Geophysical expression of hot water beneath the Cascade, Idaho area

A report prepared for the City of Cascade

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Summary

We present results from new geophysical surveys in the Cascade, Idaho area and a compilation/analysis of existing thermal data. Our objective was to locate and characterize faults or fractures within the granitic rocks beneath Cascade that may provide a conduit for upwelling geothermal fluids from great depths. Elevated groundwater and ground temperatures in the Cascade area suggest there is a potential to utilize geothermal waters for direct use heating.

We first explore the Idaho Department of Water Resources well log database to establish a geothermal gradient of 16.7° F increase per 1,000 foot depth for the Cascade region. This implies that, at the average geothermal gradient, a drill hole depth of about 9,850 ft is needed to obtain the boiling point water temperatures (212° F at sea level). Within higher temperature fracture zones, a shallower well may intersect these temperatures. We note that the granitic hills to the west and north of Cascade generally show average geothermal gradient temperatures. This suggests no dominant fractures or faults extend through these hills. Many wells located within the downtown Cascade region show shallow depths to granite and anomalously high water temperatures when compared to the regional gradient. This observation is consistent with a greater fracture density beneath downtown when compared to the granitic hills to the west and north. High temperatures are likely found at the interesection of these fractures. Wells located to the south and east of Cascde mostly bottom in sediment. These wells show a slightly higher geothermal gradient compared to the granitic hills, suggesting that the sediments do not act as a cap to upwelling geothermal water.

We conducted both magnetic and seismic surveys in the Cascade area to identify faults that may promote deep geothermal fluid circulation. The results of these surveys point to two target zones. First, the area to the west of downtown Cascade shows a 90 degree bend in the magnetic field signature that is consistent with a change in fault/fracture orientations. A north-trending fracture is noted in the granitic hills west of town and this fracture intersects the 1,085 ft deep Wellington well near the change in mapped trend of the Cascade fault. This well records temperatures above the regional gradient that may be driven by deep circulation associated with intersecting fractures or faults. Second, we present evidence to extend the Cascade fault to the north of the airport (currently it's northern mapped extent). We note that the high temperature (100+° F) Mill well is located at the intersection of this fault with a northwest-trending lineation (fault or fracture) that defines the granitic hills to the west. The Cascade fault separates greater bedrock depths to east from shallow bedrock to the west. The extension of the Cascade fault to the north explains the shallow bedrock depths beneath downtown and the greater bedrock depths to the east.

Additional observations are that seismic velocities beneath downtown Cascade are consistent with a highly fractured bedrock that may promote deep fluid circulation to shallow depths. There is no dominant trend that we observe when we integrate the seismic and magnetic results, suggesting that fault driven circulation is localized beneath town and difficult to pinpoint with our survey results. More detailed magnetic mapping is not possible due to large cultural noise signals within downtown (cars, power lines, utilities). Seismic profiling along city streets is useful for finding faults and fractures, but northern extension of the Cascade fault may be difficult to characterize near town due to the Payette River that lies above the mapped fault.

Valley County geologic and tectonic and hot spring overview

Geothermal systems are common in the western United States where active tectonics and intrusive rocks are found. Cretaceous and Tertiary granitic intrusive rocks of the Idaho batholith are likely responsible for hot springs and other the hydrothermal systems through radiogenic heat generation from the decay of isotopes like uranium, thorium, and potassium. Druschel and Rosenberg (2001) noted geothermal gradients of 25-30° C/km or about 14-17 °F per thousand ft depth for plutonic systems in Idaho (Figure 1). For reference, a worldwide average geothermal gradient away from major tectonic boundaries is estimated at between 13-16 °F per thousand ft. The closest hot springs to the City of Cascade are: 1) the 140° F to 160° F Carbarton Hot Spring and the 110° F Belvidere hot springs located to the south of town; 2) the 90° F Arling and 100° F Badley hot springs located to the north of town; and 3) the 190° F Vulcan and 120° F to 140° F springs around Warm Lake to the east (Ross, 1970; Figure 1). The Carbarton hot spring system is close to the Alpha earthquake swarm of 2005 and may suggest that active faults can play a role in deep geothermal fluid circulation. There have been no other recorded earthquake swarms for this region.

The modern tectonic framework for Valley County, Idaho is best described as Basin and Range style extension that thins the earth's crust, possibly elevating the geothermal gradient. The related faults and fractures can provide a fluid pathway for deep circulating fluids to approach earth's surface. Where faults or fractures intersect, we often observe anomalously high groundwater temperatures and springs (Figure 1). Where faults or fractures are buried, the overlying sediment can mask and contain the geothermal signature. Geophysical characterizations may help identify these buried structures.

Miocene and younger north-striking faults cut the Idaho Batholith and form the Long Valley basin, a major tectonic and structural feature near Cascade Reservoir and Payette Lake (Lewis, 2002; Figure 1 and 2). The Long Valley fault zone, located along the western margin of the Long Valley basin, is the controlling tectonic structure within Valley County (Figure 2 and 3) and is divided into a northern and southern segment (Giorgis et al., 2008). The southern segment is locally called the Cascade fault. Gravity data suggests that the Long Valley is an asymmetric basin about one kilometer (3,000 ft) deep, with the basin center located approximately 5 km (3 miles) northwest of Donnelly (Giorgis et al., 2006). Near Cascade, this basin is shallow and contains little offset on the adjacent range bounding faults. To the north of Cascade's downtown district, the Cascade fault trends northeast while the same mapped fault trends north-south to the south of town (Figure 3). This intersection of fault trends may produce dilation in the upper crust that can deliver deep circulating hot water to shallow depths. To date, no geothermal expression has been identified along the Cascade fault near the town of Cascade.

