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MODELING THE SEVIER FAULT ZONE, SOUTHERN UTAH: VALIDITY TESTING AND 3D ANALYSIS

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ABSTRACT

The Sevier fault zone near Orderville, Utah, represents a segmented normal fault system within the transition zone between the Basin and Range Province and the Colorado Plateau. This fault system consists of three primary segments: the Orderville segment, the Spencer Bench segment, and the Mt. Carmel Segment. The interactions between segments led to the development of complex structural geometries exposed along the fault zone. These geometries influence deformation and create fractures that affect expected permeability and fluid flow within the fault zone. These geometries also impact how slip-related energy is dissipated during earthquake-related slip propagation. Therefore, analysis of these geometries has implications for fluid flow and seismic hazard within segmented fault systems.

I used the Move2020 software suite by Petex to develop a 3D model of the complexly-segmented Sevier fault zone near the city of Orderville in southern Utah. Earlier researchers' subsurface interpretations were based on surface mapping rather than direct documentation of subsurface fault and layer geometries, so 3D model development permits validation of hypothesized subsurface structures. I digitized geologic contacts, faults, and stratigraphic horizons based on published geologic mapping and cross-sections to develop a 3D model of the fault network. I confirmed that the model does represent a well-constrained 3D system of the Sevier fault zone based on demonstrated integrity between the digital elevation model (DEM), and all available structural data. This work should provide future researchers with the data necessary to model evolution of the overall fault system, which will permit accurate determination of fault-related fracture development and the most likely fluid flow paths. Furthermore, development of a fully retro-deformable model of the fault zone will allow strain analysis that may help researchers understand how fault segment geometries impact earthquake slip propagation. This determination can be used to provide a conceptual framework for other researchers to better constrain the evolution of segmented fault zones worldwide.

INTRODUCTION

Segmented fault zones like the Sevier fault zone consist of many shorter normal faults that act as a continuous, corrugated fault (Ferrill et al. 1999). As fault segments interact, they form fractures, thus developing fluid flow pathways. Additionally, segmentation enables energy dissipation across the fault zone, which may impact seismic hazard and slip propagation across the region. By developing detailed three-dimensional structural models, we can better assess the spatial and temporal evolution of both fluid flow and slip propagation. Although fault growth through linkage and relay ramp formation is well known, the influence on three-dimensional fault geometry as a result of this process is not well understood (e.g., Fossen and Rotevatn, 2016). Three-dimensional modeling techniques allow me to perform analysis necessary to make interpretations about fault geometry that other methods cannot adequately address (Rotevatn et al. 2019).

I used the Move2020 modeling suite by Petex to develop a 3D model of the Sevier fault zone near Orderville, Utah. I used Move2020 because this program permits integration of digital elevation models (DEMs), geologic maps, orthophotography, and cross-sections into a single model. I successfully completed four key aspects of this digitized model in Move2020: 1) I accurately aligned the geologic map of the area with the digital elevation model; 2) I precisely placed cross-sections along mapped section lines; 3) I digitized fault and horizon lines onto each section; and 4) I interpolated these lines across sections to develop 3D fault planes and stratigraphic contacts. This model will permit future workers to evaluate fracture formation, fluid flow pathways, and seismic hazard across the segmented normal fault system. This work should provide a conceptual framework for the evolution of segmented normal fault zones worldwide, especially where those fault systems are poorly exposed or in the subsurface.

STRUCTURAL BACKGROUND

The Sevier fault zone is located within the transition zone between the Basin and Range Province and the Colorado Plateau (Fig 1). The fault zone is located within the Intermountain Seismic Belt, which has had numerous historic 7.0+ magnitude earthquakes (e.g., Christenson and Nava, 1992). Additionally, the extension in this transition zone allowed for a combination of both soft and hard fault linkage across the zone. This linkage is associated with minor fault segments and the four relay ramps located within the fault zone (Fig 2). Displacement is accommodated via two capture mechanisms. The primary capture method relies on the growth and development of dominant faults within the fault system. Dominant faults, which accommodate the most displacement, propagate laterally and transfer strain between them by relay ramp development (Crider and Pollard, 1998). The other linkage mechanism relies on the overlap of two faults where one fault hard links with the other and captures the displacement of the other fault within the system (Ferrill et al. 1999).

Schiefelbein's (2002) conclusions confirm the existence of these two types of linkage mechanisms along the Sevier fault zone near Orderville. The first subtype links the fault via fault capture in the Orderville relay ramp area (Fig. 2). The second linkage subtype occurs as a result of overlapping faults with a series of cross faults and relay ramps in the Stewart Canyon overlap zone (Schiefelbein, 2002) (Fig. 2).

