

# GP41A-0981: Investigating the structure of a shallow geothermal system in the Upper Arkansas Valley of Colorado using a combination of potential field and seismic geophysical data



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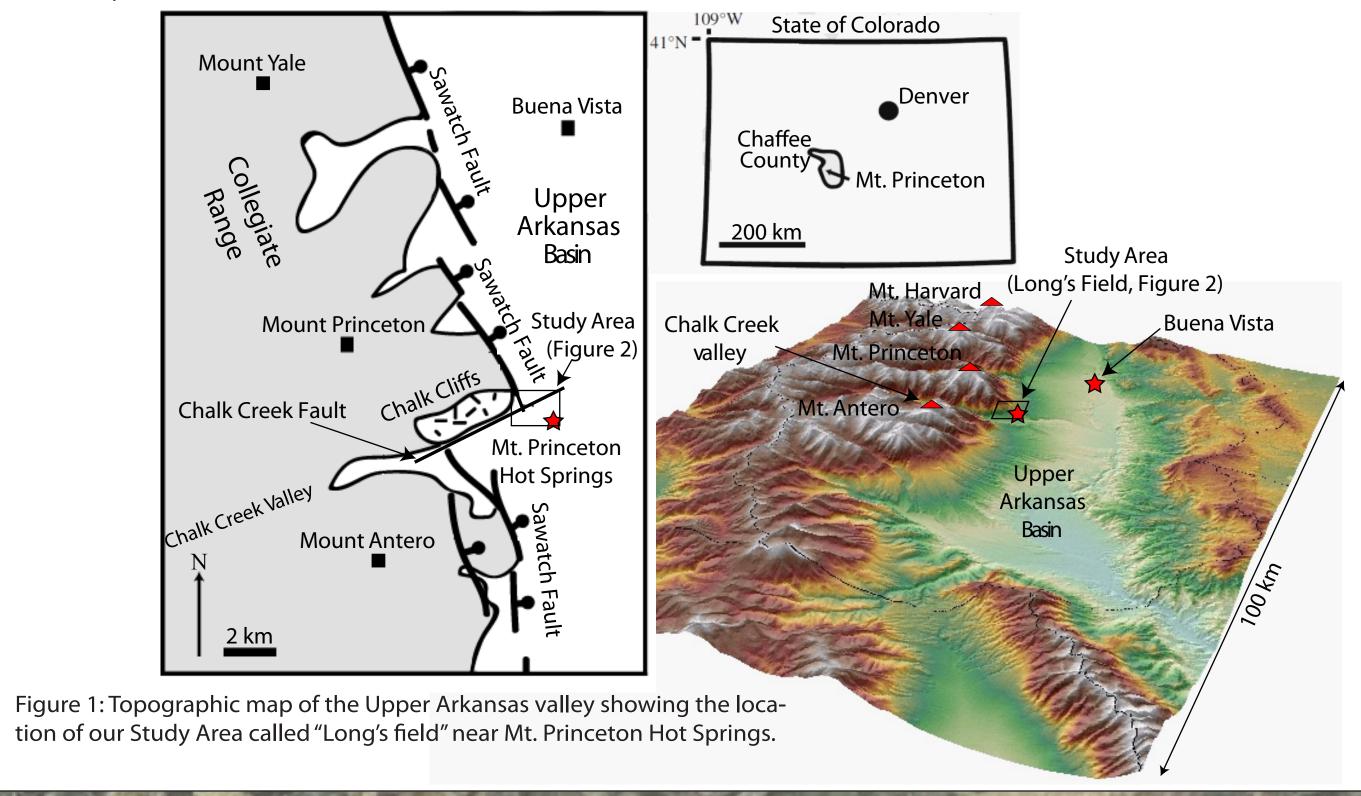


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## (1) INTRODUCTION

SIGMA

Our geothermal study area is in the Upper Arkansas valley that is the northernmost extensional basin of the Rio Grand Rift (Figure 1). The basin is a half-graben bordered to the west by a range-front normal fault (Sawatch Fault) that strikes north-northwest along the eastern margin of the Collegiate Range. This fault is laterally offset by a right-lateral strike-slip fault (Chalk Creek Fault) which coincides with an area of hydro-geothermal activity and the Mount Princeton hot springs. We use 3-D seismic, selfpotential, and DC electrical resistivity data to investigate an area of upwelling hot water in a site that is here termed "Long's field" after the surname of the property's owner. The DC electrical resistivity and self-potential data previously identified an area of upwelling hot water that was interpreted to be the consequence of small tensile fractures located 500 m south of the intersection between the Sawatch and Chalk Creek faults (Richards et al., 2010). These tensile fractures are likely related to the local dilatant stress field that have been shown to radiate from fault tips at intersecting faults in regions with similar structural geology (Roberts, 1996). Our objective is to identify and characterize these fractures through the use of 3-D seismic, self-potential, and DC electrical