Within Cascade city limits, the community uses water from a 100-106° F spring to supply the local swimming pool. Additionally, Ross (1970) identified two thermal springs that are now covered by Cascade Reservoir to the west of town. Other deep and warm wells have been drilled, but no apparent pattern of hot water has been identified. In summary, a shallow hot water expression is typical for parts of the Cascade region. Identifying buried faults and fractures in the underlying granitic rocks may be the key to characterizing geothermal resources for the community. Our study focuses on characterizing bedrock geometry to identify regional trends in buried faults or fractures. We focus on temperature data from other studies and new seismic and magnetic data acquired as part of this study.

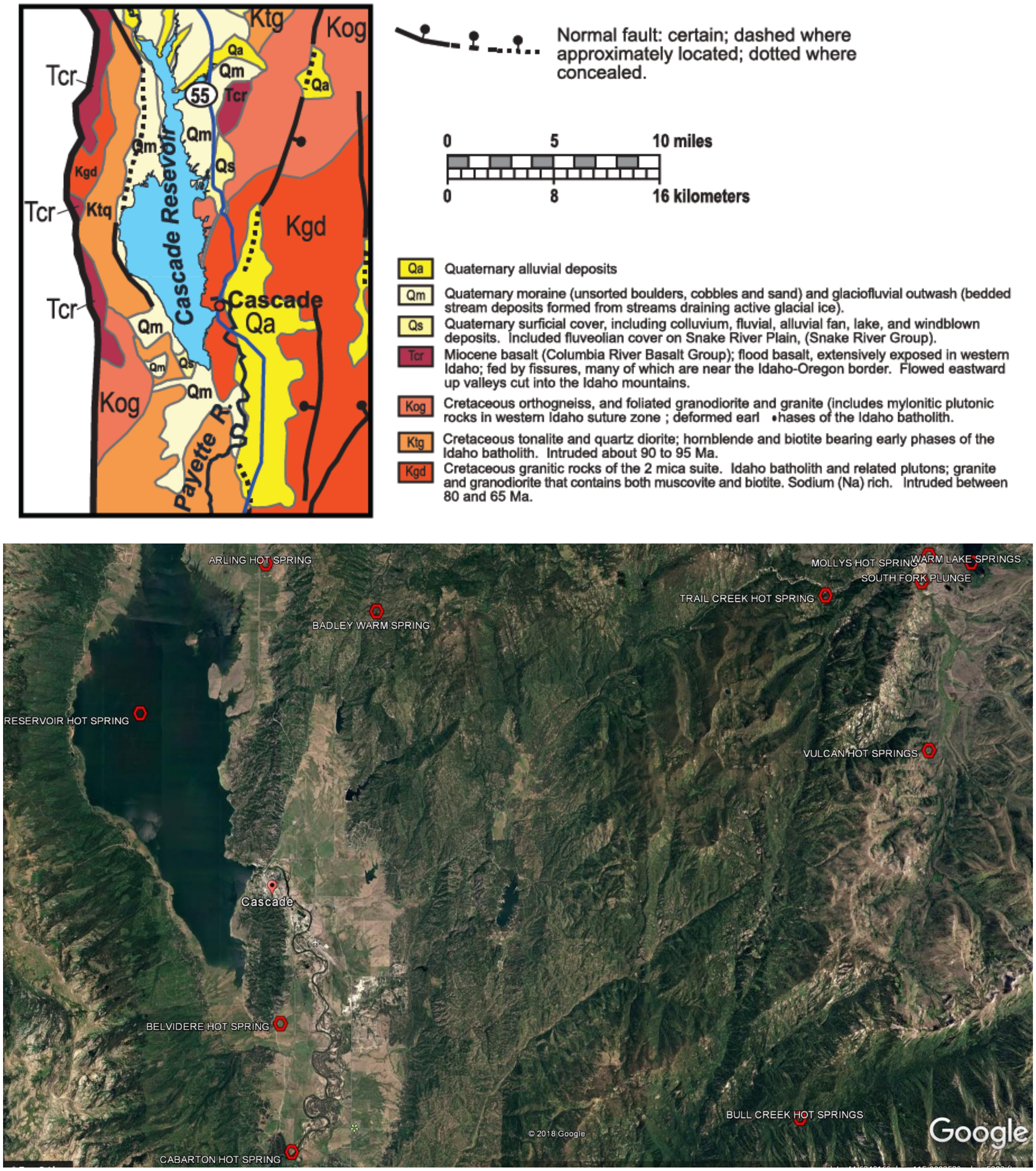

Figure 1. (top) Geologic map from Lewis (2002) for the Cascade area. Cretaceous Idaho batholith rocks surround Cascade and provide the elevated geothermal gradient for the area. (bottom) Aerial map (Google Earth) for the Cascade, Idaho region showing the distribution of hot springs throughout the region. Note the northeast-trending lineations in the hills east of Cascade. These linear features may be controlled by fractures within the Idaho Batholith.

