Learning Science Through Research
Published by the Keck Geology Consortium
Short Contributions
Keck Geology Consortium
Volume 36
May 2024
doi: 10.18277/AKRSG.2024.36.21

ASSESSING GEOTHERMAL POTENTIAL USING 3D MODELING AND RESTORATION OF THE SEVIER FAULT SYSTEM, SOUTHERN UTAH

DEMI DURHAM, Trinity University
Project Advisor: Benjamin Surpless

INTRODUCTION

Important decisions about geothermal energy production rely on both high heat flows and accurate estimates of fluid flow rates within the subsurface. As faults form and propagate, they fracture rock around them, increasing permeability and potential fluid flow rates, so an accurate analysis of the geometry of a fault system can provide spatial information we can use to assess both the accuracy of subsurface interpretations as well as geothermal potential.

To test a workflow to validate subsurface interpretations, I focused on the well-documented, west-dipping Sevier normal fault zone, near Orderville, Utah. The fault is a complex, segmented system located in the transition zone between the highly extended Basin and Range Province and the relatively stable Colorado Plateau. Basin and Range faulting is typically dominated by normal faulting and high heat flows. Thus, the results from this study can be applied to other normal fault systems across the United States with high heat flows.

I used the Move2022 modeling suite (by *Petex*) to produce a model of the Sevier fault network. I utilized ArcGIS to georeference digital geologic maps, and I downloaded a 10-meter digital elevation model (DEM). I combined these data with previously published cross-section interpretations and merged orthophotographic images. I began to build a digital fault network with horizon interpretations, but soon identified inconsistencies in cross-section interpretations based on misaligned unit horizons and fault surfaces. We revised these cross sections to create a more accurate depiction of the Sevier system with complex but viable structural geometries. We resumed analysis of both stratigraphic horizons and fault geometries to build the most accurate model possible. My final model constrains both the subsurface orientations of faults and the geometric relationships between them. This three-dimensional model of the fault network would permit targeting of fault damage zones in localities with high heat flow, where higher permeabilities would make geothermal energy production feasible.

STRUCTURAL SETTING AND FAULT CHARACTERISTICS

The Sevier fault zone is 65 kilometers east of the Hurricane fault near Zion and Bryce National Parks (Surpless, *this volume*; Taylor et al., 2024). The faulting in the Sevier fault zone is typical for that documented in sedimentary basins, where faults are steep, planar and have displacements up to hundreds of meters (Peacock, 2002). In the study area, the fault system is composed of three primary segments that accommodate extension: the Orderville, Spencer Bench, and Mt. Carmel segments. Interactions between these three segments have created complex geometries in this region (Taylor et al., 2024).

This location serves as an excellent study site for segmented fault systems because pre-existing faults or other structures do not complicate analysis (Taylor et al., 2024). Faults are rarely isolated planar surfaces but instead are most often comprised of arrays of fault segments from the earliest stages of a fault system's propagation (e.g., Camanni et al., 2019). Displacement transfer between fault segments of the system is principally accommodated by relay ramps as bedding between segments rotates (e.g., Camanni et al., 2019). The linkages within the segmented normal fault system create complex geometries that would affect local geothermal potentials.

The Sevier fault system is thought to have developed during the Miocene (20 - 10 Ma) (Davis, 1999) and in the central Sevier fault zone, features major faults that are linked by minor faults and relay ramps (Taylor et al., 2024). There, strain is transferred through four relay ramps between the primary fault segments (Surpless, this volume) and may have developed through bifurcation from a single, deeper fault surface and the transferring of displacement between fault segments (Camanni et al., 2019). Because the major segments have hard linked (Taylor et al., 2024), the fault network now behaves as a continuous corrugated fault (Faulds and Hinz, 2015).

COMPUTER MODELING OF FAULT NETWORKS

3D computer modeling of the fault system allows for investigation of the system in a way that other modeling methods and surface interpretations cannot provide. With 3D visualization of the fault network, we can also evaluate the subsurface mechanics of the system. Three dimensional models of subsurface fault interactions are commonly made based on seismic data because the data are more accurate and definitive compared to interpretations that are based only upon surface and isolated borehole data. Because no seismic data exists for the Sevier fault system, we used the published cross sections from Schiefelbein (2002) to create a model of the fault network.

