 31). The large fracture seen in the core at 2905' trends in a near E-W orientation perpendicular to the range front, with a dip azimuth of 346° and virtually vertical dip of 89.6°. The second significant fracture at 3362' has an attitude that very closely matches the trend of the range front with a dip azimuth of 96° and a dip of 63.9° (Figure 32). When this fracture is projected south to core well 38-34, it intersects very close (within 12 meters) to where the major fracture was seen in 38-34 at a depth of 3000'. Unfortunately we do not have an image log from 38-34 and the core through this portion of the well was not properly oriented in the field, so the orientation of this fracture is unknown.

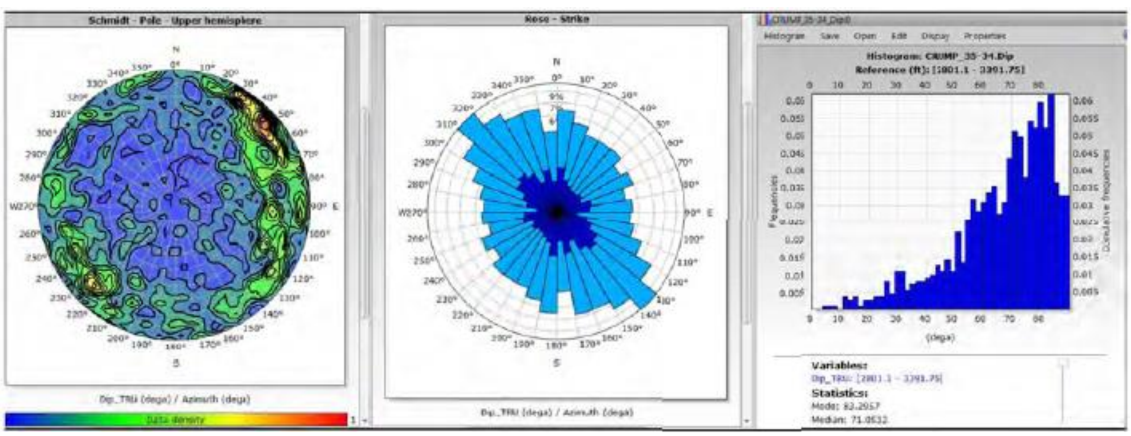

Figure 31. Histograms plotting the distribution of fracture orientations and dips identified. Histograms plotting the distribution of fracture orientations and dips identified in the 35-34 image log from 2800'-3491'. From left to right, the first plot shows the distribution of fracture dip azimuths, followed by the distribution of fracture strikes, and lastly the distribution of dip angles.