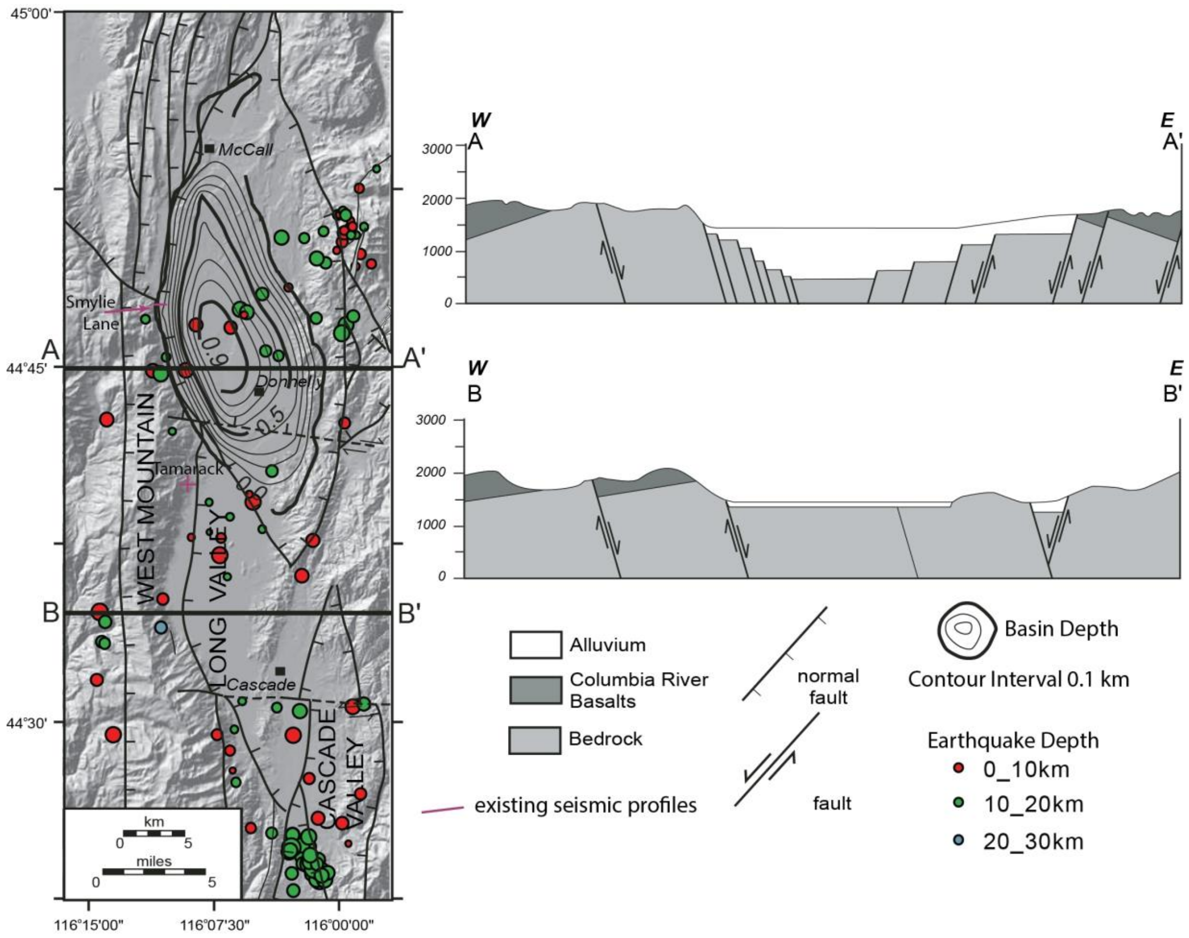

Figure 2. Gravity-derived basin geometry with cross sections, modified from Giorgis et al (2008). Dots represent earthquakes over the past 30 years. Note the Alpha earthquake swarm (green dots) to the south of Cascade. The Cascade Valley contains a thin cover of sediment above bedrock.

Local Geology

In the hills to the west and north of Cascade, granitic rocks of the Idaho Batholith are covered by a thin (5-10 ft thick) layer of colluvium (Figure 3; Breckenridge et al., 2006). The Lidar elevation data show that fractures and drainages in these hills do not host a dominant trend. One notable north trending drainage within the granite hills is noted on Figure 3 that parallels the Cascade fault. Beneath downtown Cascade, upwards of 100 ft of mountain slope colluvium covers the underlying granitic rocks. Along the Payette River and farther east, alluvial river deposits dominate the surface and subsurface geology. Lidar elevation data clearly shows older channels of the Payette River to the east of the current river location, suggesting westward stream migration over the past few thousand years. From surficial geologic maps and Lidar imagery, it appears that the Payette River has not flowed west of the current river location within the downtown Cascade area. It is not clear that changing river drainages is controlled by tectonics, but it is a possible that activity on the Cascade fault has dropped the western portions of the Long Valley basin.

