A Study of the Surprise Valley Fault Using a High-Resolution Shallow Seismic Reflection Profile

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ABSTRACT

Despite a lack of large historical earthquakes, the Surprise Valley fault system in northeastern California is presumed to be seismically active based on the presence of numerous Holocene fault scarps and a fault-controlled geothermal system. The Surprise Valley fault is believed to be similar to historically active basin and range faults such as the Dixie Valley fault in central Nevada. A 5-m-deep paleoseismic trench across the main fault revealed a steeply-dipping (~68 degrees) normal fault, while a vibrator reflection profile located a few kilometers north of the trench imaged a much more shallowly dipping normal fault (~25-30 degrees) at 0.5–1.0 km depth. It is unclear from these data if the steeply dipping fault exposed in the trench soles into the more shallowly dipping fault at depth, or if the currently active fault cuts the fault imaged in the reflection profile. Ongoing geothermal development in Surprise Valley motivates a further understanding of the fault system and thermal controlling structures. In June of 2008, we conducted a 200-m-long high-resolution shallow reflection profile across the fault at the location of the paleoseismic trench, in order to further constrain the geometry of the currently active range-front fault. The survey was conducted with a 48-channel seismograph, a 16-lb sledge, and 48 groups of six 100-Hz phones each, spaced at 2-m intervals. Optimization of P-wave arrival times for a tomographic image of the upper 50 meters shows velocities ranging from 1000 to 2500 m/s. Preliminary reflection processing, together with the optimized velocity section, suggests that the fault dips at an angle of 60 degrees in the upper 40 meters, and may suggest an antithetic fault in the hanging wall. The unprocessed data display strong reflections at depths to 200 m. A detailed understanding of the dip angle of the Surprise Valley fault will impact the ongoing geothermal development and the assessment of seismic hazard in the area, both of which will vary based on the angle of the active fault system.

Introduction

The Surprise Valley Fault (SVF), located in northeastern California along the western margin of the Great Basin (Figure 1), is an eastern-dipping normal range-front fault running 85 km along the base of the Warner Range (Personius et al., 2007a). Surprise Valley has higher rates of crustal dilation, which is typical of extensional geothermal systems (Coolbaugh et al, 2005), however is not located in a seismically active area (Egger et al., 2009). The fault displays significant offset and contributes to a fault controlled geothermal field and geothermal production in the northern portion of the valley. The SVF, while studied relatively less than other Great Basin faults, is comparative to the Dixie Valley fault (Egger et al., 2009). Similarities include a shallow fault dip in the southern portion of the valley and geothermal production in the northern portion (Abbott et al., 2001).

Figure 1. Surprise Valley is located in Northeastern California along the base of the Warner Range. Google Earth Image.

Previous work in Surprise Valley motivated this additional study. About 7 miles of seismic reflection were collected and analyzed by Optim Inc. in 2001 near the Lake City geothermal fields. Since this was done for a private enterprise, the results have not been published but indications are a high-angle fault was imaged. In 2004 a 16 km long 2-D seismic reflection line was acquired across Surprise Valley imaging a low angle fault at depths of ~7 km (Lerch et al, 2009). In 2007 a paleoseismic trench was conducted by the USGS across the SVF near the base of Cooks Canyon. Findings from the trench study, taken to an average depth of 5-m indicate that the fault dips at an angle of 60-70 degrees.

There is great interest in the SVF due to its geothermal potential and the similarities between it and the Dixie Valley fault, which also contains geothermal production. Because many geothermal systems are fault controlled, characterizing features of this fault system will aid future exploration. Features of the SVF could be used to identify properties that are likely to contain a fault controlled geothermal resource.

Figure 2. The reflection survey was conducted near the Cook's Canyon site; approximately 4 km north of Cedarville, CA.