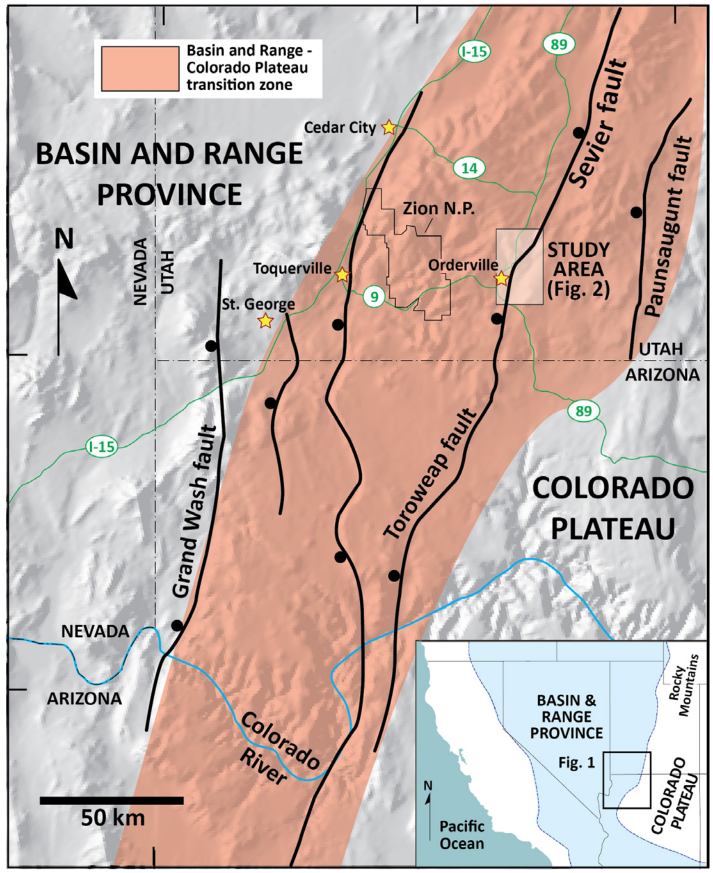

Figure 1. Transition zone between the Basin and Range Province and the Colorado Plateau displaying the primary faults that accommodate extension (modified from Thelin and Pike, 1991; Reber et al., 2001).

Two models of fault growth, the propagating fault model and the constant length fault model, provide frameworks to help explain the growth of normal fault segments. The propagating fault model asserts that fault growth occurs primarily due to the lengthening and linkage of individual, initially independent fault segments (e.g., Rotevatn et al. 2019). Meanwhile, the constant length fault model explains that rather than growing through a lengthening and linkage process over time, faults instead propagate to their near-full lengths rapidly. This propagation is typically associated with mechanical interactions between adjacent fault segments and a reduction in tip stresses (Rotevatn et al. 2019). The digitized 3D model of the Sevier fault zone that I have constructed can be used to test these end-member models. In addition to the variety of capture methods associated with different linkage types, damage zones, commonly highly-fractured rock, form as a result of fault displacement and interaction. These damage zones