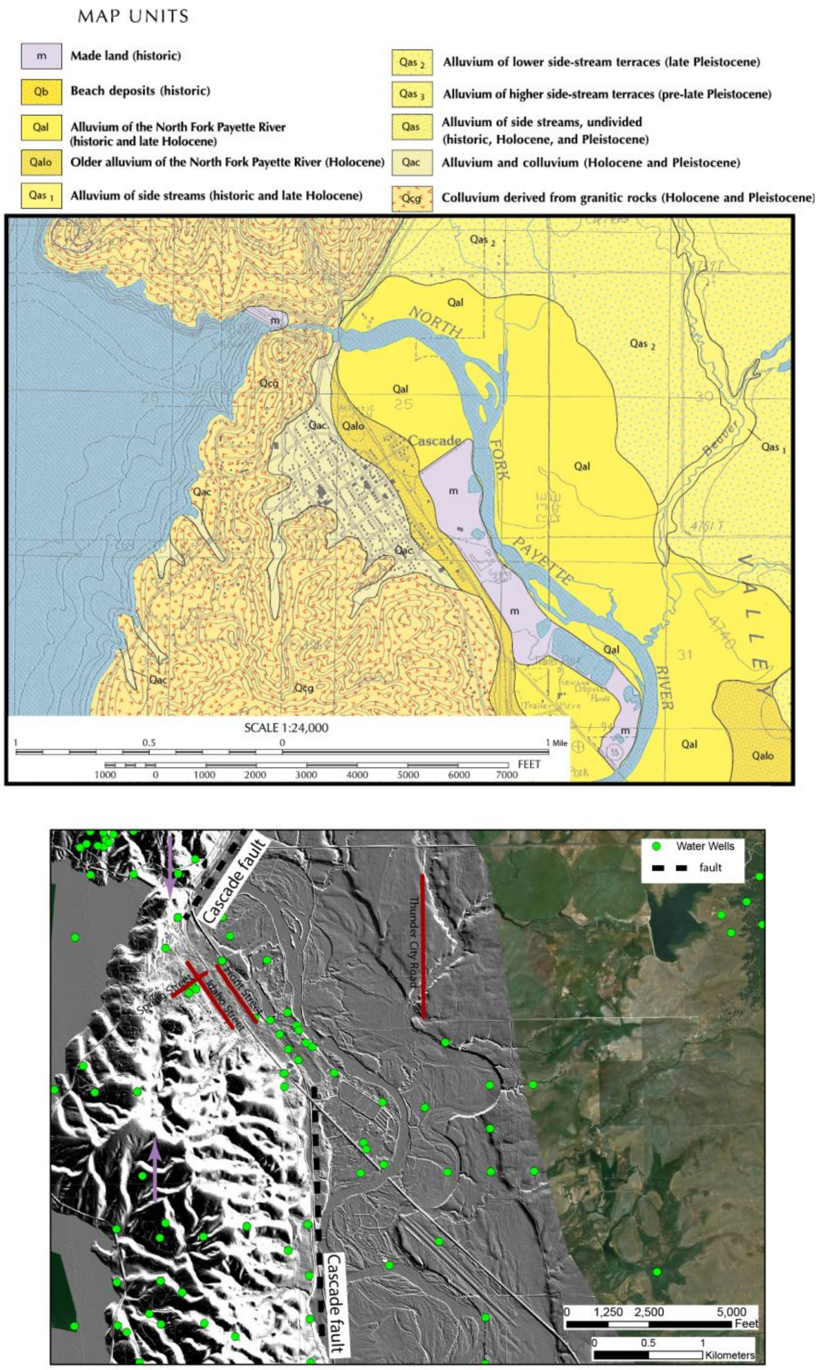

Figure 3. (top) Cascade surficial geologic map (modified from Breckenridge et al., 2006) showing granite hills to the west and north of downtown Cascade. The south flowing Payette river defines the eastern limits of downtown and separates colluvium shed from the adjacent hills from alluvium deposited from the Payette River. (below) Lidar derived hillslope map showing study area (https://www.idaholidar.org), location of seismic profiles, water well locations and mapped faults. Hill shading is from the east. Note the abandoned channels of the Payette River to the east of the current channel and the north-trending fracture in the hills south of town (purple arrows).

Well log information

The Idaho Department of Water Resources (IDWR) hosts a drillers log database (http://www.idwr.idaho.gov/). Information included in these logs include location, total drilled depth, lithology, depth to water, and bottom hole temperature. For the Cascade area, we identified 179 wells (Figure 3). From bottom hole temperatures that were logged, we estimate the natural geothermal gradient for the Cascade, Idaho region (Figure 4). We observe an average water temperature of about 47.5 degrees F for surface elevations and at 500 ft depth, an average water temperature of about 56 degrees F. The best linear fit line of all data can be represented as :

Temperature (dF) = 0.0167 * depth (ft) + 47.46

This implies that at a gradient of 16.7° F increase per 1,000 foot depth, a drill hole depth of about 9,850 ft is needed to obtain the boiling point water temperatures (212° F at sea level). It is worth noting that these temperatures may not accurately reflect bottom hole temperature due to short measurement time window. The temperatures may also be influenced by seasonal temperature variations, and may be influnced by frature flow, flow barriers, or varying infiltration rates. However, the analysis shows that the Cascade, Idaho area contains a higher than normal geothermal gradient compared to the global average of 13-16° F per 1,000 ft. We use this database to search for high temperature wells with respect to the regional gradient (Figure 5).

Of particular note from this analysis, wells that are located close to Lake Cascade or Payette River generally show lower lower temperatures due to the influence of the surface water infiltration, even to great depths. One example is the 880 ft deep Alfred Day well, located northwest of the Cascade city and along the Lake Cascade shore line. If these cold wells are removed from the analysis, the geothermal gradient is closer to 18° F per 1,000 ft. Figure 4 also shows the wells that bottom in sediment and those that bottom in (weathered) granite. Although lithologies derived from the drillers logs can be very subjective (e.g., where fractured/weathered granite are sometimes labeled coarse sediment), this analysis shows that wells emplaced in granite (mostly west of the Payette River) do not show higher geothermal gradients than those wells that bottom in sediment (mostly east of the Payette River). Thus, there is no strong barrier (i.e. aquatard) in the alluvial sediment to limit vertical groundwater flow.

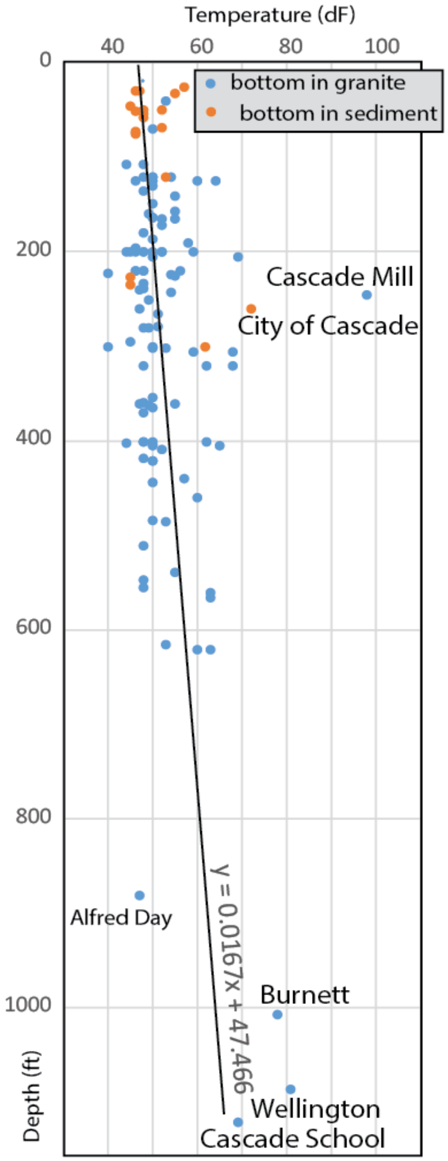

Figure 4. Bottom hole temperatures derived from drillers logs for the Cascade region. See Figure 4 for locations.

