A Revised Interpretation of 3D Seismic Data, Hawthorne Army Depot, Nevada: Faulted-Basin Reflections or Sill Intrusions?

Annie Kell-Hills¹, Louie, J.¹, Kent, G.¹, Pullamanappallil, S.², Sabin, A.³, Lazarro, M.³
1. Nevada Seismological Laboratory, University of Nevada, Reno
1664 N. Virginia St., Reno, NV 89557; kell@seismo.unr.edu
2. Optim, Inc., 200 S. Virginia St., Reno, NV 89501
3. Geothermal Programs Office, U.S. Navy China Lake Naval Weapons Center, Ridgecrest, CA, USA

The Hawthorne geothermal prospect is located in the Walker Lake province of the Walker Lane (figure 1), an area of the Great Basin containing numerous extensional geothermal systems (Surpless, 2008; Oldow, 2003). A 3d seismic reflection volume collected by the Navy Geothermal Programs Office (GPO) provides rare insight to possible controlling structures within an extensional geothermal system. In areas of extensional geothermal systems, fluid flow is commonly controlled by faults and crustal thinning provides heat (Coolbaugh et al., 2005). The initial interpretation of the GPO data showing bright, high amplitude reflectors as fault planes is revised to include the possibility of sill intrusions. By adjusting our interpretation to include the possibility that observations seen in subsurface seismic sections could be caused by magmatic sill intrusions, we present a case for the geologic role of volcanism within the Walker Lane as seen in Long Valley, California (Bursik & Sieh, 1989) (figure 1).

The Walker Lane province of the Great Basin is an area of the Western United States dominated by NNW striking normal faults that contribute an estimated 25% of the strike-slip motion between the North American and Pacific plates. Much research involving geothermal structures shows that the Walker Lane contains “typical” extensional geothermal controls, such as complex fault zones rather than single faults (Blackwell et al., 1999). Surface evidence in Hawthorne indicates
numerous steeply-dipping basinward step faults, though there is little evidence for these in the 3d seismic data. Strong, high-amplitude reflection events seen in the data reveal low angle (\sim 20^\circ) east-dipping reflections throughout the southern half of the seismic volume (figure 2). Similarities of these reflections to sill intrusions in fault zones as seen in seismic sections in the North Sea and Gulf of California motivate the exploration of a sill hypothesis (Thomson & Hutton, 2004; Kluesner et al., 2009).

Figure 2: Dominant features seen within the data include high-amplitude reflection bands dipping east intersecting concave-up reflections. These features are continuous throughout the southern half of the volume and abruptly end toward the north.

Thomson and Hutton (2004) and references therein have extensively studied magmatic sill intrusions within the North Rockall Trough of the North Sea. Identifying features for saucer-shaped sills include high-amplitude flat inner sills flaked by concave up “wings” (Polteau et al., 2008). Above the concave up reflections, there are often observations of domed overburden as well as cross-cut stratigraphy. Models show that as intrusion proceeds, the magma pools to form the flat inner section and pushes up the overburden, forming a dome above the sill. As the thickness of the sill becomes larger with respect to the thickness of overburden, stresses along the sill edges change direction causing the intrusion to travel up and radially out, creating the observed saucer shape (Polteau et al., 2008). Numerous examples show that such dikes intrude into fault zones resulting in areas of saucer-shaped sill structures between zones where the magma travels along the fault plane (Valentine & Krogh, 2006; Hansen & Cartwright, 2006).

The seismic volume collected by the GPO was acquired and processed by Dawson Geophysical in 2001. Acquisition and processing techniques included industry standard narrow-azimuth survey design, vibrator sources, 3d velocity modeling from stacking and migration analysis, and prestack time migration. All our visualizations of the data we created in the OpendTect system by dGB Earth
Sciences. Time-to-depth conversions were made using a combination of observations from well logs within the seismic volume correlated to reflections, sonic logs, and the migration velocity model. Hawthorne, Nevada is located along the eastern edge of the Wassuk Range, south of Walker Lake. The inline sections were oriented perpendicular to the range-front fault system in order to most clearly image these faults (figure 1).

Initially, the high-amplitude reflections observed in the Hawthorne 3d volume were interpreted to be fault plane reflections. However, dip calculations after making reflection ties to newly drilled wells reveal only a <20° dip on these reflections. Such a low-angle dip makes the origin of these reflections as normal faults less likely.

Similarities we observe in the Hawthorne seismic volume to prior sill studies include concave-up, saucer-shaped refraction bands with disruptions in the overlaying stratigraphy and concentric circles in time sections. Figure 3 outlines the features noted within the seismic data that are indications for dike-intruded sills. Strong indicators for sills include high amplitude synclines, concentric circles in time sections and stratigraphic disruption above that could be caused by uplift in the overburden. Figure 3 is a time section at 1024 ms showing two sets of concentric circles and a vertical section that passes through. In the vertical section there are a series of synclines interpreted as saucer shaped sills and a large section of the overburden that has been disrupted.
Figure 3: Composite view of a time section at 1024 ms and a vertical inline section showing sill identifying features.

These data, however, do not show cross-cut stratigraphy or deeper vertical dikes that would serve as feeding structures. Studies by Valentine and Krogh
suggest that cross-cutting would not be expected within the Great Basin due to the poorly consolidated basin fill. It should also be noted that a vertical dike structure, even if present, would be difficult to capture in the Hawthorne seismic section due to the survey design and difficulties inherent in seismic imaging of vertical structures.

We have also explored the option that the 20°-dipping reflections and sub-horizontal bands could be fault plane reflections intersecting the basin bottom. The sub-horizontal reflections seen at ~1.0 s are not suspected to be basin-bottom has to do mainly with the fact that it is not observed in the more northern portion of the seismic volume. If this were the bottom of the Walker Valley basin, the depth and reflectivity would be consistent throughout, revealing the same appearance in seismic sections from both the northern and southern sections.

In researching what material would create such high-amplitude events we found similarities to several studies conducted within the Great Basin. Seismic sections show shallow 20°-dipping events that have similar reflectivity to the concave-up reflection bands. Studies of dike intrusions as revealed at outcrop in Paiute Ridge, Nevada (Krogh & Valentine, 1996; Valentine & Krogh, 2006) and through drill logs in Long Valley, California (Bursik & Sieh, 1989; Bursik et al., 2003) show that as magma intrudes into a normal fault, it both pools between faults and also travels along the weakened fault plane (figure 4).

Figure 4: High-amplitude events seen within these data resemble examples of sills that have intruded along pre-existing fault planes.

Observations along Paiute Ridge show saucer shaped sills that are inferred to have traveled along an existing fault plane (Krogh & Valentine, 1996; Valentine & Krogh, 2006). The cross sections created within their studies show shapes that greatly resemble the shape of the high amplitude events seen within the GPO 3d...
data. Other outcrop observations studied by Goulty and Schofield (2008) of the Golden Valley Sill in South Africa also show concave-up elliptically shaped sills, a shape that can be seen in volume-rendered views of the Hawthorne data.

Though there is much suggestion within the seismic sections for dike intrusions, there are no observations of volcanism near Hawthorne, making seismic evidence the only suggestion of a sill interpretation. In nearby Long Valley, dike-intruded faults were revealed through drilling projects. Drilling of the southern section of the Hawthorne 3d seismic volume is not likely to be conducted during geothermal exploration. Further work planned for the Hawthorne geothermal field includes detailed geologic mapping by Hinz (this volume) and gravity and magnetic studies (Shoffner, this volume), which will likely lead to development of the geothermal resource within the northern part of the seismic volume.

Works Cited


