

Developing an Understanding of a Naturally Enhanced Geothermal System (NEGS™), Imperial County, California

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ABSTRACT

Much work has been done to further understanding of stimulating hot rock to be able to capture the heat. Davinci has focused on developing a better understanding of a hydrothermal system in high quality reservoir rock that is intensely naturally fractured due to local significant tectonism. We are suggesting a new term for this type of reservoir: *Naturally Enhanced Geothermal System* (NEGS™). The Imperial Valley of Southern California has been an historical geothermal province exploited by vertical wells drilled to recover heat by either flashing to steam or binary heat transfer methods of electrical generation. Davinci has used gravity, aeromagnetic, and 3D seismic data to supplement previous studies to characterize the direction and intensity of fractures in the pull-apart basin transfer zone between two segments of the San Andreas Fault called the Brawley Seismic Zone. Horizontal drilling to intersect the dominant fracture directions in high permeability reservoir is planned. No additional artificial stimulation is required to achieve high flow rates of high temperature water from these wells. With over 18,000' of high net to gross fluvial and lacustrine sediments, there is large undeveloped potential in this NEGS™.

Since the 1970s, the Imperial Valley of Southern California has been an important geothermal province, with vertical wells historically developed for both flash and binary power generation. DAVINCI EP is re-evaluating this resource through the lens of a new conceptual framework: the Naturally Enhanced Geothermal System (NEGS™) a hydrothermal reservoir in which tectonically induced pervasive fracturing provides permeability comparable to, or possibly exceeding, that achievable through artificial stimulation.

Using integrated gravity, aeromagnetic, and 3D seismic datasets, Davinci has delineated a structurally controlled transfer zone within the Brawley Seismic Zone, located between two segments of the San Andreas Fault. The results reveal a dense fracture network with preferred orientations favorable for horizontal wellbore intersection. A pilot horizontal drilling program planned for 2026 will test the NEGS™ model, quantify directional permeability anisotropy, and evaluate sustainable high-temperature flow from producers and injectors without hydraulic stimulation.

With more than 18,000 feet of high net-to-gross fluvial and lacustrine sediments and strong convective heat transfer, the Imperial Valley represents a substantial untapped resource base. If validated, the NEGS™ model could enable widespread geothermal development in tectonically fractured sedimentary basins worldwide — expanding access to sustainable, low-impact geothermal energy without reliance on artificial reservoir stimulation.

1. INTRODUCTION

The geothermal system in the Imperial Valley (IV) of Southern California has long been recognized as high heat hydrothermal system. Geothermal exploration and development began in the 1960's. There are 5 geothermal fields (GF) that have been developed across the area (Fig. 1). These GF have various specific geological differences, but all are primarily classified as hydrothermal GF and produce from clastic reservoirs containing brine. In some areas, faulting and fracturing plays a role in enhancing or reducing permeability. This type of geothermal system is differentiated from Enhanced Geothermal Systems (EGS) in that artificial fracture stimulation is not needed to provide commercial fluid flow from the hot reservoirs. This paper formally introduces and defines Naturally Enhanced Geothermal Systems (NEGS™) to describe hydrothermal system sweet-spots that are fractured by localized tectonic processes in clastic reservoirs, providing significant fluid flow from wells drilled either vertically or horizontally.

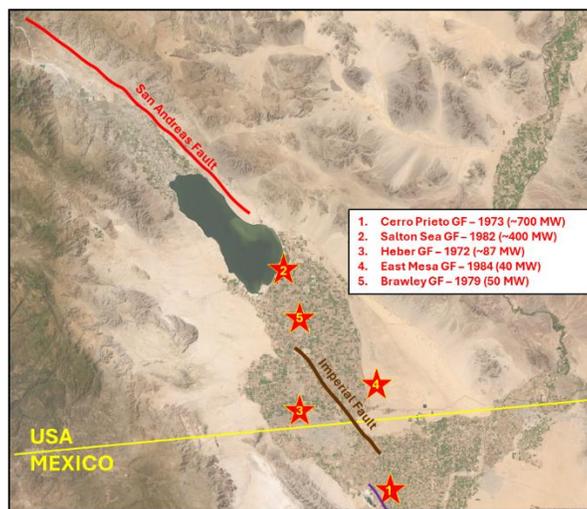


Fig. 1. Imperial Valley with locations of geothermal fields.