I used Move2022 (by *Petex*) to create an accurate three-dimensional depiction of the subsurface based on DEM data and cross sections from Scheifelbein (2002). These models make it possible to evaluate subsurface locations with elevated fluid flow rates and thus geothermal potentials without seismic data. Figure 1 shows a completed, fully restorable model of the fault system. Models like this reveal characteristics about fault and horizon geometries that can be used to constrain fault-related damage zones and therefore locations with elevated permeabilities.

GOALS OF RESEARCH

In this study, I focused on the following four research goals:

1. Test previously constructed cross-sections (Scheifelbein, 2002) to determine if they are viable in

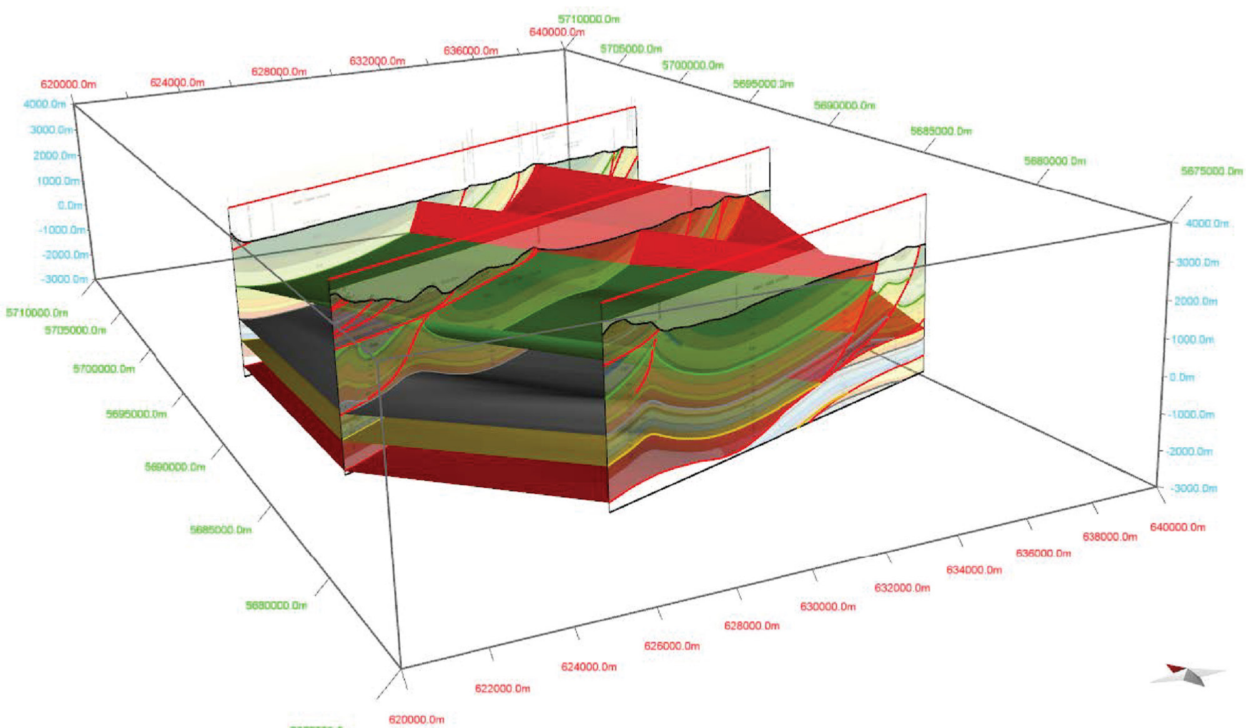

Figure 1. Completed 3D model of a fault system before restoration and validation. Figure modified from Petex (2022).

three dimensions.

2. Examine how fault geometries accommodate extension across the Sevier fault zone using 3D modeling within the Move2022 software suite.

3. Use modeling results to identify the likely orientations of fault damage zones, which would likely display high fluid flow potential.

4. Determine whether this workflow could be used in similar but less well-exposed segmented fault systems with high heat flows, thus providing a way to better constrain geothermal energy potential.

METHODS

I used Move 2022 software to create a 3D model by first importing and georeferencing cross-sections constructed by Schiefelbein (2002) from surface data then creating fault surfaces from these cross sections (Fig. 2). I first inserted cross sections using UTM coordinates for tie points defined by a geologic map by Schiefelbein (2002) and an imported DEM. I then traced faults and horizons in 2D for each cross-section. To create a 3D depiction of the fault network, we interpolated between 2D surfaces to create 3D surfaces.

