Full Tensor Gradiometry imaging of a blind geothermal play in the Crescent Valley Geothermal Field of northern Nevada, USA

Alan Morgan, James Brewster, Colm Murphy - Bell Geospace*

Summary

Faults play a critical role in fluid flow and conduction of heat in geothermal systems by facilitating or stifling fluid flow. Identification of fault geometry is key to determining prospectivity. Faults buried under recent alluvial cover are challenging to identify without benefit of seismic data and full geometric interpretation of such faults often require the acquisition of expensive 3D seismic data. Gravity data is a cost-effective solution to identify geometry of faults, but the time required to collect data may be lengthy or land access may be restricted. Airborne Full Tensor Gradiometry (FTG)

FTG data acquired over the Crescent Valley geothermal field in Nevada reveals previously unmapped faults and identifies their relationship to the regional structural framework. Intersections of faults are additionally identified through lineament extraction methodologies, which in turn contribute to the identification of favourable geothermal prospects.

A buried relay ramp is identified through the interpretation of the FTG data that was not previously evaluated for geothermal prospectivity.

Introduction

The Crescent Valley geothermal field is a convection type geothermal play that is located along the eastern edge of the Northern Nevada Rift within the Basin and Range province of Nevada. Several hot springs are located along the eastern edge of the rift, with the Beowawe Hot Springs, Dry Hills Hot Springs and Hand-Me-Down Creek Hot Springs being the most proximal to the study area.

The assessment of faults is key to identifying favourable geothermal plays within an extensional basin convectional geothermal play. Faults act as a conduit for heat flow and may also contribute to localized permeability when compared to the local stress regime. Faults with surface expression are readily mapped by both remote and field methods. Faults covered by sedimentary fill are challenging to map and often require expensive data acquisition to yield results. 3D methods are often out of budget for geothermal exploration, leaving possible missed resources due to the limited coverage of 2D methods.

Full Tensor Gradiometry was acquired over the Crescent Valley geothermal field with a nominal spacing of 200m in 2005 for the purpose of identifying hydrothermal gold prospects. Additional constraining data were published in 2018, providing a structural fault framework comparable to the results of FTG acquisition to investigate possible missed structures

Theory and Methodology

Gravity methods offer the ability to detect density contrast with dependence on the magnitude of density contrast, size of the mass excess or deficit and distance between source and instrument. Faults in an extensional setting in the form of normal faults commonly exhibit density contrast where sediments above the hanging wall are lower density and sediments below the foot wall are higher density. The amount of offset will often dictate the magnitude of the gravity anomaly. Strike-slip faults don't always show density contrast along the entire trace of the fault and so, present a challenge to being interpreted via gravity methods. Anomaly offsets and truncations are indicators of strike-slip faults.

Qualitative methods for detecting faults include grid enhancements and derivative calculations. Historically, vertical derivative and total horizontal gradient enhancements have been utilised to delineate basin geometry and detect edges of buried geologic features including faults. The directional sensitivity of Full Tensor Gradiometry detects these changes directly without enhancement. In addition, information related to shape and structural style of subsurface structural complexity within basins are directly mapped.

Faults are one of the highest expected density contrasts, however, additional sources of density contrast are expected to be encountered that are related to geothermal activity. Silica precipitation in pore space is commonly encountered in active geothermal settings where mineral rich waters cool when interacting with near-surface water of meteoric origin. Such mineralization increases density by as much as 0.4g/cc (Folsom et al.,2020).

Full Tensor Imaging is a form of ternary imaging which is traditionally utilized with airborne radiometric data. The ternary imaging helps to organize the gradients inherent in the Full Tensor Gradiometry into a single meaningful grid by separating shades of red, green and blue, which are individually assigned to vertical, horizontal and curvature components. Equal amounts of each component will result in white colours, while disproportionate amounts result in varying shades of red, green and blue. Low density, high

Full Tensor Gradiometry imaging of a blind geothermal play in the Crescent Valley Geothermal Field of northern Nevada, USA