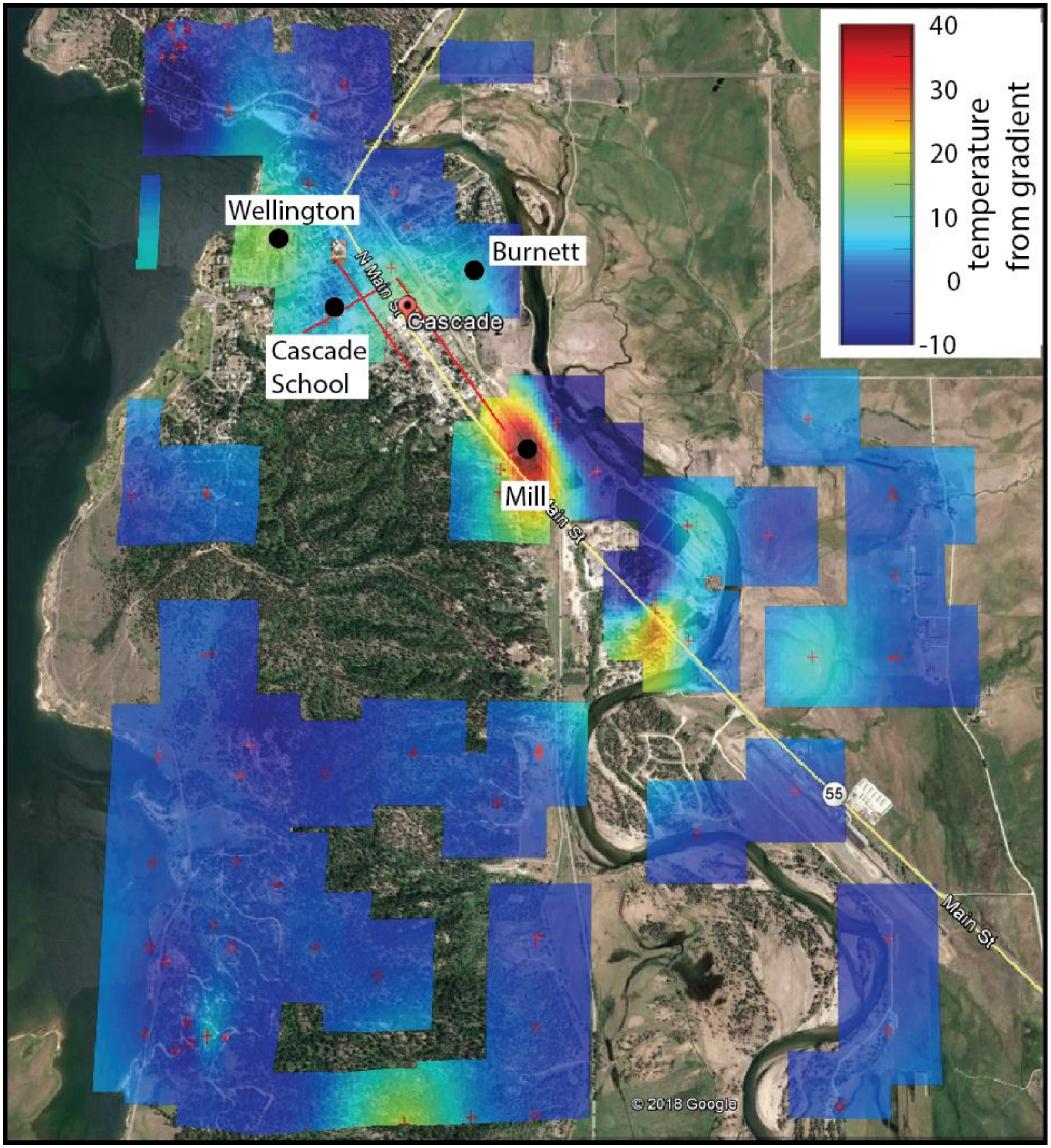

Figure 5. Deviation temperature map calculated by subtracting the average regional temperature from the measured temperature at well bottom (see Figure 4). The map is masked at distances beyond 800 feet from the nearest well. Note that temperatures in the granite hills mostly represent average gradient values. The red zone south of downtown is the anomalously high temperature mill site. Most of the deep downtown wells show higher than average temperatures. This suggests a higher fracture density beneath town when compared to the granitic hills to the west.

The Figure 5 map shows deviation from the regional geothermal gradient superimposed on the aerial photo for the Cascade region. This map overlay was calculated from the Figure 4 data for each well in the IDWR database. The average gradient temperature at the well depth was subtracted from the measured bottom hole temperature to identify anomalously high temperature wells. We then masked the region where no measurements were available. The largest temperature anomaly is for the Mill site (Rec District) well where measured temperatures (100° F) are about 40° F above the regional gradient at 245 feet depth. Also, many other deep wells in the downtown region show bottom hole temperatures between 10-20° F above the regional geothermal gradient. For example, the 1085 ft deep Wellington well has a bottom hole temperature of 81° F (15° F above average). This well lies at the intersection of the prominent north-trending fracture (purple arrows on Figure 3 and 6) and the southern limit of the northern strand of the Cascade fault (Figure 3). Anomalously low temperatures are mostly found along the Payette River and Cascade Reservoir, as surface water has likely influenced groundwater temperatures. Wells that were drilled in the granitic hills to the north and west of town typically show average temperatures. Assuming these temperatures and locations logged by drillers are accurate, this suggests that no dominate or controlling fracture system is evident in the hills to the west of town. This conclusion supports the use of geophysics to map subsurface geology without drilling.

Geophysical surveys

To explore for faults/fractures and to map bedrock depth beneath the Cascade region, we conducted two geophysical surveys. First, we acquired a regional magnetic survey to search for variations in total magnetic field that would represent faulted or offset granitic bedrock. Second, we conducted seismic surveys in select locations to identify and characterize fractures in the bedrock.