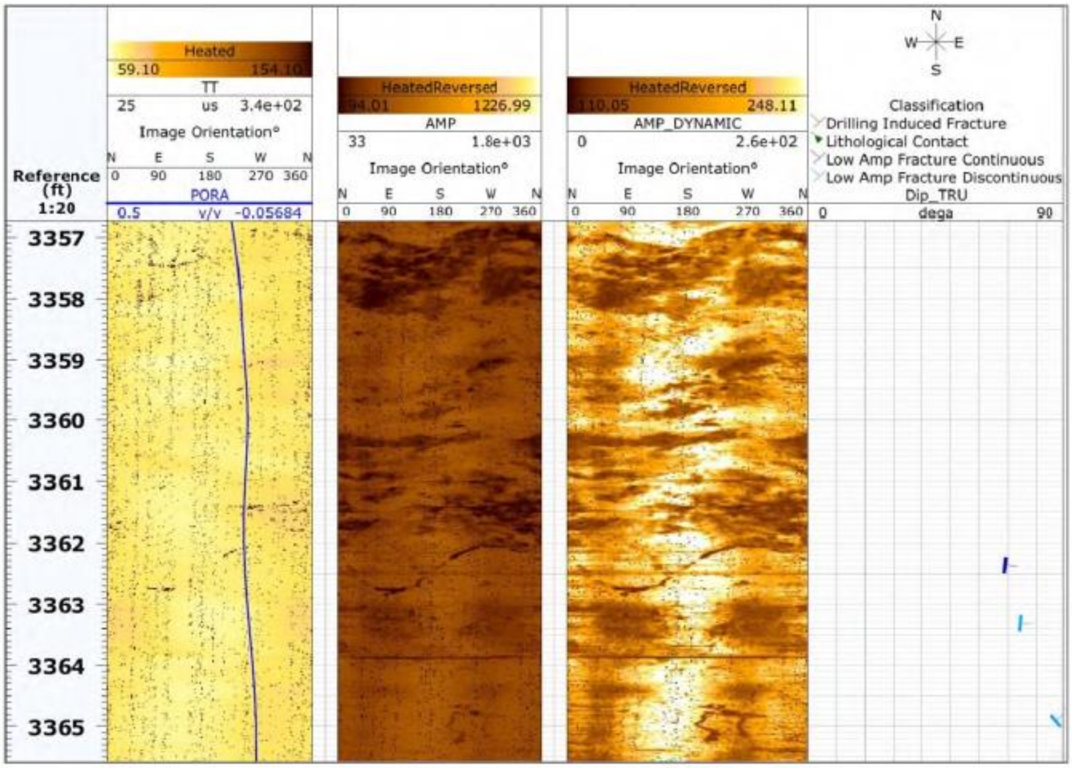

Figure 32. Screenshot of the 35-34 Acoustic Image log showing the continuous fracture at 3362'.

4.6 Injection Test Results

Injection tests were performed on two Crump core holes on April 19, 2012. Injectivity was 0.05 gpm/psi for 35-34, and permeability-thickness was 0.14 indicating low injectivity and permeability. Water was injected in 35-34 for one hour. Injection rate at the end of the test was 1 gpm and wellhead pressure was 66 psig.

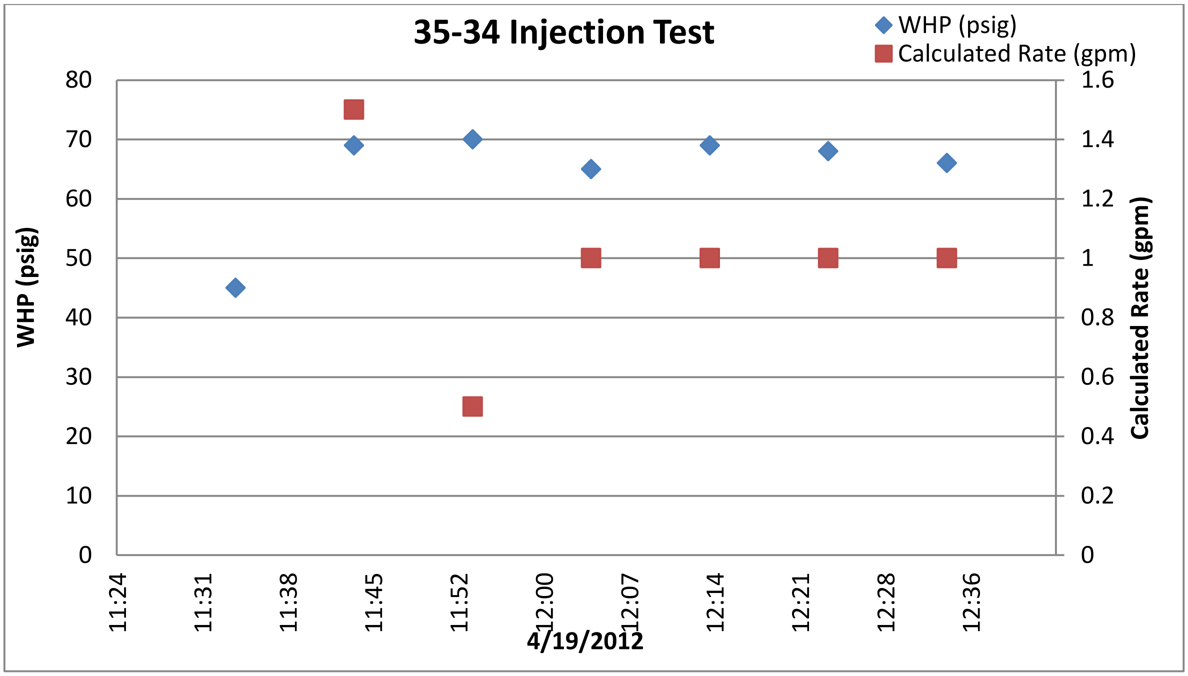

Figure 33. Well 35-34 Injection Test Results

Pressure falloff was recorded at 2903 feet during injection and for one hour after injection was shut off.