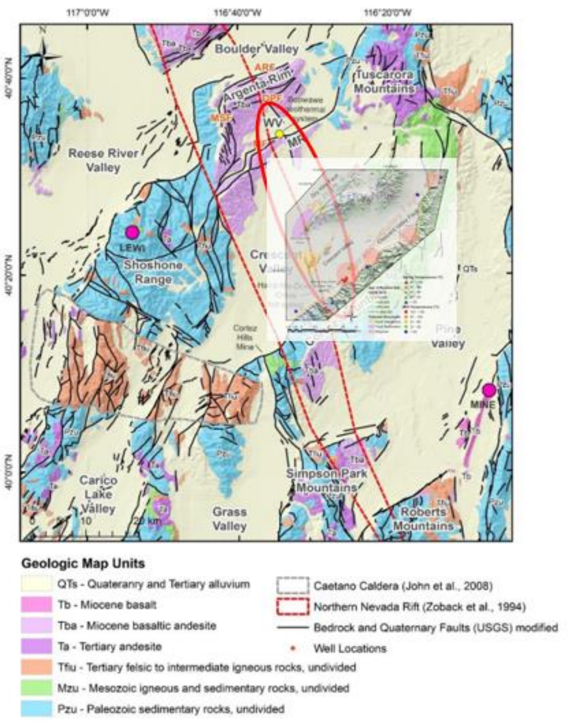

Figure 1: Regional geologic map showing area of interest overlain by McConville 2018 study area (Modified by Morgan et al., 2021).

curvature and high horizontal gradient will yield green to cyan colours while high density, high curvature and high horizontal gradient will yield colours from yellow to white. Lineaments extracted via tilt and total horizontal gradient methods can additionally be introduced in greyscale to reinforce locations of interpreted faults.

Crescent Valley Field Study (2018)

Favorable locations are identified in a geothermal study performed in 2018 which covered the southeastern rim of Crescent Valley (McConville 2018). A regional geologic map with McConville's area of interest overlain is shown in Figure 1.

This work utilizes regional and ground gravity and 2D seismic reflection profiles to interpret geometry of faults. Ground gravity stations are irregularly spaced over the area of interest with the station spacing concentrated to the southwest of the Dry Hills. Vertical derivatives of the ground gravity reveal locations of intersecting faults, where geothermal prospectivity are considered more favorable.

Both the Cottonwood Creek Fault and Dry Hills Fault are clearly delineated in the vertical derivative enhancement of the ground gravity data (Figure 3). Additional faults that were previously unmapped from the surface are identified by McConville.

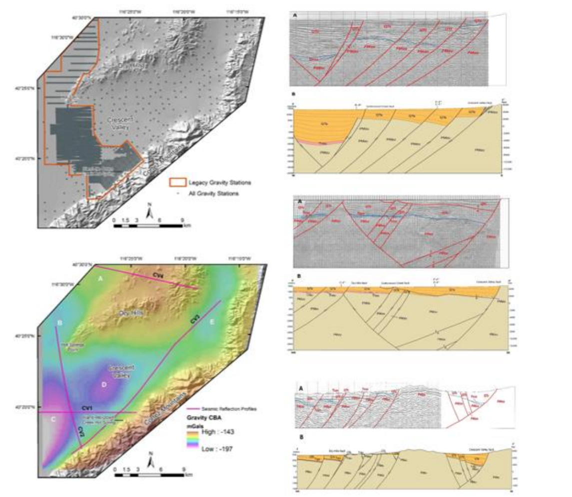

Figure 2: Ground gravity station map (upper left), Vertical gravity data (lower left) along with 2D seismic reflection profiles (right) used to evaluate geothermal prospectivity over part of the Crescent Valley geothermal field (McConville 2018).

Full Tensor Gradiometry Data

Full Tensor (Gravity) Gradiometry data acquired in 2005 at a line spacing of 200m are terrain corrected to a value of 2.7g/cm^3. The resulting terrain corrected data show strong correlation to both the Cottonwood Creek Fault and the Dry Hills Fault, while revealing additional faults to the north of the Dry Hills that were not within the boundaries of contemporaneous geothermal lease blocks.

Lineaments are extracted from the FTG data which are expected to align with density contrast associated with normal faults over the FTG survey area. Faults are interpreted from the extracted lineaments along with the Full Tensor Imaging products.