The Imperial Valley Geothermal Province is in the San Andreas Fault Zone (SAF), a right lateral transform plate margin separating the Pacific and North American Plates. Faulting characteristics in this area have been defined by earthquake activity, seismic data, detailed mapping of fluid flow within the various GF and, on the margins of the basin, from surface outcrop data. This paper presents an interpretation of a data set of high-density aeromagnetic data recently acquired by the USGS which helps characterize the orientation of lineaments associated with tectonic activity in the IV.

1.1 Geothermal Reservoir Regimes: Hydrothermal, EGS, and NEGST™

Observed geothermal reservoirs cluster into distinct regimes based on the origin of permeability, its persistence through time, and the mechanisms required to access it at commercial scale. Conventional hydrothermal systems are characterized by matrix-dominated permeability supplemented by localized fault-controlled flow. Commercial productivity depends on the fortuitous intersection of permeable stratigraphic intervals or discrete structures, and permeability is often heterogeneous and directionally unpredictable at field scale.

Enhanced Geothermal Systems (EGS) rely on the artificial creation or enhancement of fracture permeability in otherwise impermeable rock through hydraulic stimulation. While scalable in principle, EGS development is associated with elevated technical complexity, higher capital intensity, and increased induced seismicity risk, reflecting the need to engineer permeability rather than exploit it.

Naturally Enhanced Geothermal Systems (NEGST™) occupy a distinct and intermediate regime. In NEGST™, permeability is generated naturally through long-lived tectonic deformation, producing dense, connected fracture networks within otherwise high-quality reservoir rock. These systems are characterized by strong permeability anisotropy, predictable fracture orientations governed by stress state and fault kinematics, high transmissivity without artificial stimulation, and compatibility with directional drilling as a primary development strategy.

Table 1. Comparison of Geothermal Reservoir Regimes

Dimension	Hydrothermal	EGS	NEGST™
Permeability Origin	Matrix + localized faults	Artificially created	Tectonically pervasive
Stimulation Required	No	Yes	No
Seismicity Risk	Low	Elevated	Low
Permeability Predictability	Low (stochastic)	Engineered	Moderate (structurally governed)
Development Strategy	Opportunistic	Stimulation-centric	Directionally targeted
Risk Profile to Scale Development	Persistent (stochastic each well)	Constant/Increasing (cumulative seismicity)	Decreasing risk front-loaded, template transfers)

In NEGST™ reservoirs, permeability enhancement is not incidental or localized, but pervasive and structurally organized. As a result, these reservoirs are directionally harvestable by design rather than opportunistically productive.

2. USGS AEROMAGNETIC AND RADIOMETRIC DATA VOLUME

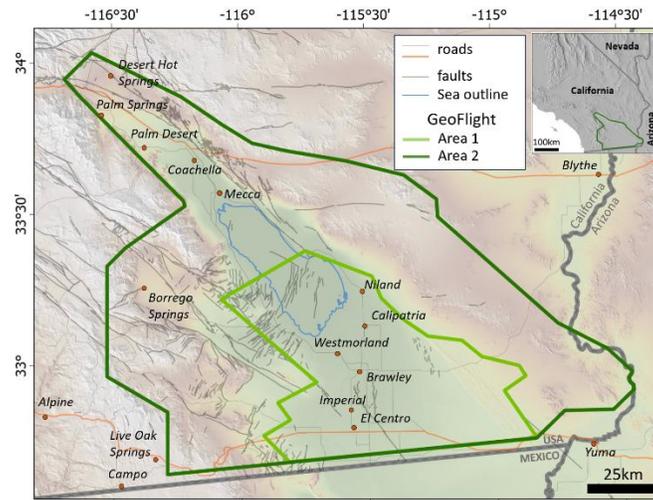


Figure 2. Extent of USGS Aeromagnetic and Radiometric Survey showing the previous fault mapping by the USGS.

This survey (Fig 2.) was approved in 2021 by the United States Geological Survey (USGS) and the Department of Energy (DOE). The aeromagnetic and radiometric data was acquired through the sub-contractor EDCON-PRJ, Inc in various stages from 2022 to 2024. The combined GeoFlight surveys involved a total of 94,671 line-km resulting in a dataset consisting of 16,772 square kilometers (6,475 sq. miles) of aeromagnetic data with 200 meters by 2,000-meter flight line spacing (USGS, 2024). Data is available for download as a series of images of processed data, grids, and a report, which details all the processing parameters for these datasets. Data was made publicly available in 2024.

The authors accessed these data in 2025 and integrated the aeromagnetic data into an overall interpretation of the geology, including fault interpretations from previous work in the IV as shown on Figure 3 (Anderson et al, 2025; Sims et al, 2025; USGS, 2024).