If there are issues with the alignment of fault surfaces or layer contact horizons, I edit the 2D cross-sections to better align at cross-section junctions and to build complete, continuous fault and horizon surfaces. If necessary, additional cross-sections between existing 2D sections may add the detail required for more accurate surface building. For interpolations of fault and horizon surfaces between 2D cross-sections, I used Delaunay triangulation, ordinary kriging, spline curves, and linear methods to create fault and horizon surfaces (*Petex*, 2022).

After all horizon surfaces are created and continuous, the model can then be restored. Restoring the model first requires the separation of different volumes within the model to create fault blocks that can be manipulated by the user. When the fault blocks are separate objects, I can then use the model to reverse displacements accommodated by faults across the system, thus testing the evolution of the fault system through time.

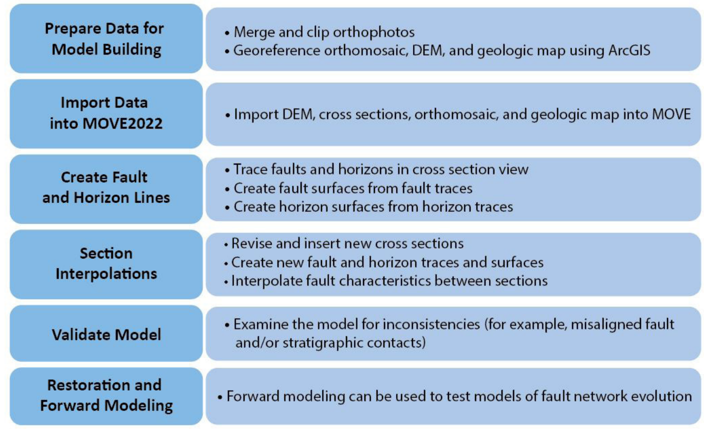

Figure 2. Six step modeling workflow used to develop the high-resolution 3D model of the Seiver fault zone.

RESULTS

After constructing the DEM surface and importing cross-sections by Schiefelbein (2002), I noticed that both fault surfaces and horizon contacts did not align where cross sections met, resulting in an inaccurate portrayal of the system. To address this problem, I edited the original cross sections from Schiefelbein (2002). I revised the cross sections by changing layer thicknesses and positions, changing fault dips, strikes, and map-view length. For example, Figure 3 displays an original, erroneous cross-section and the revised, more accurate version of the cross-section. I also added new cross sections between these revised cross-sections to better constrain strike-parallel changes in fault and horizon geometries. When I interpolated faults and horizons between the denser cross-section distribution, I was able to build a more detailed depiction of the system. Figure 4 shows the geologic map laid over the DEM, with the revised cross sections inserted vertically in the model to show the subsurface.

In the Southern region of the fault zone, faulting is less complex compared to the northern region. This allowed us to make interpretations about displacement. Figure 5 shows horizon surfaces and the displacement between them in the southern region of the Sevier Fault Zone. The horizon layers help visualize displacement and dip as well as provide an exact measurement of the displacement. In the figure, we can see that displacement varies along strike by

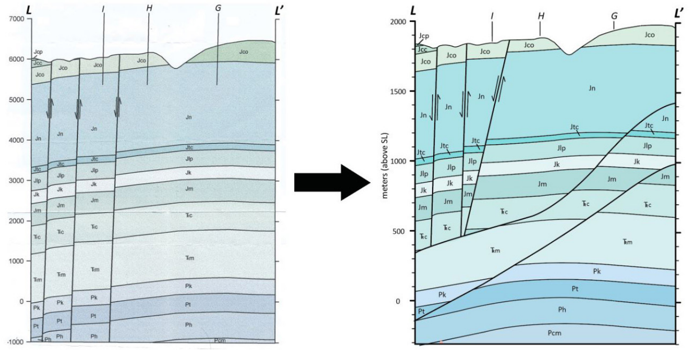

Figure 3. Cross-section prior to model building (left) vs. same cross-section revised after model building (right). Note especially the addition of two faults.

a factor of about three. Figure 5, indicates that the easternmost fault creates more displacement by a factor of about three moving northward along the fault.