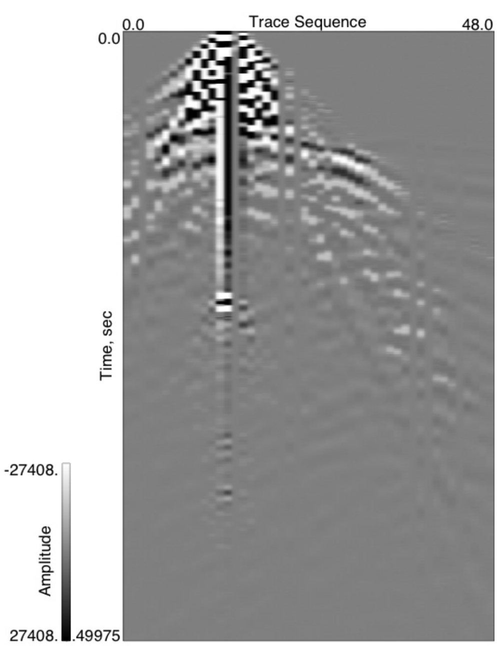

Figure 3. The June 2008 Seismic reflection line spanned the visible fault scarp from the bedrock above the scarp into the lake sediments into the valley. Google Earth Image.

Data Acquisition

In June of 2008 a 250 m long high-resolution shallow seismic reflection line was acquired using the Bison Galileo 21 seismograph. The survey consisted of 72 stations of 6-phone groups of 100-Hz geophones at 2-m spacing, with source inputs from a 16-lb sledge. Source offset went to a maximum distance of 40 m offend and maximum fold of 50. Offend source spacing varied, while inline source spacing remained constant at 2 m. A total of 118 reflection records were recorded. The survey was conducted over two days, the first day comprising of 48 channels while the second day used a shorter array of 24 channels.

The survey, located near the base of Cooks Canyon, ~4 km north of Cedarville, California, spanned an elevation of 45 m across the fault scarp (Figure 2). The line started near to the exposed bedrock ~70 m above the scarp and extended into the valley ~180 m (Figure 3). Most noted in the survey topography is the fault itself. The rise of the fault is 8 m and the scarp offset is 5.5 m (Personius et al., 2007).

Figure 4. Raw shot gather displaying the visible reflections in the raw data.

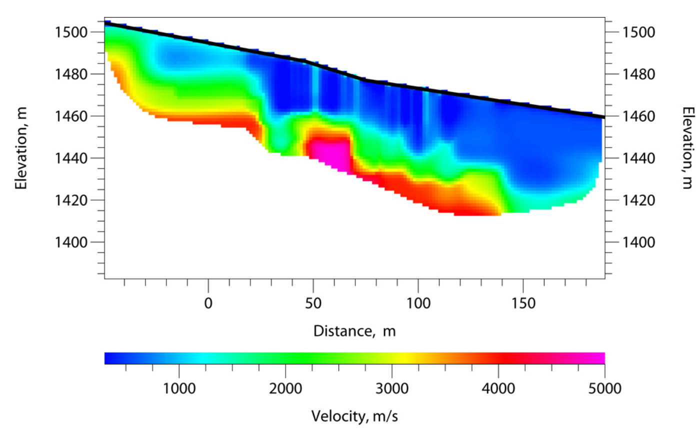

Figure 5. SeisOpt® @2D™ optimized Velocity Model created from first arrival picks displaying the upper 40-m to 60-m of the subsurface.

Processing and Analysis

Raw data displayed strong reflections to an apparent depth of 200 m (Figure 4). Data processing consisted of applying an 80-200-Hz bandpass filter and a 250 ms automatic gain control. The two days of data were added together and then 72 gathers were stacked into a common velocity stack where reflections were picked and used to calculate the desired velocity for a common mid-point (CMP) stack. With a stacking velocity of 1800-m/s, the profile is projected to a total depth of 900 m.

First arrivals were picked and were used to create a tomographic profile of the survey using SeisOpt® @2D™ (© Optim, 1999-2008) (Figure 5). This software uses a simulated annealing optimization to of picked P-wave first arrival times to derive a detailed velocity model of the subsurface. The software uses only pick times and requires no additional constraints (Pullammanappallil and Louie, 1994). This produces a model down to a depth of about 60 m (Figure 4).

The velocity profile was extended to a depth of ~900 m at 1.5 m bins by continuing the maximum velocity found at each CMP (Figure 6). The extended velocity profile was then used to create travel-time files for each CMP location and each depth bin. These files will be used to run a pre-stack depth migration (PSDM), which will allow greater confidence in a final stack. This migration technique is essential at this location due to the lateral heterogeneity in the velocity profile. The PSDM program requires a rectangular velocity rectangular velocity section so the area above ground is given an air velocity of 300-m/s.