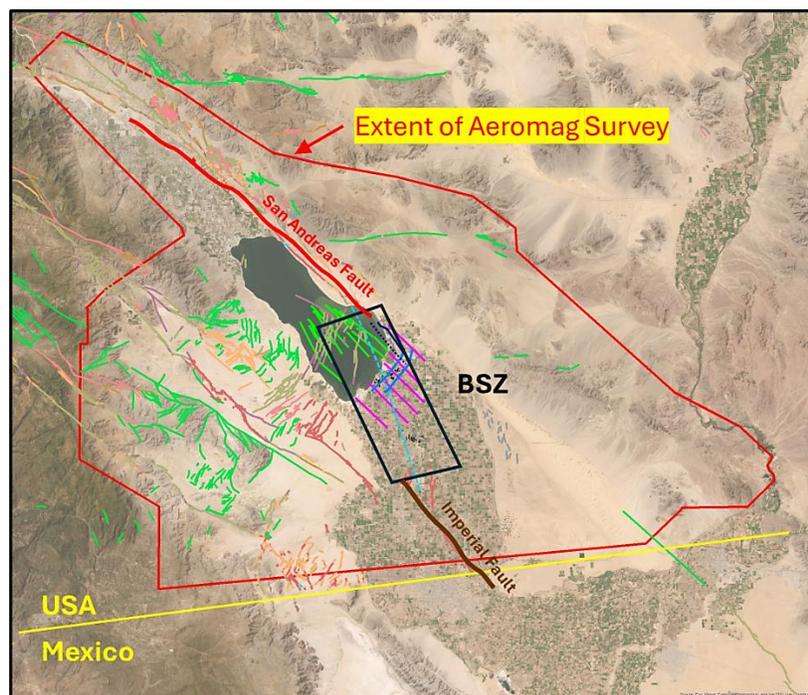


Figure 3. Previous faulting interpreted from USGS; Sims, 2024; Barbour, 2016; and Meidav, 1970

The Total Magnetic Intensity Reduced to Poles (TMI_RTP) was calculated for the USGS and provided as a grid. Figure 4 shows the TMI_RTP for the entire Salton Sea Survey and the Brawley Seismic Zone (BSZ), which is a transtensional-dilational stepover from the SAF to the Imperial Fault (IF). Within the BSZ, there are several significant geothermal fields that are dominated by hydrothermal flow with complex faulting, crustal thinning and resultant high heat flow.

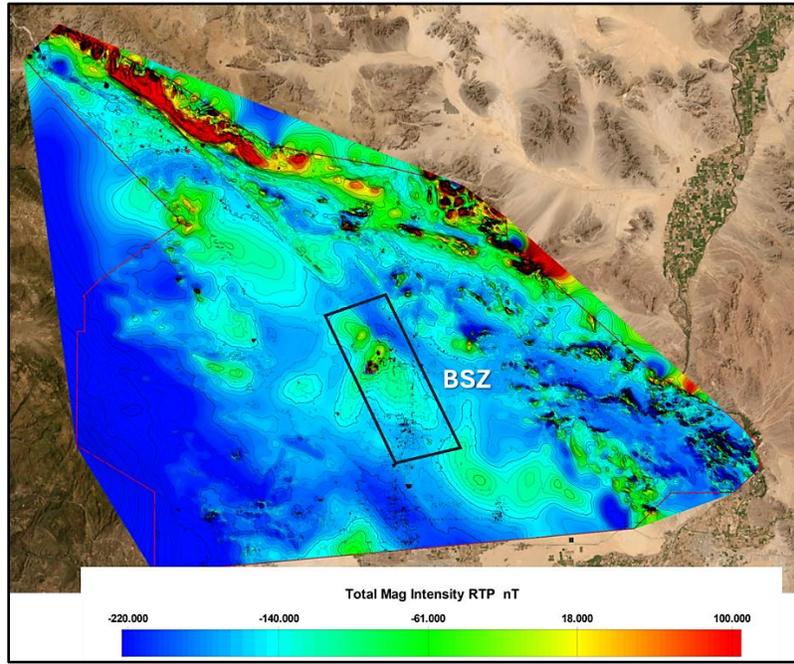


Figure 4. Total Magnetic Intensity Reduced to Poles from USGS Salton Sea Survey.

TMI RTP data can be useful for mapping concealed structures and differences in basement composition, faults, folds and ore bodies, especially in areas where surface topography does not reveal any sense of subsurface structure. TMI RTP will show the entire magnetic susceptibility of all the material under any datapoint. Large-scale geologic features such as the San Andreas Fault are obvious on the TMI dataset.

