GEOPHYSICAL INVESTIGATION REPORT

2D Seismic Reflection Survey
Crump Geyser Geothermal Prospect
Warner Valley, Oregon

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Executive Summary

Zonge Geosciences, Inc. (Zonge) conducted a two-dimensional (2D) seismic survey at the Crump Geyser geothermal prospect in the Warner Valley in south-central Oregon for Nevada Geothermal Power Company. The 2D seismic reflection survey was conducted over the prospect in the fall of 2010. Data were of good quality showing faults and structure.

The 2D seismic survey at Crump Geyser produced good seismic images to several thousand feet depth. Faults are readily identified and have been mapped across the prospect area. Sedimentary and perhaps volcanic layering was imaged and mapped. Time structure maps were produced on six (6) seismic events. Depth conversions were done on the deepest 2 events, which have locally stronger amplitudes. These stronger amplitude reflection events may be interpreted as the buried basaltic bedrock; however, without additional geologic and/or geophysical information to calibrate and correlate with these seismic sections, the cause of these deeper reflection events is based on experience, to-date site information, and interpretation.

Introduction

In October 2010, Zonge Geosciences, Inc. (Zonge) conducted a high-resolution two-dimensional (2D) seismic reflection survey on the Crump Geyser geothermal prospect in the Warner Valley of south-central Oregon (Figures 1). The 2D seismic survey is in Lake County between Crump and Pelican Lakes. The project was performed under the direction of John Casteel, of Nevada Geothermal Power.

The 2D reflection survey was completed collectively between Bird Seismic, Excel Geophysical, ExplorTech LLC, and Zonge. These teaming partners have successfully worked as subcontractors to Zonge on numerous seismic investigations for nearly a decade. 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 geologic information provided indicates 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 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 or interpretations presented herein. 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. The proposed seismic reflection survey was designed to image the Qal / basalt contact as it drops to the east, in a series of anticipated normal faults (according to the existing geophysical modeling, performed by another contractor to NGP). The area of interest is primarily along that southwestern lake or playa flat of Crump Lake. The area has been studied for many years as a potential geothermal prospect.

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 (inset picture). 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. Figure 2 is a screen shot of a field shot record showing good reflected energy.

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 3 is the survey layout plotted on the local topography and Figure 4 is the seismic shot point map for the 7 lines that were recorded.

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 data processing sequences for this survey are listed below:

1. Reformat Field Data / Seg-2 to Seg-Y
2. Trace & Record Edit
3. Geometry Definition & Application
4. **Spectral Analysis & Filter Analysis to determine frequency range**
5. Green Mountain Refraction Program
6. Picking of First Breaks & Refraction Solution
7. Gain Recovery & Spherical Divergence Correction
8. Deconvolution / Spiking 2 gate overlap
9. Spectral Whitening / 15 hz to 140 hz
10. Long Gate Trace Balance
11. Datum Statics (Datum: 4600’ / Vr: 5000’/sec.)
12. Statics to Floating Datum
13. Interactive Velocity Analysis
14. Brute Stacks: Datum Statics vs. Refraction Statics
15. Surface Consistent Residual Autostatics (First Pass)
16. Interactive Velocity Analysis with 1st Autostatics Applied
17. Surface Consistent Residual Autostatics (Second Pass)
18. Normal Moveout
19. Statics to Flat Datum
20. **First Break Mute Analysis**
21. First Break Mute Application  
22. CDP Trim Static  
23. CDP Stack  
24. **Filter Testing on Unfiltered Final Stack**  
26. FX Filter / Random Noise Attenuation  
27. Long Gate Trace Balance  
28. Kirchoff Migration (Using Various Velocities / 70%, 80%, & 90%)  
29. Output Seg-Y Stacks for Interpretation  

The quality of the processed data is very good. Figures 5 through 8 show the final, uninterpreted, migrated processed sections that were used for the interpretation. 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.  

**Results and Interpretations**  

After the seismic data were processed, they were loaded into a SMT/Kingdom seismic interpretation workstation. No surface lithologic or borehole geological/geophysical information was furnished to Zonge for the interpretation of this data set. As a result, the seismic horizons picked could not be directly correlated to known geologic or formation contacts. Before the horizon picking was done, faults were picked on each of the seven (7) seismic lines (see Figures 9 through 13). 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. Of course, the best way to track the lateral position of faults across a survey area is with 3D seismic data. Fault geometries and continuity were tested for each mapped fault using fault plane maps.  