Results

The optimized velocity profile indicates velocities that range from 500-5000 m/s. Below the fault scarp, the primary velocity is less than 100 m/s, while there is a velocity increase above the scarp. There is a noticeable increase in velocity ~20 m above the fault scarp that follows an apparent angle of ~60 degrees.

Reflection truncations from a CMP stack are visible suggesting the location and dip of the fault (Figure 7). The stack can be aligned along the topography of the velocity model and a match between the sharp velocity heterogeneity and reflection truncations is apparent (Figure 8).

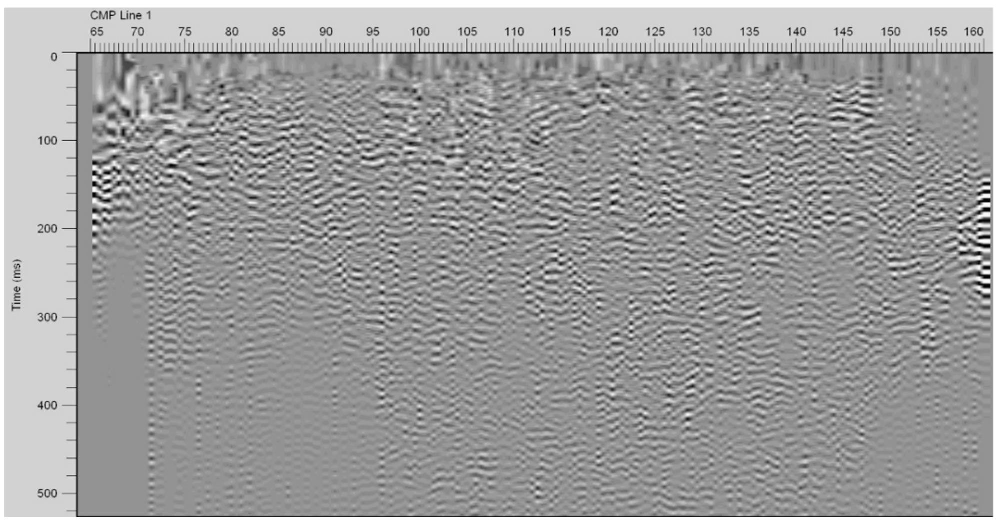

Figure 7. CMP stacked section of 72 channels.

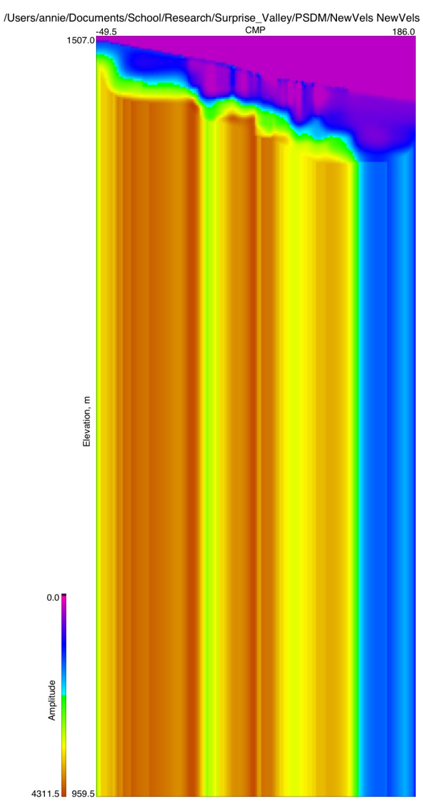

Figure 6. Extended velocity model used to create travel time files for a Pre-stack depth migration.