Filtering the data tends to enhance the shallower features. The authors decided to calculate the Total Horizontal Derivative (THD) of the aeromagnetic to better highlight edges, faults and lineaments in order to develop a better understanding of the orientation of faulting within the BSZ underneath the IV farmland.

3. METHODS OF ANALYSIS

The Salton Sea Survey TMI RTP dataset was processed to calculate the THD. First the Total Horizontal Derivative had to be calculated in both the X direction and the Y direction (Figure 5)

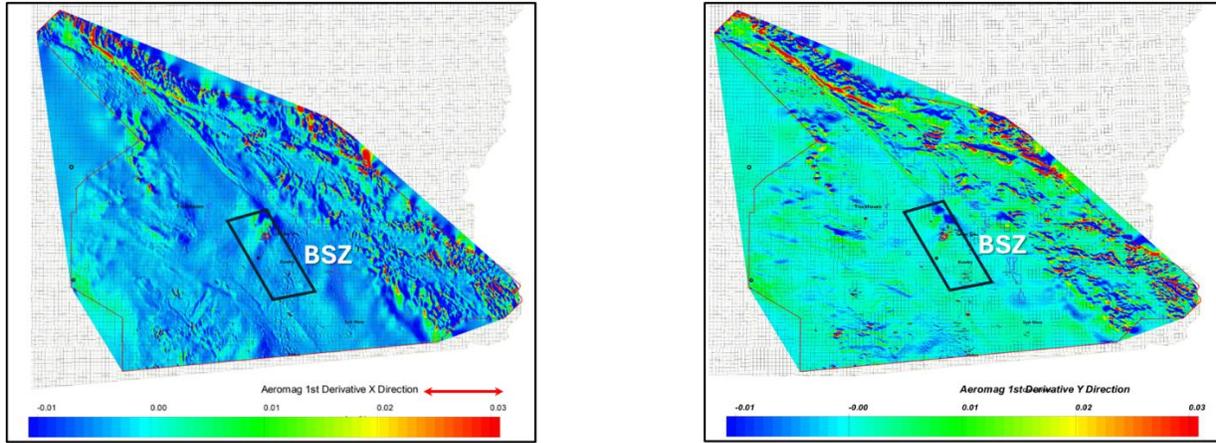


Figure 5. Horizontal Derivative calculated in the X direction and the Y direction

First Horizontal Derivative in the x-direction:

$$\frac{\partial B}{\partial x}(x_n, y_n) \approx \frac{B(x_{n+1}, y_n) - B(x_{n-1}, y_n)}{2\Delta x}$$

Where $B(x_{n+1}, y_n)$ is magnetic field value at next grid point in x-direction and $B(x_{n-1}, y_n)$ is the magnetic field value at the previous grid point in the x-direction. Δx is the grid spacing (distance) in the x direction.

First Horizontal Derivative in the y-direction

$$\frac{\partial B}{\partial y}(x_n, y_n) \approx \frac{B(x_n, y_{n+1}) - B(x_n, y_{n-1})}{2\Delta y}$$

Where $B(x_n, y_{n+1})$ is magnetic field value at next grid point in y-direction and $B(x_n, y_{n-1})$ is the magnetic field value at the previous grid point in the y-direction. Δy is the grid spacing (distance) in the y-direction.

In order to better understand the edges and structural elements these grids need to be added together to be able to see the THD. The formula for THD is:

$$THD = \sqrt{(B/x)^2 + (B/y)^2}$$

Where B/x is the derivative of the magnetic field in the x-direction and B/y is the derivative of the magnetic field in the y-direction.

The grid calculation for THD is shown on Figure 6. The color bar was chosen to accentuate edges and boundaries in the survey. THD provides an understanding of structural edges such as contacts and faults, boundaries between different geological units such as magnetic basement and non-magnetic cover. Structural complexity such as lineaments and fractures can be seen in this volume, helping to understand tectonic history of the area.

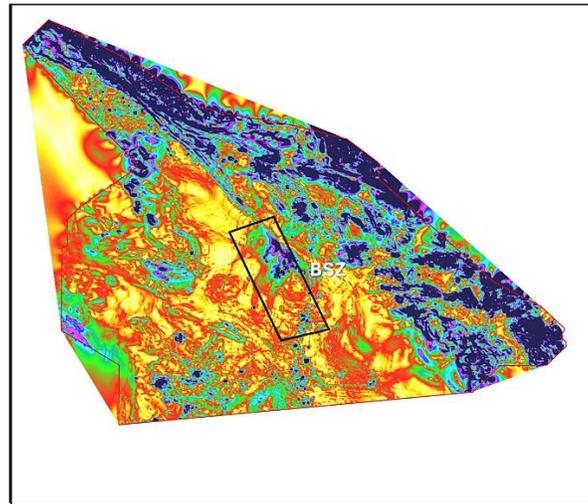


Figure 6. Total Horizontal Derivative volume with the Brawley Seismic Zone highlighted.