#### (2) BACKGROUND

Long's field is composed of Quaternary glacial till and alluvial sediments overlying geothermally altered Tertiary quartz monzonite. The field is located at a lateral transition between hot and cold ground water as observed in water wells for the area (Figure 2). Hot water wells are aligned in an east-west direction with the most northerly and southerly wells defining a 200 m wide corridor with geothermal activity. Self-potential and DC resistivity surveys helped explain the possible reasons for the pattern of hot water wells in the valley (Richards et al., 2010) and identified specific areas of upwelling hot water that were interpreted to coincide with a fault passing through the self-potential anomalies shown in Figure 2. To further investigate these upwelling hot water events, we designed a 235 m by 220 m high resolution multicomponent 3-D seismic survey to coincide with the largest upwelling event located at the eastern portions of the self-potential dataset (Figures 2 and 3).

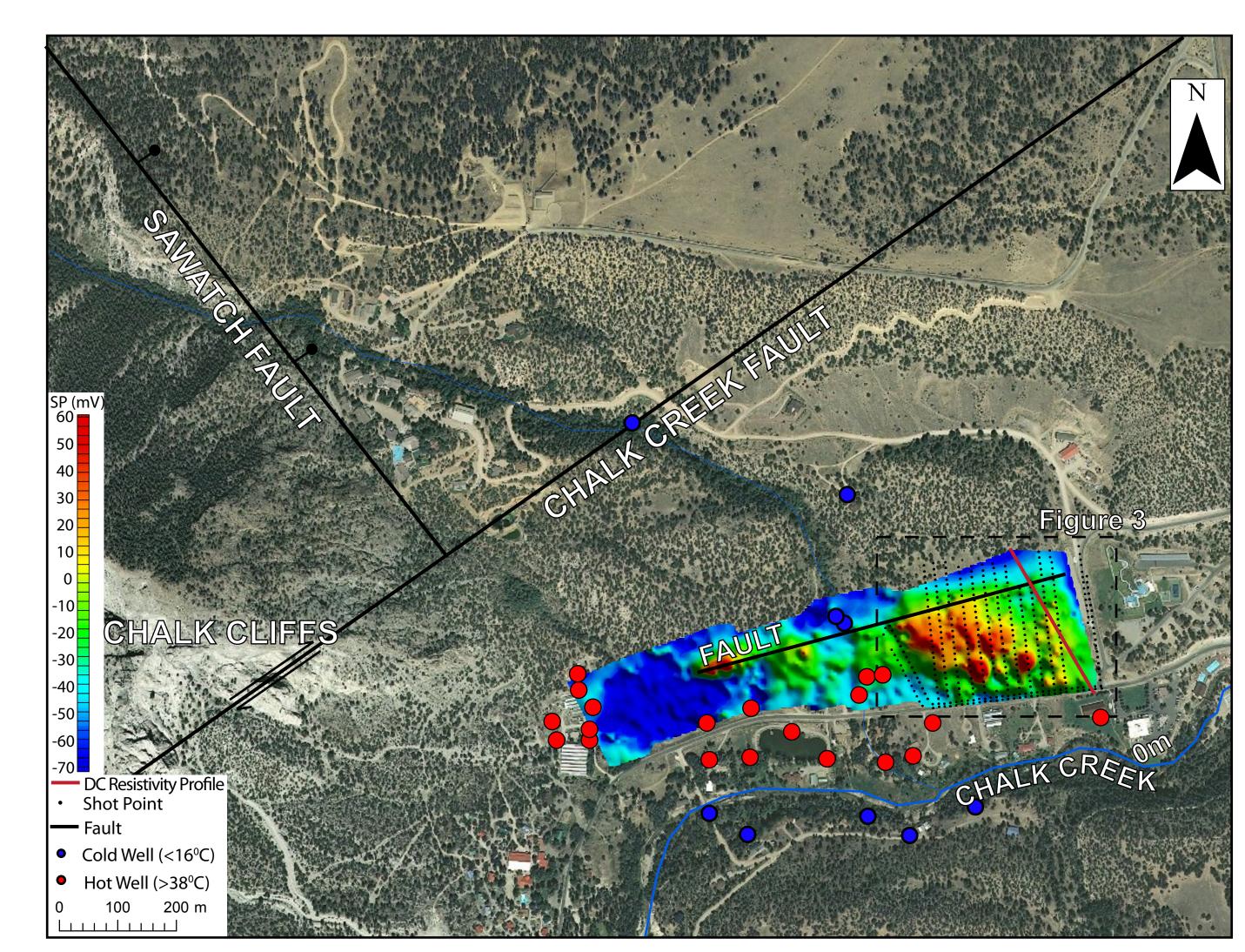
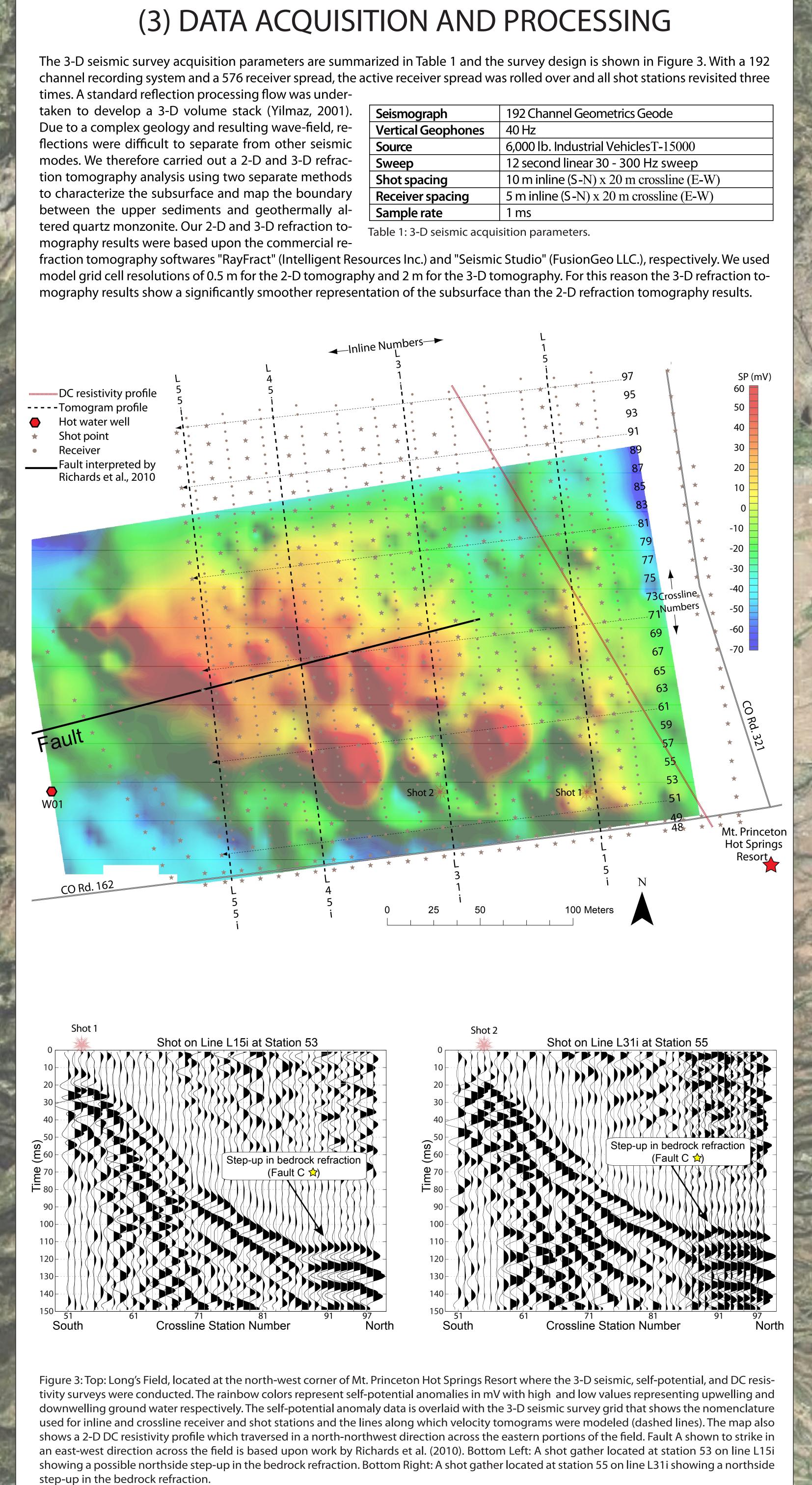
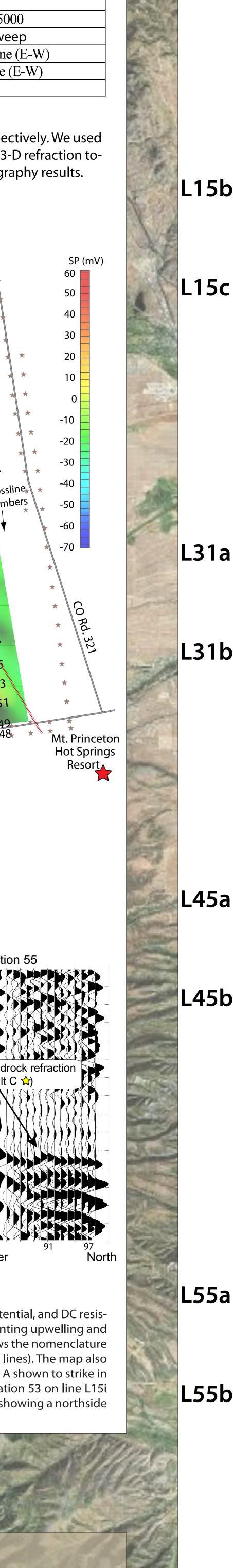
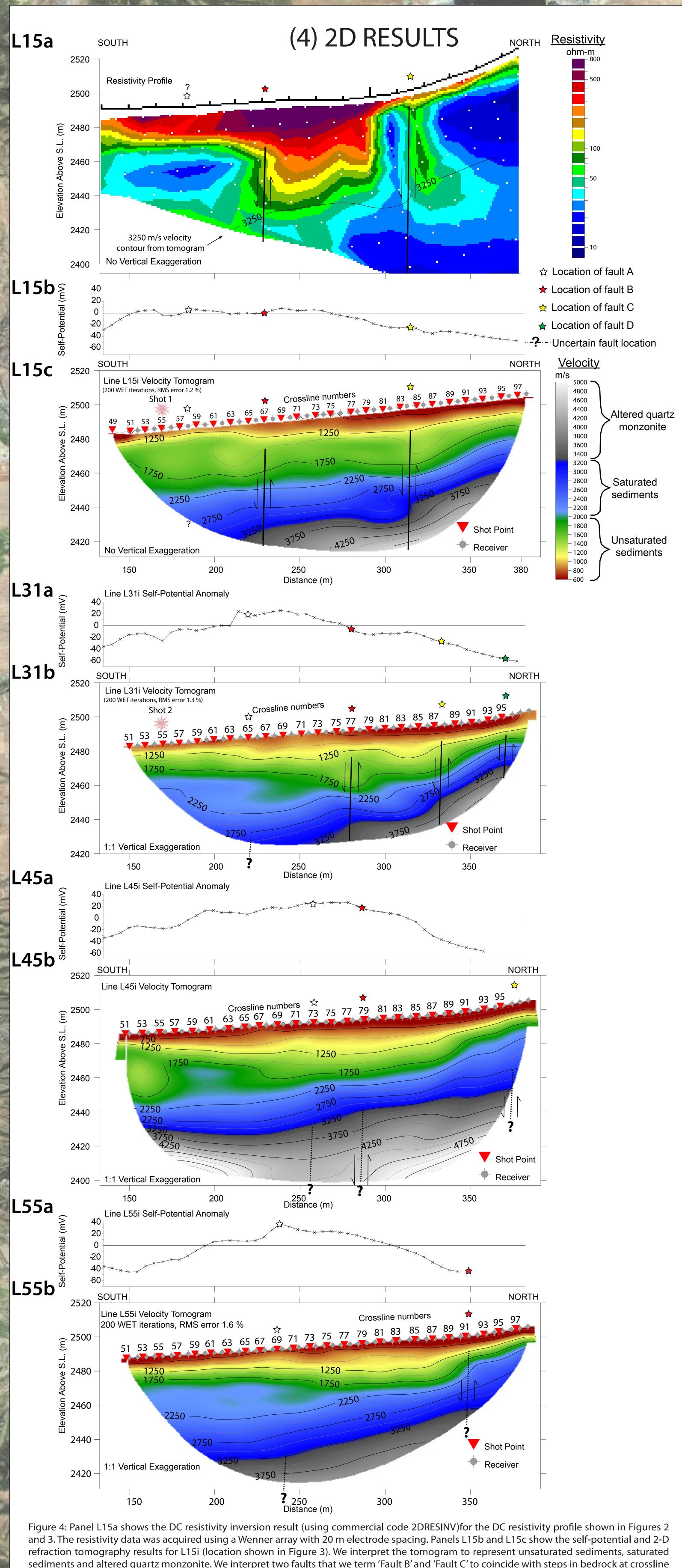