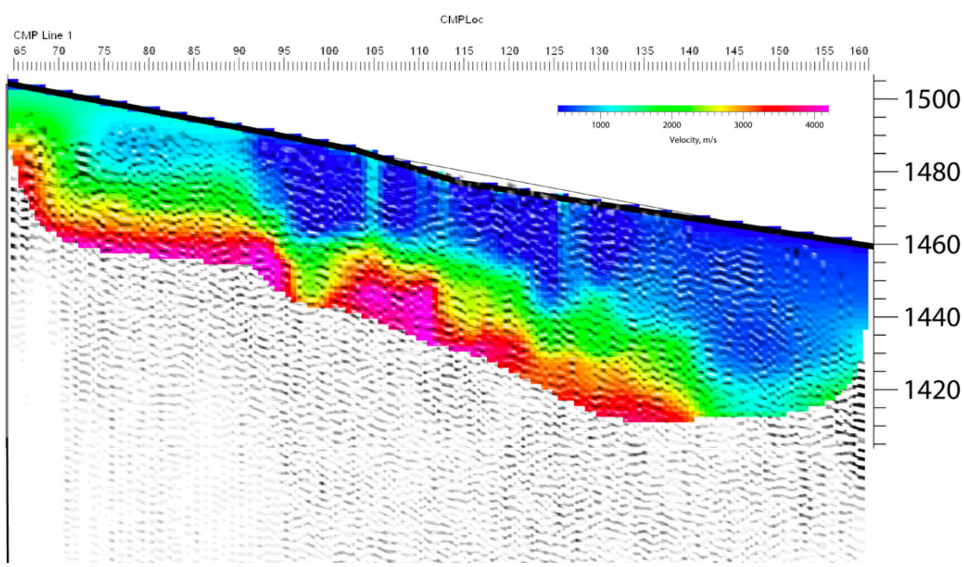

Figure 8. Overlay of the stacked section and the velocity model showing a correlation between the seismic image truncations and the velocity model discontinuity.

Conclusions

Velocities in the upper portion of the section are consistent with basin sediments It is confirmed from the velocity model that the upper portion of the fault has an initial dip of ~60 degrees in the first 40 m.

Though the CMP stacked section images to a greater depth, there is less confidence in an interpretation. The data do display a discontinuity near the location of the fault scarp however it is difficult to trace at depth. The first 200 m suggest a dip of ~60 degrees, however it is unclear from these data whether or not the fault soles out to a shallower angle at depth. It is intended that there be a pre-stack depth migration done on these data which will better image a high angle fault, allowing a better understanding of the controls on the Surprise Valley geothermal system.

References

Abbott, R.E., Louie, J.N., Caskey, S.J., and Pullammanappallil, S., 2001, Geophysical confirmation of low-angle normal slip on the historically active Dixie Valley fault, Nevada

Coolbaugh, M.F., Arehart, G.B., Faulds, J.E., and Garside, L.J., 2005, Geothermal systems in the Great Basin, western United States: Modern analogues to the roles of magmatism, structure, and regional tectonics in the formation of gold deposits, *in* Rhoden, H.N., Steininger, R.C., and Vikre, P.G., eds., Geological Society of Nevada Symposium 2005: Window to the World, Reno, Nevada, May 2005, p.1063–1081.

Duffield, W.A., and McKee, E.H., 1986, Geochronology, structure, and basin-range tectonism of the Warner Range, northeastern California GSA Bulletin; v. 97; no. 2; p. 142-146

Egger, A.E., Glen, J.M.G., and Ponce, D.A., 2009, The northwestern margin of the Basin and Range Province, Part 2: Structural setting of a developing basin from seismic and potential field data2, Submitted to Tectonophysics, in review

Lerch, D.W., Klemperer, S.L., Egger, A.E., Colgan, J. P., and Miller, E.L., 2009, The northwestern margin of the Basin-and-Range Province, Part 1: Reflection profiling of the moderate-angle (~30°) Surprise Valley Fault, Submitted to Tectonophysics, in review

Personius, S.F., Crone, A.J., Machette, M.N., Lidke, D.J., Bradley, L.-A., and Mahan, S.A., 2007, Logs and scarp data from a paleoseismic investigation of the Surprise Valley fault zone, Modoc County, California: U.S. Geological Survey Scientific Investigations Map 2983, 2 sheets.

Pullammanappallil, S.K., and Louie, J.N., 1994, A generalized simulated-annealing optimization for inversion of first arrival times: Bulletin of the Seismological Society of America, v. 84, p. 1397-1409.