Full Tensor Gradiometry imaging of a blind geothermal play in the Crescent Valley Geothermal Field of northern Nevada, USA

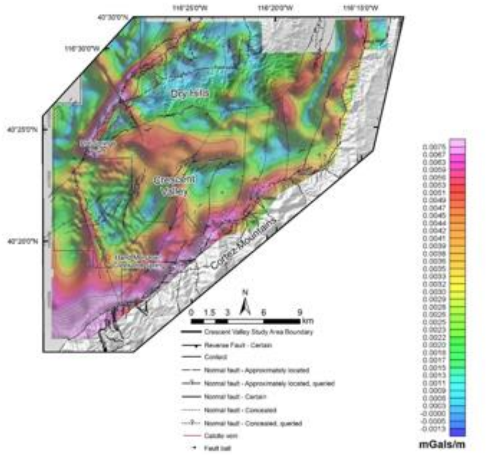

Figure 3: Vertical Gravity Gradient (Tzz) enhancement of the ground gravity data reveal close correlation to mapped faults while identifying additional faults between the Dry Hills and the Hand-Me-Down Creek Hot Springs area (McConville 2018).

Results

Full Tensor Imaging (Figure 4) reveals a pattern of fault intersections consistent with a schematic representation of a relay ramp to the north of the Dry Hills Hot Springs. Additionally, similar relay ramps are interpreted along the Cottonwood Creek Fault. Fault terminations are imaged with greater clarity where ground gravity stations were sparse.

Conclusions

FTG data are sensitive to shallow density contrast that is associated with the shallow faults expected to host geothermal prospects in the Crescent Valley geothermal field. Data resolution is comparable to the highest resolution ground data acquired over the area of interest, with the FTG data providing an improved image of fault terminations. FTG data is acquired with regular spacing that gives the interpreter an advantage when applying enhancements to reveal linear trends associated with faults in the subsurface. The data is acquired and processed rapidly, and offers coverage which is able to image areas where ground crews have limited access.

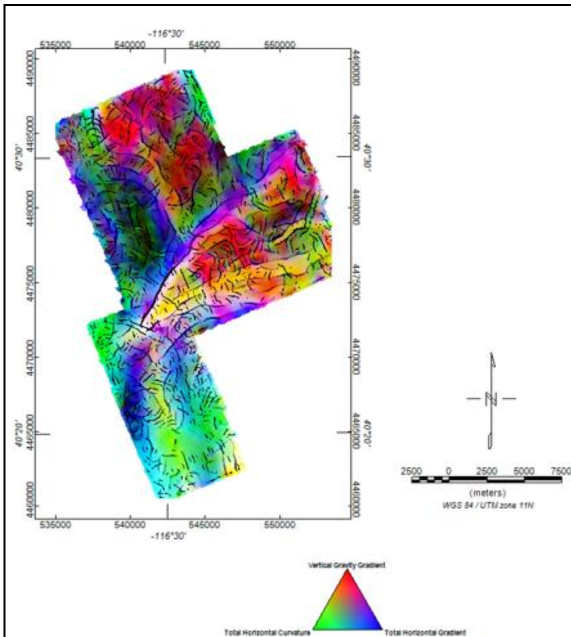

Figure 4: Full Tensor Imaging product combines Vertical Gravity Gradient, Total Horizontal Gradient and Total Horizontal Curvature to reveal complex fault networks beneath the surface of the Crescent Valley geothermal field.

References

Folsom, Matthew, Libbey, R., Feucht, D., Warren, I. and Garanzini, S. 2020. Geophysical Observations and Integrated Conceptual Models of the San Emidio Geothermal Field, Nevada. In *Proceedings of the 45th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, USA* 21p.

McConville, Emma 2018. Detailed Analysis of the Geothermal Potential in Crescent Valley, North-Central Nevada: M.S. Thesis, University of Nevada, Reno 135p.

Morgan, A., Murphy, C. and Brewster, J. 2021. The Utility of Full Tensor Gradiometry in Geothermal Resource Mapping: An Example from the Basin and Range Province of Nevada. 2nd Geoscience and Engineering in Energy Transition Conference 2021.