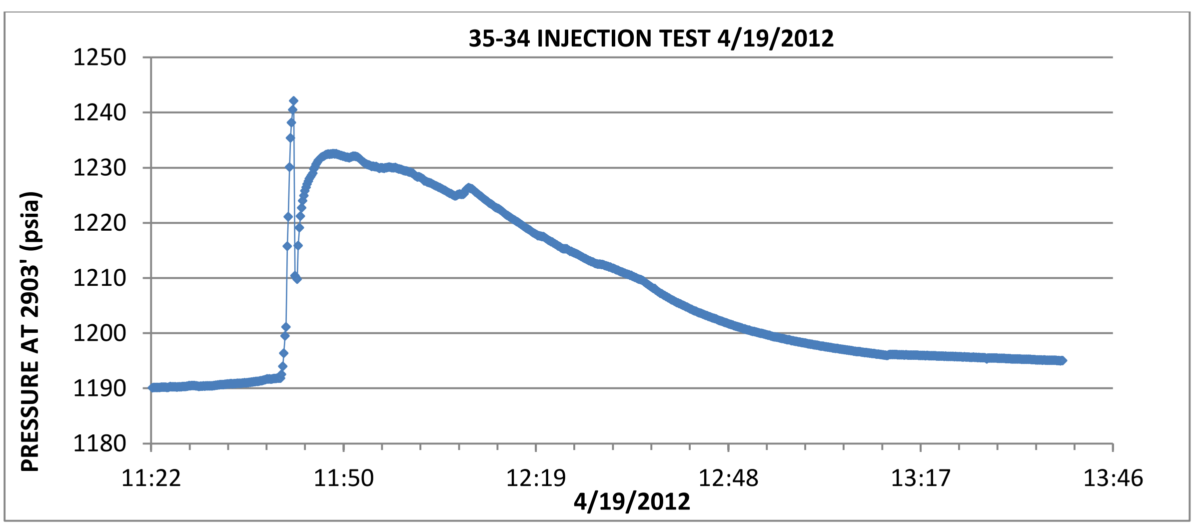

Figure 34. Well 35-34 Injection Test Results

Pressure transient analysis was performed using Roland Horn's computer aided analysis technique. Calculated permeability thickness is 0.14 d-ft with -1.3 skin. Pressure at 2903 feet was 1190 psia before injection and 1210 psia with 1 gpm of injection so injectivity was 0.05 gpm/psi.