Figure 2: Major fault systems and Long's Field located at the north-west corner of Mount Princeton Hot Springs Resort where the 3-D seismic, selfpotential, and DC resistivity surveys were conducted. The rainbow colors represent self-potential anomalies in mV with high (red) values indicating upwelling ground water and low values (blue) representing downwelling ground water. The self-potential anomaly data is overlaid with the 3-D seismic survey shot points that are shown in more detail in Figure 3.







stations 67 and 84 respectively. The interpreted faults correspond with lateral contrasts on the resistivity profile. We have also represented the

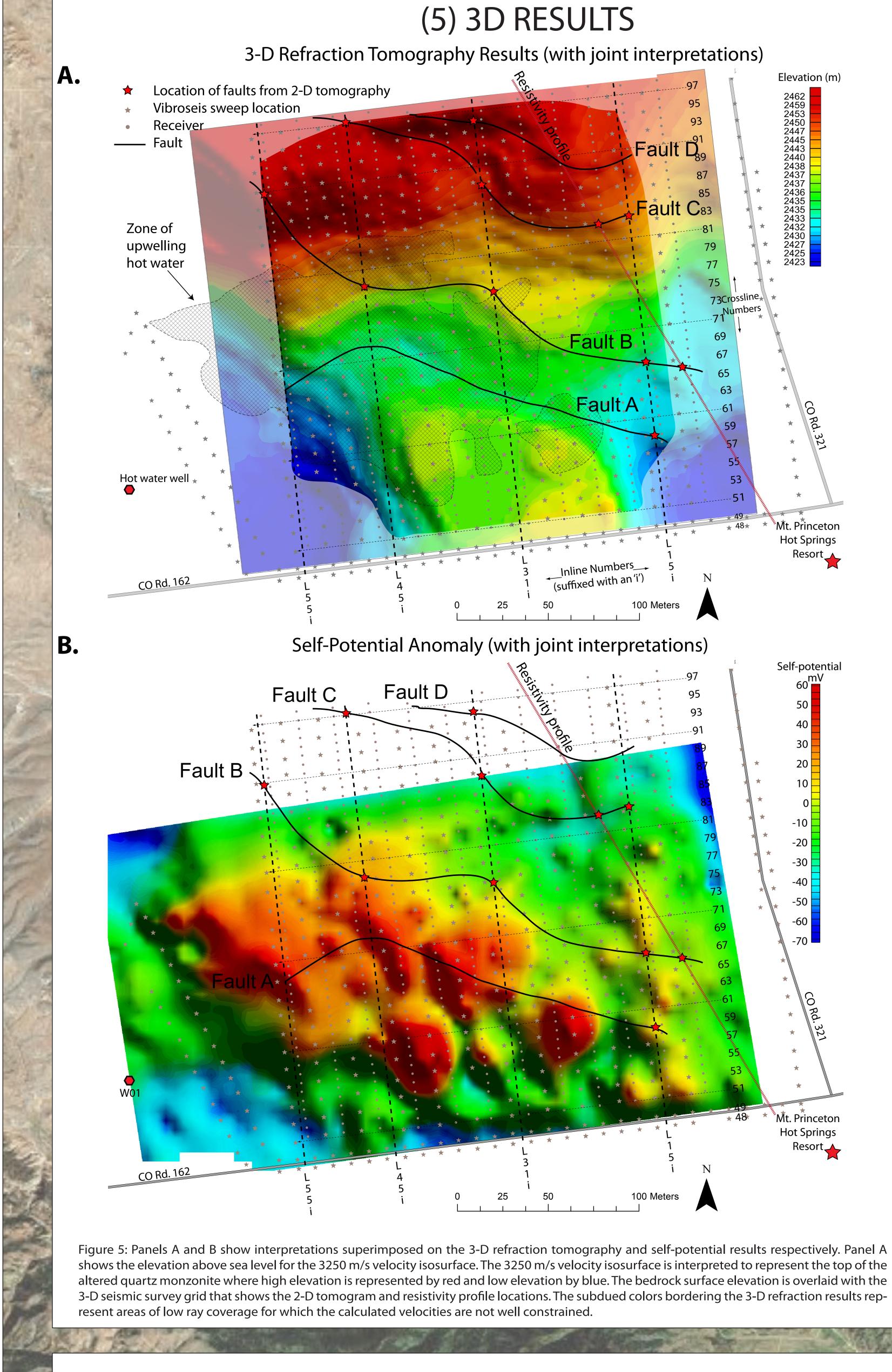
location of the bedrock low from our 3-D refraction modeling results using a white star and we interpret this to coincide with the fault interpreted