We attempted to construct horizon surfaces from the revised cross sections in the northern region to permit accurate restoration of extension. However, the faulting is so complex and difficult to interpret in the subsurface that we could not build realisitc horizon surfaces in the north. We also tried to build the horizons from the built 3D fault system using interpolation methods, which yielded inaccurate results. Continuing the restoration process with inaccurate horizons in the northern region would have provided us with an inaccurate representation of the displacements and stratigraphic geometries in the northern region of the study area, affecting the validity of the entire model.

DISCUSSION

Based on the geometries depicted in my completed 3D model, I have demonstrated that both hard and soft linkages help accommodate extension in the system, as hypothesized by Scheifelbein (2002) and Taylor et al. (2024). I have also shown that there are different locations along the fault system where there are higher densities of faulting and relay ramp development; in the model, I can trace faults and fault intersections throughout the subsurface of the study area.

With better visualization of the system that precisely locates linked fault segments and with knowledge of the local geothermal gradient (assuming high enough heat flows), I would be able better target geothermal

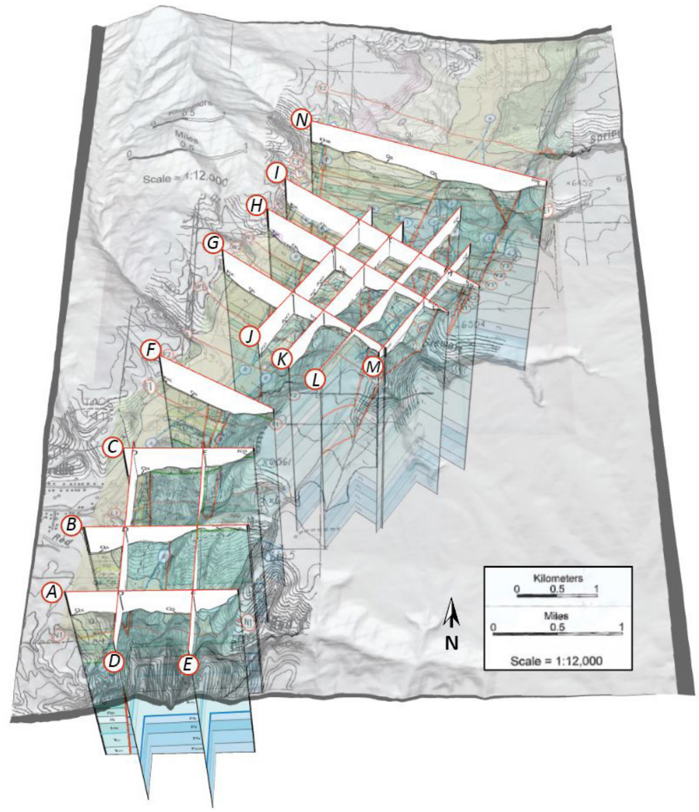

Figure 4. DEM with map overlay. Map features display surface observations. Cross sections (lettered) display subsurface fault and stratigraphic unit interactions. Fault and horizon surfaces were created by linking fault and horizon lines between sections.

energy resources. As mentioned earlier, faults generate highly fractured damage zones that improve fluid flow rates. Therefore, a rock volume with multiple faults in close proximity, like the Sevier system, has characteristics that are necessary for the production of geothermal energy.

These modeling methods allowed us to test the validity of the published cross-sections. Without model results, we would not have known about errors in the cross-sections. Creating a 3D model of this system allowed us to visualize the fault structures of the Sevier fault zone. With corrected cross sections, I was better able to see how the faults interact at depth. With a better understanding of these geometries, I could potentially improve geothermal targeting techniques at various stages of segmented normal fault evolution. Additionally, more information about segmented normal fault systems, other researchers and power utilities can effectively target sites in the subsurface with high geothermal potential.

The 3D model can also reveal details about fluid flow in the system. Increased permeability and fluid flow