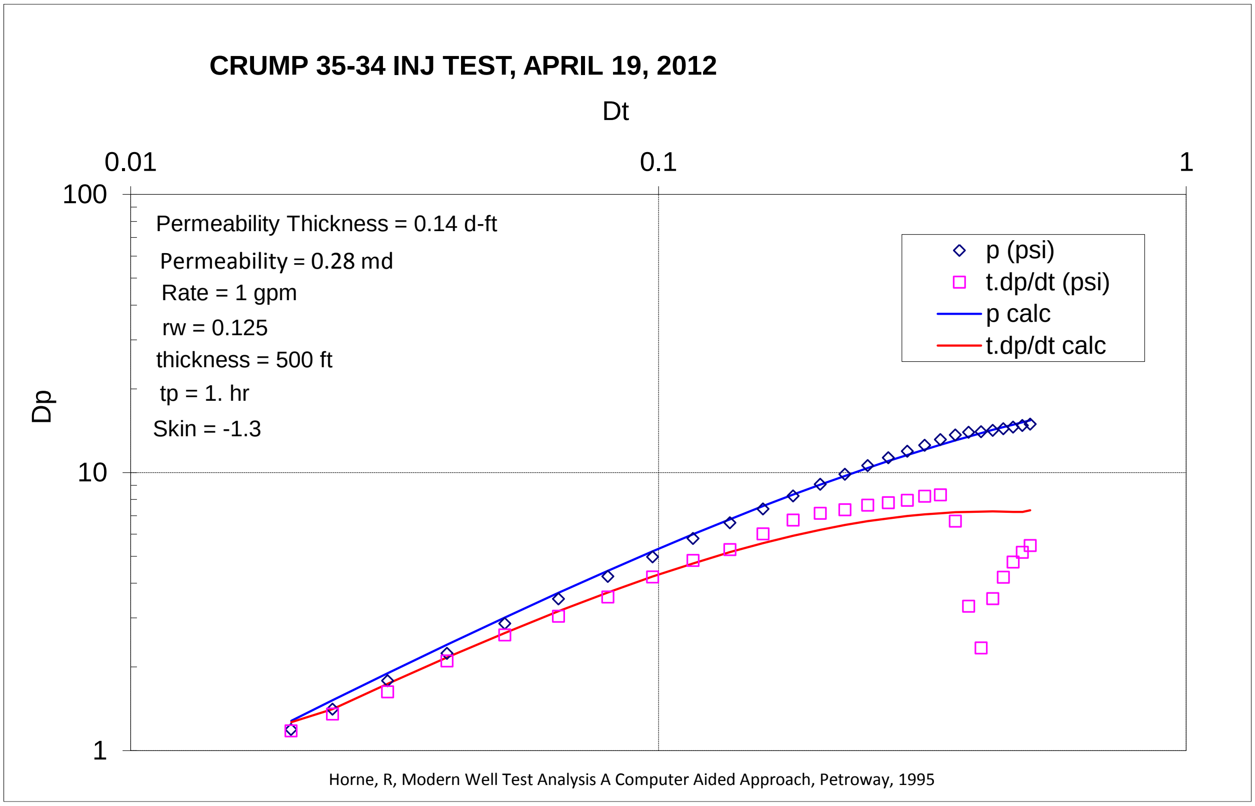

Figure 35. Well 35-34 Injection Test Results

Testing showed limited permeability. Ormat, acting as project managers under Crump Geothermal Company LLC decided not to pursue drilling of the second slim-hole that was part of the Statement of Project Objectives.

5. Conclusion

The Crump Geyser project was operated under a Joint Venture Agreement between Nevada Geothermal Power (NGP) and Ormat Nevada Inc (Ormat) from November 2010 until August 2014 when NGP sold the project to Ormat. At the time of the project sale, through discussions with the Department of Energy, it was determined that a Novation would not be possible due to the limited amount of time remaining in the award period. NGP was unable to continue as managers of the award for a project they did not own due to liability issues. It was decided that the best course of action was to discontinue the award and complete the final reporting requirements. The final Task of the award Statement of Project Objectives was subtask 6.1 – the drilling of slim-hole #35-34.

This award allowed NGP to further explore the Crump geothermal reservoir in South Central Oregon. It created short term employment while conducting important geological and geophysical surveys while assessing an alternative energy resource. The work completed demonstrated a high precision but low cost geophysical strategy for geothermal exploration and well testing in a setting with strong geophysical contrasts that could be applied to other locations in the region.

Unfortunately not all of the project objectives were not completed as set out. Project work did not get to the stage of demonstrating the innovative use of Flowing Differential Self-Potential (FDSP) to monitor the affects of well testing on a known low temperature shallow aquifer as a guide to exploration and resource management. Or to test a combination of electrical resistivity tomography with FDSP to co-interpret fluid flow and resistivity. The surface electrode network was designed to be applied to an electrical resistivity tomography survey to provide another detailed geophysical data set to support future drilling and reservoir operation. Overall, however, this award was very valuable in furthering the exploration of the Crump geothermal project and demonstrating a cost effective, environmentally friendly exploration program.

6. References

Peterson, , N. V., 1959, Lake County's new continuous geyser, The Ore. –Bin, State of Oregon Department of geology and mineral industries, p. 83-88.

Glen, J. M. G., and Casteel, J., Principal facts for gravity data collected in the vicinity of Warner Valley, Oregon, 2011, USGS Open File Report 2011-XXX, 17 pp.