4. INTERPRETATION

Overlying previous fault interpretations (Anderson et al, 2025; Sims et al, 2025; USGS, 2024) shows good correlation between THD lineaments and those interpretations (Fig. 7). The USGS fault interpretations cover a large part of the aeromagnetic survey and good correlation between surface features and interpreted faulting provides confirmation that the THD provides good lineament data for further interpretation.

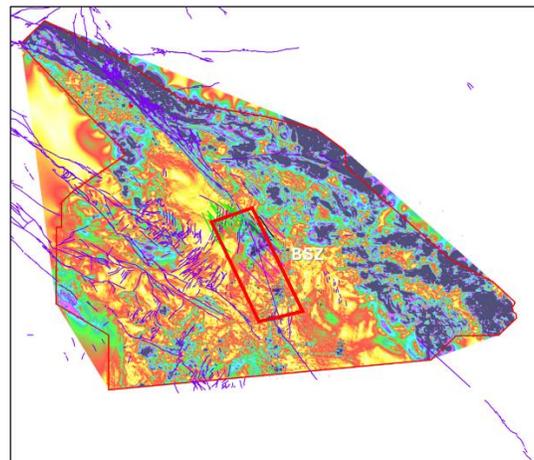


Figure 7. Previous faulting interpreted from USGS; Sims, 2024; Barbour, 2016; and Meidav, 1970 with THD backdrop.

Using a high contrast color bar is effective in utilizing the THD volume for lineament analysis. Picking lineaments across the survey (Fig. 8) yielded new insights to the nature of the tectonic fabric in the area, including within the BSZ, where subsurface features have little to no surface expression. The authors focused on areas that had little or no previous interpretation of faulting. The area within the BSZ was an area of focus as there has been more drilling activity and production from several geothermal fields there.