Magnetic survey

Many geologic rocks (including granite) contain high susceptibility magnetic minerals while sediments (colluvium) typically measure low magnetic susceptibility values (that depend on their mineral content). The total magnetic field falls off with the square of the distance from a magnetic body. Thus, if there is a large change in rock depth, the total magnetic field will be reduced. If the magnetic rock is vertically offset along a fault, we expect to see a linear trend that represents the fault surface.

We collected 29 miles of ground-based magnetic data along the streets of Cascade and adjacent farm fields using a Geometrics MagMapper 850 ‘walking magnetic gradiometer’ and a Geometrics 856 base station (Figure 6). The magnetometer measurements are highly sensitive to cultural noise (power lines, cars, other metal objects), so significant signal processing is needed to separate, isolate, and identify rock properties from cultural signals. To attenuate near surface cultural signals from deeper geology, we chose to remove data points that are greater than 2 standard deviations from the mean and upward continue the total magnetic field by 100 m (330 ft). This approach is equivalent to collecting the magnetic data above the land surface by the upward continued value and reduces the effect of localized magnetic sources from cultural signals.

The results of the magnetic survey show the highest total magnetic field values are observed in the granitic hills to the west of Cascade and the lowest values are found through the central portions of town to the west of the Payette River where mountain slope colluvium is mapped (Figure 3 and 6). This increasing depth to bedrock beneath town is confirmed by drillers logs and the Petty and Trexler (2008) geothermal report and suggests that no large offset fault extends beneath town. Similar to the topographic map, the magnetic map points to a right-angle bend near the western termination of Spring Street that may reflect the changing Cascade fault geometries beneath the western portion of town (green dashed lines on Figure 6). Along the north-south lineation (bracketed by purple arrows on Figure 6), the high temperature Wellington well is located, consistent with this surface lineation extending to depth where geothermal waters can rise. This right angle bend may be a place for further geothermal exploration. Additional northwest-trending lineations (green dashed) may promote greater fluid flow.

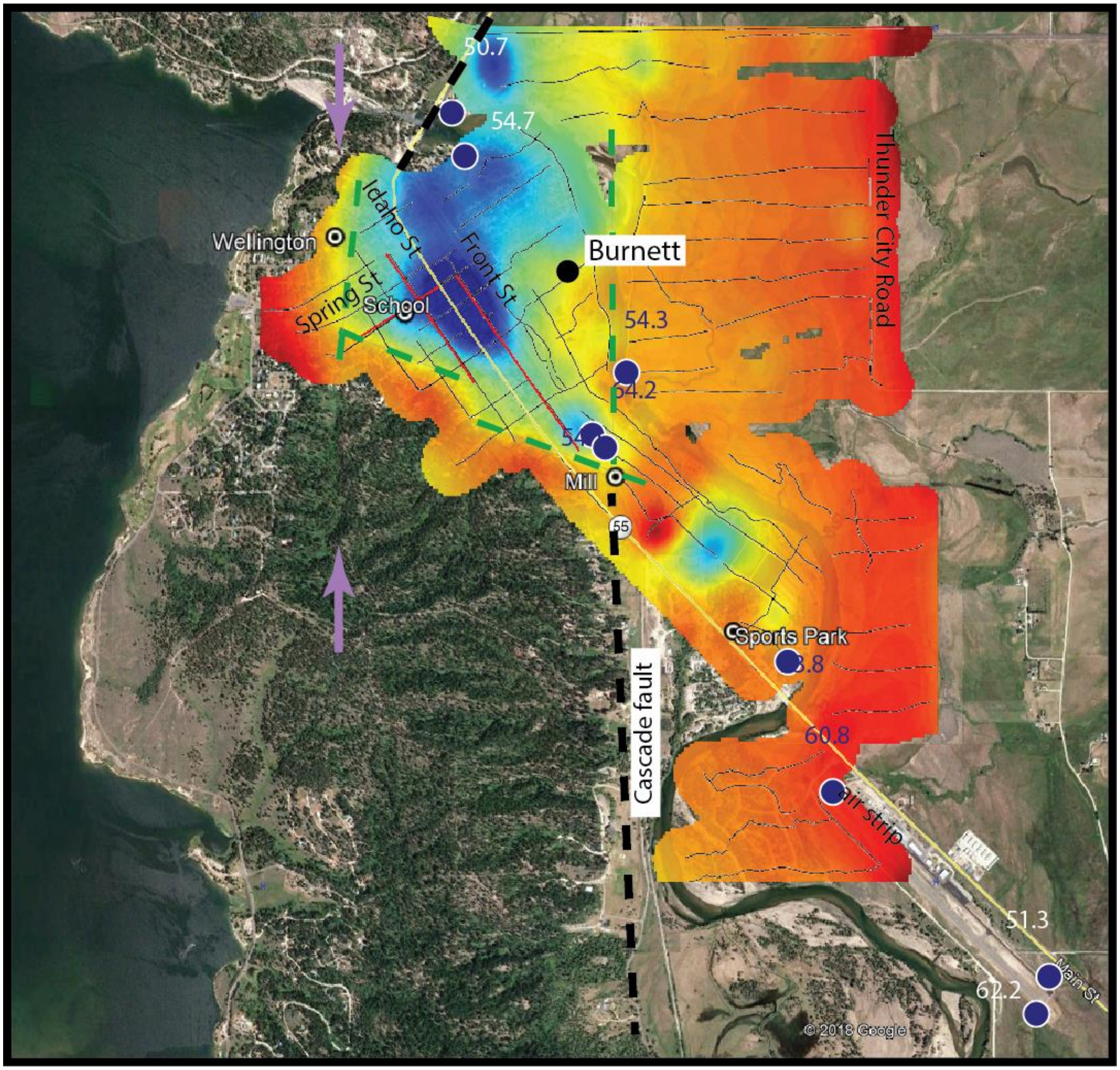

Figure 6. Upward continued (100 m) magnetic survey results with highs (red) occupying the hills to the west of Cascade and lows (blues) beneath the downtown Cascade area. Gray lines represent profile locations used to generate the map. Deep wells are labeled and 2 m temperature probe data are noted. Note that values away from survey lines are extrapolated values and not represented by measured signals. Black dashed line represents the mapped Cascade fault. Green dashed lines highlight linear trends on the magnetic survey map.