After the faults were interpreted, six (6) seismic events from shallow to deep were interpreted. These horizons are identified with names based on increasing relative depth (1 Very Shallow, 2 Shallow, 3 Medium, 4 Medium Deep, 5 Strong Deeper and 6 Deep). The two (2) deepest events (5 Strong Deeper and 6 Deep) have the strongest amplitudes, which may indicate the top of the basalt sequence. It is not clearly obvious which event is produced by the anticipated basaltic bedrock. However, there are some weak seismic events that can be identified locally below these stronger events. These
Time structure maps were made for each of these six horizons with fault polygons (dip directions indicated) along the interpreted fault traces. These six time structure maps are shown in Figures 14 through 19. The deepest area on all maps lies in the northwestern part of the survey associated with lines L1 and L4. The main large fault (e.g., mountain frontal fault?) is red on these maps and appears to be offset by a transverse west-northwestern oriented fault (blue) that lies between Lines L3 and L6.

Since seismic data are measured, processed, displayed and interpreted in time (seconds), additional data are needed to quantify the depths that are being mapped. Borehole data are the best way of converting time-to-depth. Since there are no velocity data, vertical seismic profiles or compensated borehole sonic log data available in the existing exploration boreholes at this site, we searched regionally for wells with sonic logs that were drilled only in Quaternary valley-fill sediments. The closest well that had usable data was to the south in California south of Cedarville. The American Thermal Goodwin 1-11 well showed shallow velocities in the 6,000 to 8,000 feet per second (fps) range. This provided the suggestion that the valley fill sediments in the Crump Geyser prospect area are quite slow and that they should have an average velocity in the range of 7,000 to 8,000 fps down to 4,000 feet. We would expect that the velocities will increase significantly when basalts are encountered.

Based on the limited velocity data, we decided to use the average velocity method to depth convert the two deepest time structure maps. These two maps reflect the strongest events found in the survey area, which may be interpreted as down faulted basalt layers. Average velocities of 7,000 and 8,000 fps should capture the range of depths that would be expected here. An average velocity of 7,000 fps is equivalent to 3.5 feet of depth per millisecond (0.001 second) of seismic time. 4 feet of depth per millisecond of seismic time is equivalent to an average velocity of 8,000 fps. While we can be certain that these average velocity functions are not absolutely correct, and are likely different from in-situ formation velocities, they do provide a general link for use of the seismic data in an approximate depth-converted fashion. Using a slower velocity function will push the time structure down and, conversely, a faster velocity function will pull the projection up in time. Of course, getting direct velocity measurements at the site (e.g., compensated sonic logging, check shot surveys or vertical seismic profiles) in future boreholes would be helpful.

With the caveats of being very cautious about using these simplified, or average velocity functions; we have made depth (below the 4,600 feet above sea level (fasl) seismic reference datum) conversions for the 5 Strong Deeper and 6 Deep time structure maps. Figures 20 through 23 are depth maps of these two time structure maps using 7,000 and 8,000 fps average velocities. Figures 24 through 27 are the
structure maps (elevation in feet above sea level - fasl) for these depth maps. Again, caution should be made with using these maps. The maps made with the higher velocity function (i.e., 8,000 fps) should capture the deepest a well will have to be drilled to intersect either of these reflecting surfaces. When targeting a fault zone, a depth to the fault (below 4,600 fasl) can be estimated by using 3.5 or 4 feet per millisecond as measured from the seismic section.

**Conclusions**

The 2D seismic survey performed at the Crump Geyser geothermal prospect site 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. Sedimentary layering interpreted to be volcanic (basalt) was imaged and mapped at depth. Time structure maps were produced on six (6) seismic events. Depth conversions were done on the deepest 2 events, which have locally stronger amplitudes, using an average velocity function. These stronger amplitude reflection events may be interpreted as the buried basaltic bedrock; however, without additional geologic and/or geophysical information to calibrate and correlate with these seismic sections, the cause of these deeper reflection events is based on experience, to-date site information, and interpretation.

In order to better define time-to-depth conversions in the future, it is recommended that velocity data be collected in wells that 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. If future seismic surveys are conducted here, 3D seismic surveying should be considered in order to accurately determine the positions of the faults across the area. This can help to properly place wells that are targeting fault zone permeability and productivity.
We appreciate the opportunity to perform the 2D reflection survey at Nevada Geothermal Power’s Crump Geyser prospect area. We believe Zonge’s seismic investigation successfully met the objective and shows that 2D seismic reflection surveying can image the subsurface structures here. If you have any questions regarding the data acquisition, processing, or interpretation, please do not hesitate to contact Dr. John Arestad (303-290-8384) or myself.

Sincerely,

Phil Sirles
Managing Geophysicist / VP