using self-potential data by Richards et al. (2010) (Figure 2). Panels L31a through L55b show the self-potential and 2-D refraction tomography re-

sults for lines L31i, L45i and L55i (locations shown in Figure 3). Our interpreted location of Faults A through D are shown on each of the these

panels along with a shot gather from station 55 on line L31i. The shot gather shows a step-up in the bedrock refraction at station 91 that is

common to many of the shots shooting northwards in the eastern half of Long's field.



#### (6) DISCUSSION & CONCLUSIONS

- Linear moveout analyses were performed on the two dominant refractions observed in the 3-D seismic survey shot gathers. This linear move-out analysis found the velocity for the first refraction to be from 1750 m/s to 2100 m/s while the second refraction was found to be from 3100 m/s to 3300 m/s. Using well logs and surface geology information as controls, we interpret the first refraction as the interface that separates unsaturated and saturated sediments and the second ~3200 m/s refractor as the bedrock surface which is a combination of quartz monzonite and kaolinite depending on the degree of alteration.
- The 2D and 3D seismic tomography results show the bedrock dipping to the south with average bedrock dips between 4° and 20° and localized maximum dips of up to 50° (e.g. stations 73 and 85 on L31i and station 77 on L15i).

The low resistivity (< 100 ohm-m) and seismic velocity (~3200 m/s) values for the quartz monzonite (Figure 4) suggest that it is highly fractured and saturated. The low resistivity values suggest that it has been altered to kaolinite as observed on the exposed Chalk Cliffs located 500m to the west.

Abrupt lateral contrasts in the resistivity profile suggest offset stratigraphy that we interpret as near vertical faults. These offsets are also observed in the velocity tomograms with the most significant offsets being Faults B and C in the western half of the

field (L15b and L31b, Figure 4).

- The smaller scale self-potential anomalies in Figure 5b have a NW-SE trend that can also be observed more subtly in the 3-D tomography results (Figure 5a). We use these mapped NW-SW trends to tie together the faults observed in our 2-D data (Figure 4) and show four interpreted faults in Figure 5. Fault C lies along the northern margin of the self-potential anomaly and may therefore be a northern bounding fault for upwelling hot water. This interpretation is consistent with well temperature data and self potential data further to the west that shows a boundary between hot water wells to the south and cold water wells to the north (Figure 2).
- We interpret Fault A to coincide with an axial low in the bedrock that is also aligned with the larger scale positive self-potential anomalies to the west (Figure 2). It is possible that this bedrock low is not real and is instead an apparent low caused by a localized slow down in bedrock velocity. This would be representative of changing bedrock conditions caused by upwelling hot water degrading the quartz monzonite, as suggested by the corresponding positive self-potential anomaly. It is inconsequential as to whether the bedrock low is real or apparent because a bedrock low or velocity slow down could both be interpreted to represent an area of structural weakness and a pathway for upwelling hot water.
- Our seismic tomography results show NW-SE striking faults and a bedrock low projecting in the direction of Mount Princeton Hot Springs resort to the SE. These results strengthen results from previous self-potential and DC resistivity studies that interpreted the self-potential anomalies in Figure 2 as being the source of the Mount Princeton Hot Springs (Richards et al., 2010)

These results exemplify the combined use of seismic, self-potential and resistivity data to identify fault structures responsible for upwelling hot water in hydrogeothermal systems; information that can be used by local stakeholders to make better informed decisions about where to drill wells in order to efficiently develop their geothermal resources.

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