The eastern and southern portion of the survey shows a magnetic high region (Figure 6). On the farm fields to the east of the Payette River, few water wells logs are available (Figure 3). Because of the greater depth to granite in this region (from a few wells and from seismic results), we conclude that high susceptibility sediments are present to the east and south of Cascade (from a different sediment source than the downtown region). The boundary that separates high and low magnetic zones lies along the northern extension of the north-south Cascade fault segment along the Payette River (east of downtown and green dashed line on Figure 6). The drillers logs note high temperatures (72° F at 260 ft depth) within interbedded clays and sands (City of Cascade wells) near the airport (east of the fault), and Mink (2014) found anomalously high temperatures in this area from a two-meter temperature probe survey (Figure 6). The Cascade fault is a normal fault with presumably a 40-70° dip to the east. This high temperature zone may reflect the interaction of the fault surface at depth with the granitic bedrock (of unknown depth). The change in bedrock geometry from north-trending to northwest-trending immediately west of the Mill well at an eastward deflection of the Payette River may point to intersecting faults and/or fractures that promote geothermal circulation from great depths (green dashed lines on Figure 6). This area is worth further exploration. It is also worth noting that local high and low magnetic zones may be related to fill and other cultural noise sources in this area.

In summary, the magnetic survey shows high susceptibility granite in the hills to the west of town, low magnetic susceptibility colluvium in the downtown area, and intermediate susceptibility sediments (interbedded sands/clays) in the areas to the east of the Payette River and east of the Cascade fault. We find evidence to extend the north-trending Cascade fault farther north and beneath the Payette River east of downtown. The termination of low susceptibility colluvium near the Mill well coincides with the intersection of a northwest-trending magnetic lineation with the Cascade fault. This interaction of faults and/or fractures is consistent with the elevated temperature zone (Figure 5). The right angle bend in magnetic bedrock to the west of town (near the Wellington well) may also provide elevated ground water temperatures through interaction with faults or fractures.

Seismic surveys

We conducted three seismic surveys through Cascade; along Front Street, Idaho Street, and Spring Street and a profile along Thunder City Road. We acquired the data using a 500 lb accelerated weight drop source and a seismic land streamer system to map bedrock depth and to search for low seismic velocities beneath bedrock that may indicate the presence of faults or fractures. For the survey through town, we used a 48-channel, 1 m spaced geophone array. For the Thunder City survey, we used a 96-channel 200 m long streamer to map bedrock to greater depths.

Seismic velocities of unconsolidated saturated sediments are typically between about 1,500-2,000 m/s. Loosely consolidated rock velocities are typically between 2,000-3000 m/s and consolidated rock velocities are typically greater than 3,000 m/s. Laterally changing seismic velocities beneath the top of bedrock are likely related to changing rock properties (e.g. fractures) within the granite. Low velocities beneath the top of granite (bold contours on Figure 7) point to regions where more fractures are present.

Seismic results along Front, Spring and Idaho Streets all show consolidated rock velocities between 4-15 m (13-50 ft) depth, consistent with drillers logs for the area. These results suggest that no large step in bedrock appears along these profiles that may provide a conduit for upwelling geothermal fluids. The results also show high and low velocity zones every few hundred feet, consistent with a more fractured bedrock when compared to the adjacent hills. Laterally changing rock velocities may point to localized fractures. For example, the Cascade School well was drilled in a low velocity area adjacent to high velocity rock. This low velocity area may be responsible for the anomalous water temperatures, but the School well was drilled to depth that exceed our seismic imaging capabilities for this location and the shallow results do not necessarily point to deep fractures. It would be difficult to fully map fractures beneath Cascade due to the degree of fracturing that the seismic data point to.

We acquired a 1420 m (4660 ft) seismic profile along Thunder City road to the east of Cascade to search for any northeast/east-trending bedrock steps that extend from the hills east of town to the downtown area. A conspicuous bend in a creek to the east of this road (best seen on Figure 3) suggested a fault or fracture zone may cross this road and extend to the west through town. Figure 8 shows the results of this survey where we image about 800 ft of sediment above a strong amplitude (large density contrast) reflector. Because no wells are located along this profile, it is difficult to say for sure what this reflector represents. We interpret this reflector as top of bedrock, but it Is not clear whether this is granite or a younger basalt flow. The thickness of sediment is significantly greater than any region within the town of Cascade. There is no large offset step along this profile, but the seismic character changes about position 900 m where the flat lying reflector becomes a more undulating surface. It is possible that this zone represents fractures within the bedrock. Below this reflector, a ~20° north-dipping reflector is also observed. This reflector may represent the top of granite that shallows to the south. Regardless of the lithology above and below this boundary, we observe no reflector step that would point to a fault or target for geothermal development. However, the thickness of sediment along this profile is significantly greater than below the downtown area. This change in sediment thickness to the east of town is consistent with the northern extension of the Cascade fault near the Payette River. Additional seismic imaging is needed to characterize bedrock geometry across the Cascade fault.

In summary, the seismic survey shows the shallow bedrock beneath downtown Cascade is highly variable in seismic velocity. This variability is best explained with large variations in fracture density. There is no apparent change in bedrock depth along any of these profiles, suggesting that there is no major geothermal system driven by a buried fault beneath downtown. The localized fractures are likely the source of elevated groundwater temperatures. This observation suggests geothermal prospects may be limited within the downtown portion of Cascade. The increase in bedrock depth along the Thunder City profile compared to the downtown profiles suggests that east-west seismic profiling would be beneficial to identifying/characterizing the Cascade fault. The optimal location for an additional seismic profile would be across the Payette River between the Mill well and Thunder City Road.