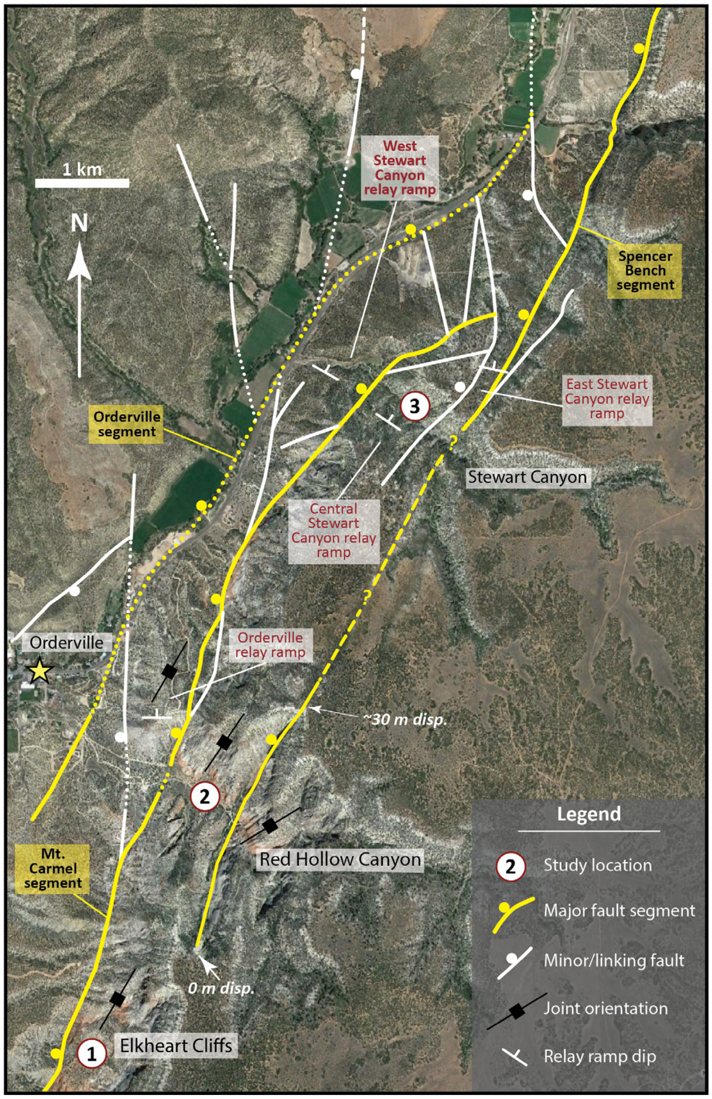

Figure 2. Structural map of the fault network within the Sevier fault zone at Orderville. Thick yellow lines are primary segments of the Sevier fault zone (Simoneau et al., 2016; Hankla et al., 2019).

are classified based on the structural position of the damage. Damage zones form along the tip, wall, or linkage zone between fault segments (e.g., Long and Imber, 2011). These damage zones are commonly associated with the breaching of relay ramps between dominant segments of the Sevier fault zone. These damage zones release stresses associated with fault tip propagation and may serve as conduits for fluid flow (e.g., Fossen and Rotevatn, 2016).

METHODS

I designed an eight-step modeling workflow in order to efficiently develop a high-resolution model of the Sevier fault zone (Fig 3). I performed all steps of the modeling workflow except for the Georeference Geologic Map step, which I completed in ARC-GIS,

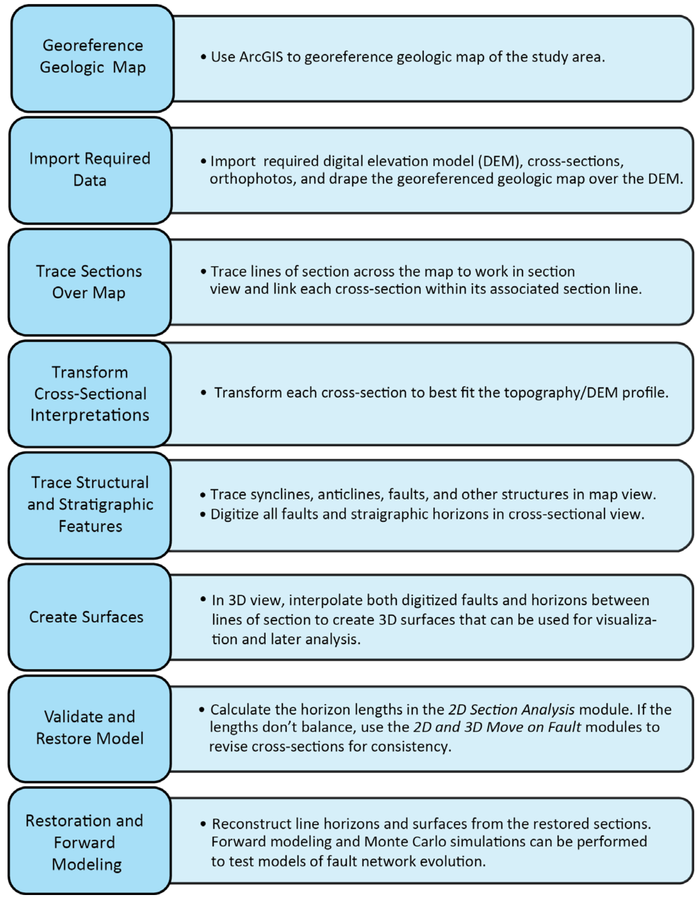

Figure 3. Eight-step modeling workflow used to develop a high resolution model of the Sevier fault zone.

within Move2020. The restoration and reconstruction steps only need to be completed if 2D section analysis reveals the horizon lengths to be inconsistent. An example of a model created prior to restoration with this modeling workflow is shown below (Fig. 4). I completed through step 6 of the modeling workflow, the Create Surfaces step. Completion of this step relies on interpolating fault and line horizons across multiple cross-sections in order to translate 2D data into 3D space. The primary data I used for this process, imported during the Import Required Data step, were cross-sections and a geologic map created by Schiefelbein (2002). The majority of these cross-sections were constructed in the southern portion of the geologic map, where there is sufficient data density, so I focused on the southern portion of the map area to assess the most complex portion of the fault system.