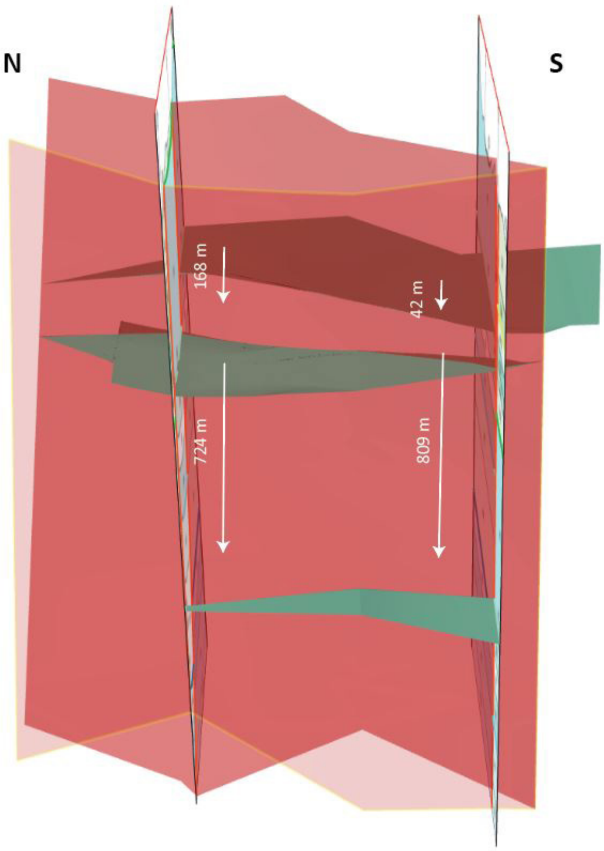

Figure 5. East-looking view between sections A and C. Faults A and B are partially transparent to show the displacement of the horizon between the Tenny Canyon Tongue (Jtc) and the Navajo Sandstone (Jn). Unit layers are dipping south, and fault A causes more displacement compared to fault B.

caused by intense faulting and deformation is likely to increase geothermal potential when the fault system is in a region with high heat flows. An accurate analysis of the geometry of a fault system can provide spatial information about fracture formation and fluid flow, which is vital for geothermal energy production.

ACKNOWLEDGEMENTS

This material is based upon work supported by the Keck Geology Consortium and the National Science Foundation under Grant No. 2050697. Funding for this project was provided by a 2023-2024 Keck Geology Consortium Advanced Research Project Grant as part of an NSF-REU Award to the Keck Geology Consortium (EAR 1659322; PIs Wirth, K., and Davidson, C.). Funding was also provided by NSF Award 2042114 to PI Surpless. A special thanks to Petroleum Experts for donating the MOVE 2022 software suite to Trinity University.

REFERENCES

Camanni, G., Roche, V., Childs, C., Manzocchi, T., Walsh, J., Conneally, J., Saqab, M.M., and Delogkos, E., 2019, The three-dimensional geometry of relay zones within segmented normal faults: Journal of Structural Geology, v. 129, p. 103895, doi: 10.1016/j.jsg.2019.103895.

Davis, G.H., 1999, Structural geology of the Colorado Plateau region of southern Utah: Geological Society of America Special Paper 342, 127 p.

Faulds, J., and Hinz, N., 2015, Favorable Tectonic and Structural Settings of Geothermal Systems in the Great Basin Region, Western USA: Proxies for Discovering Blind Geothermal Systems, in Proceedings, World Geothermal Congress, Melbourne: Australia, Nevada Bureau of Mines and Geology.

Peacock, D.C.P., 2002, Propagation, interaction and linkage in normal fault systems: Earth-Science Reviews, v. 58, p. 121–142, doi: 10.1016/s0012-8252(01)00085-x.

Petex, 2022, Tutorial 7: Building, Restoring, and Validating a Geological Model, 84 p.

Roche, V., Camanni, G., Childs, C., Manzocchi, T., Walsh, J., Conneally, J., Saqab, M.M., and Delogkos, E., 2021, Variability in the three-dimensional geometry of segmented normal fault surfaces: Earth-Science Reviews, v. 216, p. 103523, doi: 10.1016/j.earscirev.2021.103523.

Rotevatn, A., Jackson, C.A.-L., Tvedt, A.B.M., Bell, R.E., and Blækkan, I., 2019, How do normal faults grow? Journal of Structural Geology, v. 125, p. 174–184, doi: 10.1016/j.jsg.2018.08.005.

Schiefelbein, I., 2002, Fault segmentation, fault linkage, and hazards along the Sevier fault, southwestern Utah [M.S. thesis]: Las Vegas, University of Nevada at Las Vegas, 132 p.

Taylor, W., Surpless, B., and Schiefelbein Kerscher, 2024, Complex segment linkage along the Sevier normal fault, southwestern Utah: Lithosphere, doi: 10.2113/2024/lithosphere_2023_332