Recommendations

This report suggests that the Cascade, Idaho region contains anomalously high geothermal gradients and exploitation of this resource is possible. We did not identify any through going fault or fracture system beneath downtown Cascade, but the intersection of magnetic lineations at the Mill well suggests this site may be best for geothermal development. There is no evidence for intersecting lineations to the south of the Mill well. Cultural noise prevents more detailed exploration of fractures with magnetic methods. Seismic methods point to large changes in granitic bedrock that are best explained by localized fractures. The increase in bedrock depth to the east of the Cascade fault may host increased fluid circulation. Where this fault intersects northwest-trending structures, the highest temperatures have been identified.

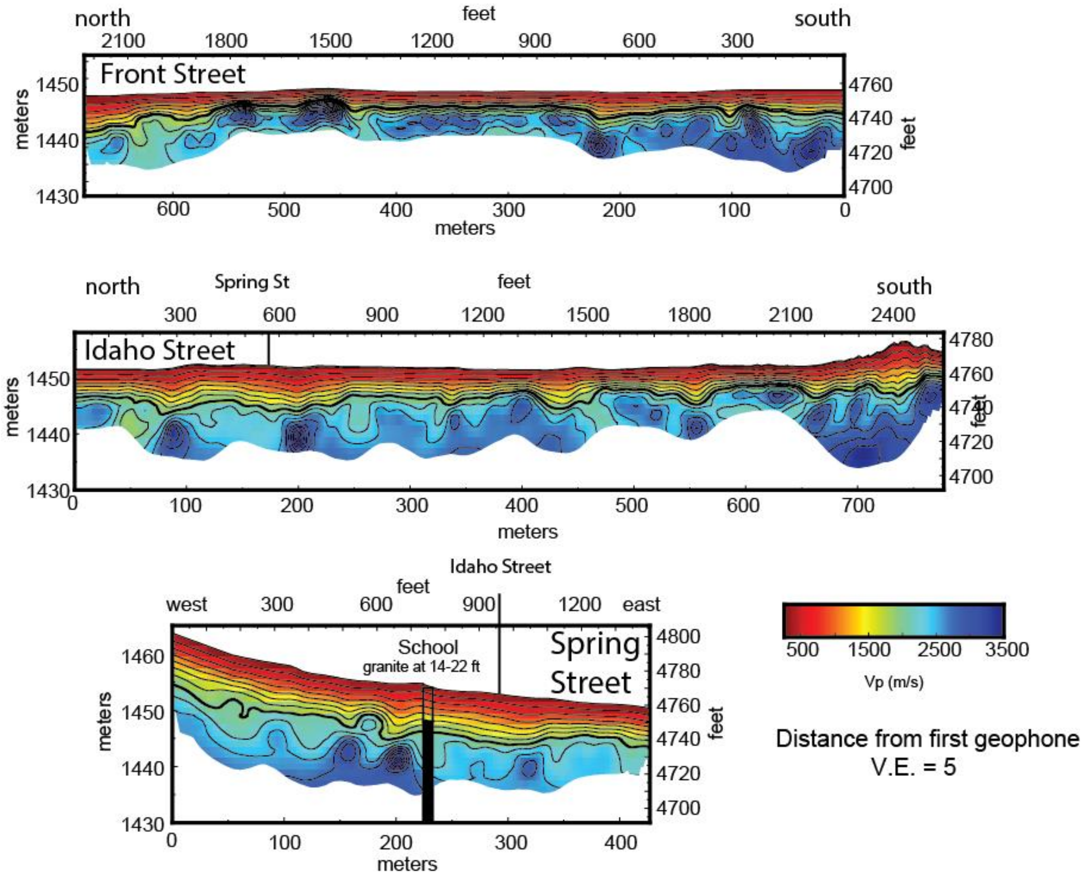

Figure 7. Seismic refraction results. The bold contour is at 2,000 m/s, consistent with the transition from sediment to rock.

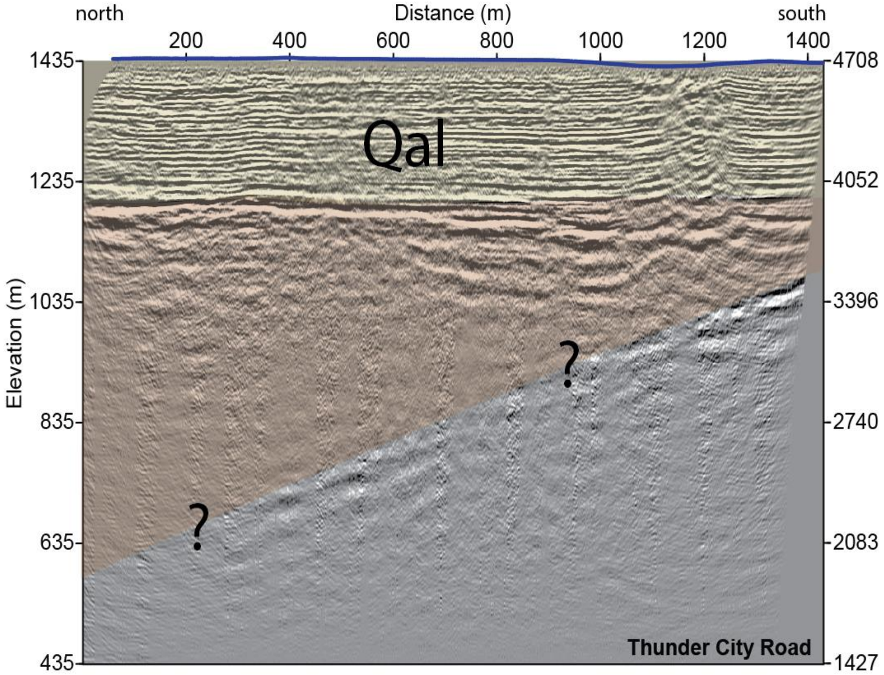

Figure 8. Seismic reflection results along Thunder City Road (see Figure 3 for profile location). Vertical exaggeration is about 1:1

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