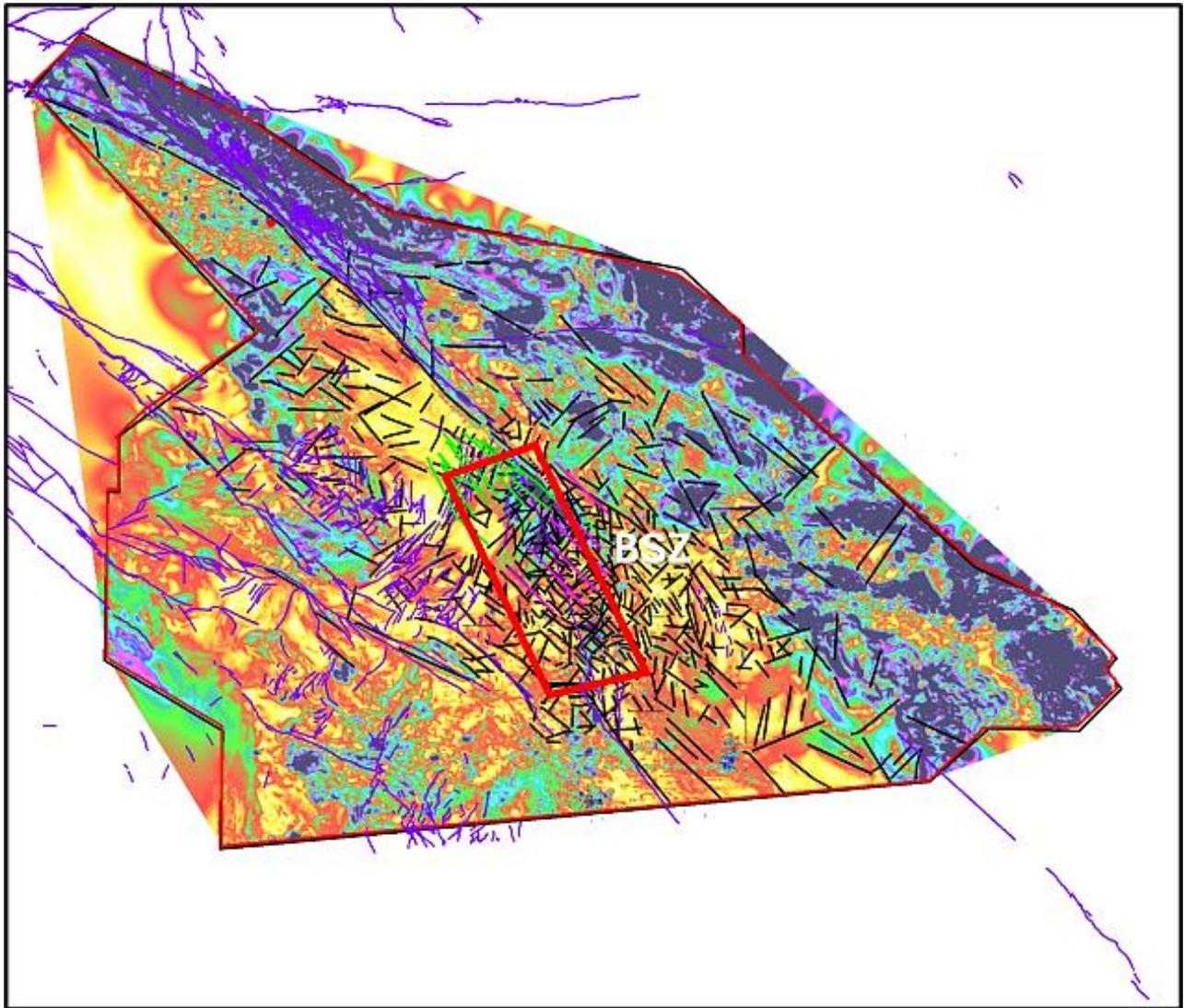


Figure 8. THD volume with previous fault interpretations and lineaments interpreted by authors throughout the survey

5. DISCUSSION

The Brawley Seismic Zone is the transtensional-dilational stepover from the SAF to the IF and is an area of extensive faulting and fracturing. This tectonic deformation, along with the thick section of high net to gross sandstones provide the ingredients for the NEGS™ system. The right lateral general nature of the deformation from the SAF to the IF yields lineaments with dominant and subordinate orientations. NW-SE and NE-SW lineaments dominate the BSZ. A detailed look at the area of the BSZ (Fig. 9a) shows the nature of the lineaments as interpreted from the THD and how these relate to the surface expression, or general lack thereof, across areas where farming and flooding occur (Fig 9b).

Figure 9a

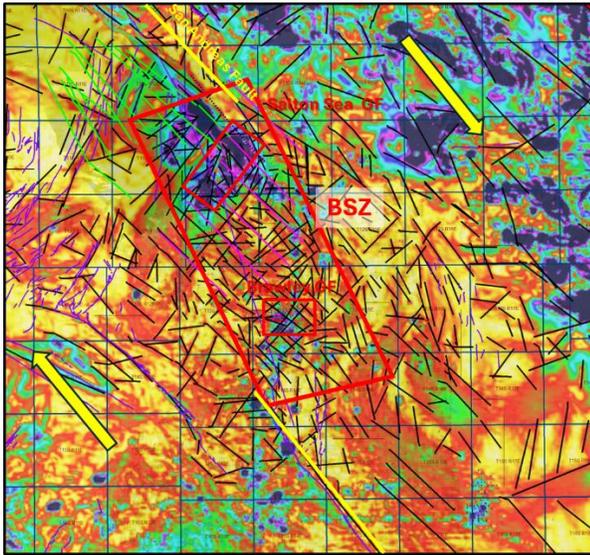


Figure 9b

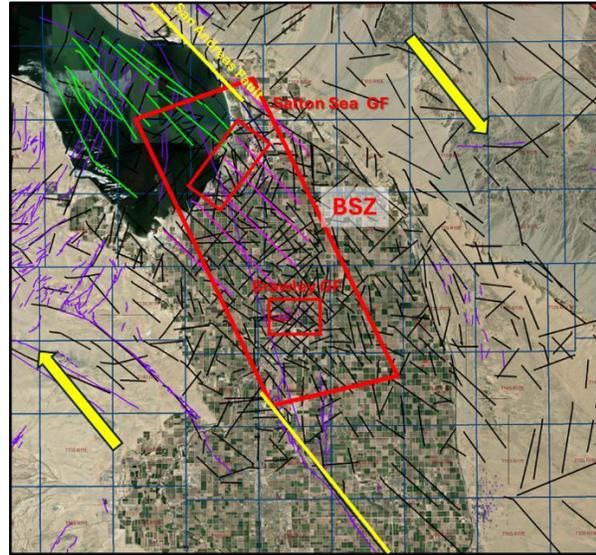


Figure 9a. Detailed view of the THD volume with lineament interpretation within the BSZ. The right lateral movement associated with the SAF and IF affects the distribution of fracturing within the BSZ. Figure 9b shows just the lineament distribution to aid in understanding the nature of the NEGS™ across areas with no or little surface expression.

The dominant fracture orientation may not be easily determined from the aeromagnetic data interpretation, but a review of historical earthquake records offer a view of how modern deformation has occurred. Following a 2012 series of earthquakes in the Brawley area (Hauksen et al, 2013), the dominant direction of fault movement was NE/SW, but there is control and limitations on that dominant movement from the NW/SE lineaments. SHmax within the BSZ ranges from N5E to N12E (Barbour, 2016)

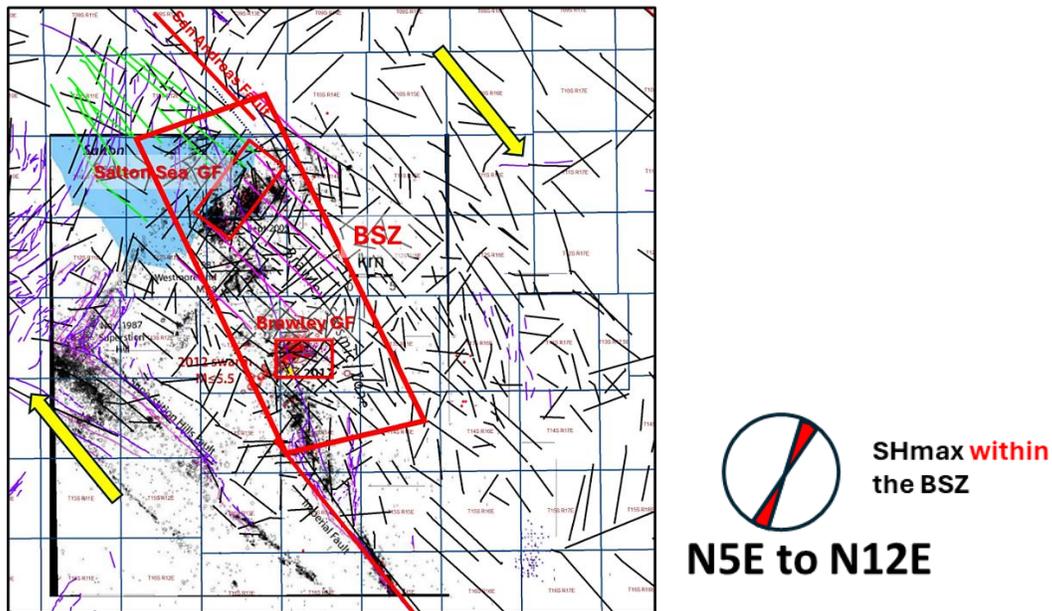


Figure 10. Lineaments from aeromagnetic THD data with historical earthquake data from 1981 to 2012 (Hauksen et al, 2013)

Lineament analysis within the BSZ suggests that the orthogonal pattern of faulting sets up fracture presence throughout the area within the reservoir. These fractures, along with matrix porosity and permeability, contribute to production of heated brines within the geothermal fields located within the BSZ. The Salton Sea Geothermal Field (SSGF) and Brawley Geothermal Field (BGF) have a long history of producing heated brines from vertical wells with no artificial stimulation required. This constitutes the principal components

of NEGS™. It is difficult to understand the net contribution of production associated with matrix versus fractures in vertical wells. Lost circulation of drilling fluid has been observed in wells drilled in both SSGF and BGF and is interpreted as evidence of significant fractures present in these areas. Porosity ranges from over 35% in shallow (<3000') to 12% in deeper, more altered sandstones (Fig. 11). No core is publicly available in the deeper sediments in either the SSGF or BGF, so permeability is inferred from production documented from wells.

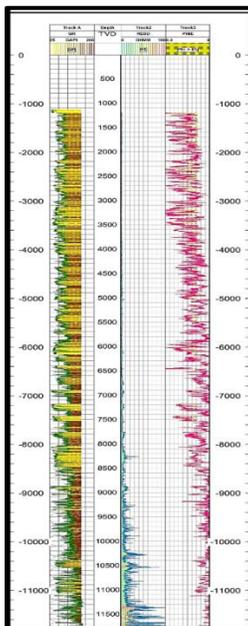


Figure 11. Type log in the vicinity of the Brawley Geothermal Field. Porosity scale is 0 to 30%. Porosity generally decreases with depth.

This structural control has direct implications for geothermal development strategy. Vertical wells intersect fracture networks stochastically, obscuring the relative contributions of matrix and fracture flow and limiting the ability to deliberately access the highest-permeability domains. In contrast, horizontal wells drilled with respect to the prevailing stress field and dominant fracture orientations are capable of intersecting orders of magnitude greater fracture surface area, systematically harvesting naturally enhanced permeability without artificial stimulation. In this sense, NEGS™ reservoirs are directionally harvestable by design rather than productive by chance.

Because fracture orientations and stress conditions are structurally governed and regionally persistent, the characterization investment made to develop the first NEGS™ wells transfers directly to subsequent development. This creates a fundamentally different risk profile than EGS, where each well requires independent stimulation, or conventional hydrothermal, where permeability intersection remains stochastic. In NEGS™ reservoirs, development risk is front-loaded and diminishes with scale—a characteristic more analogous to manufacturing than exploration. Further development with this NEGS™ may benefit from horizontal drilling designed to intersect more fractures. Access to fracture surface area massively increases permeability and matrix porosity contribution. Due to the higher quality of the matrix along with fractures providing additional fluid flow from the reservoir, artificial stimulation generally used in EGS reservoirs is not necessary. Historical drilling in the GF within the BSZ had production from depths generally shallower than 4,000' (Fig.11).

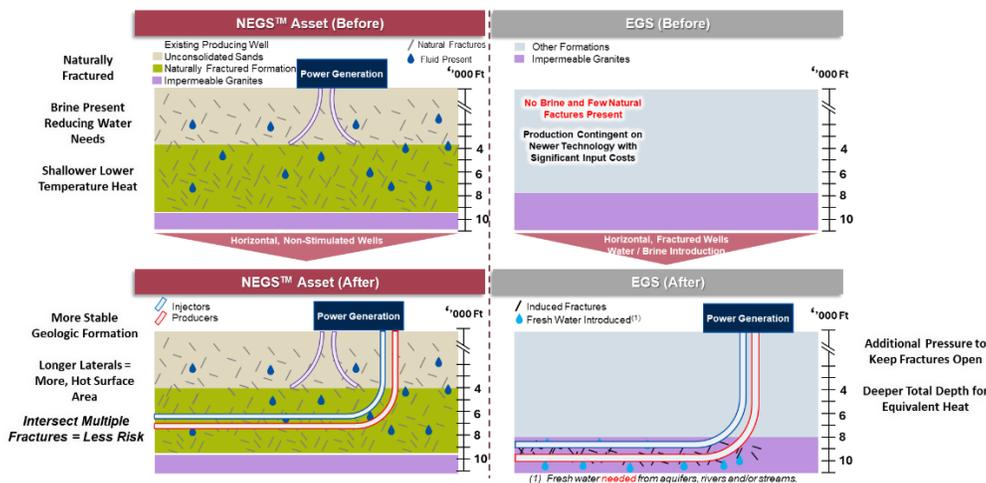


Figure 12. NEGS™ development would benefit from horizontal drilling in the deeper reservoirs and will have less drilling and completion costs due to the higher quality reservoir rock and no need for artificial stimulation.

6. CONCLUSIONS

The Imperial Valley geothermal system represents a canonical Naturally Enhanced Geothermal System (NEGS™). Recognition of NEGS™ as a named geothermal reservoir paradigm reframes geothermal development from a stimulation-centric approach to one focused on structural understanding and intentional permeability capture. The Imperial Valley system is inconsistent with both classical hydrothermal and EGS models, requiring recognition of a distinct reservoir regime governed by tectonically induced fracture connectivity. This paradigm has implications that extend beyond the Imperial Valley, enabling scalable, lower-risk geothermal development in tectonically fractured sedimentary basins worldwide.

Characterization of the nature of transtensional-transpressional fracturing and faulting with the BSZ was enhanced with the use of the large USGS aeromagnetic survey and the Total Horizontal Derivative technique that allowed for lineament analysis. This analysis suggests two primary fracture orientations across this area. Historical earthquake data suggests that the primary movement occurs on the NE/SW fractures and faults. Historical production of hot brines in the SSGF and BGF are from high porosity and permeability sandstones at depths generally shallower than 8,000’ at SSGF and 4,000’ at BGF. Further development in these areas at greater depths through horizontal drilling will allow the NEGS™ reservoirs to become a larger part of the geothermal energy equation.

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