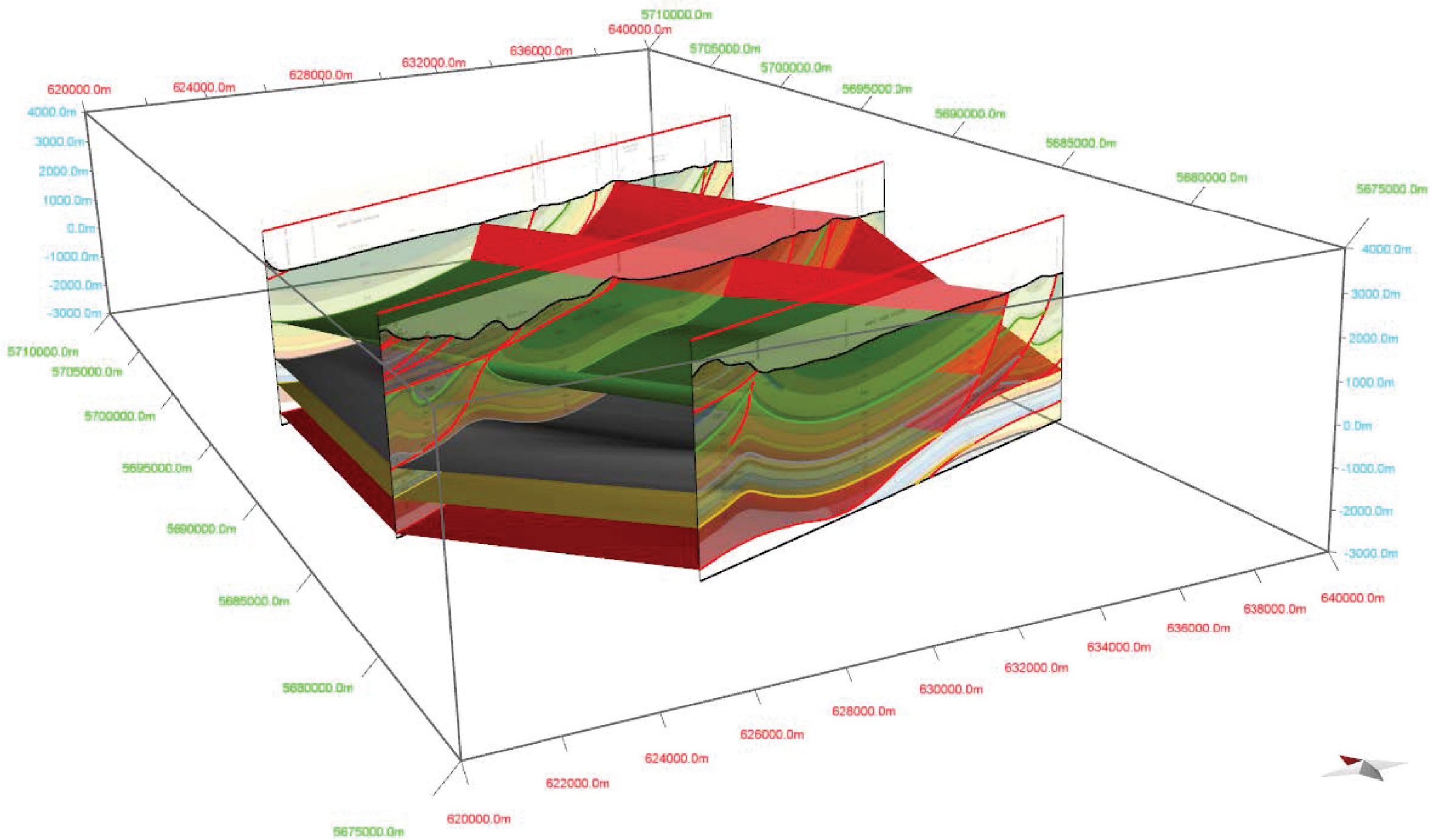

Figure 4. Completed 3D model prior to validation and restoration. This example was created using the modeling workflow shown in Figure 3.

RESULTS

I succeeded in developing a well-constrained 3D model of the Sevier fault network near Orderville, Utah. My model demonstrates integrity between the DEM, geologic map, cross-sections, and stratigraphic horizon displacements. I have been able to evaluate displacement gradients across the fault zone by aligning the georeferenced geologic map, DEM, and cross-sections within section lines. Additionally, I successfully demonstrated the general validity of the original cross-sectional interpretations by establishing line-length consistency across and between cross-sections. I have used my model to document along-strike changes in displacement of a stratigraphic horizon surface along a fault plane where subsurface interpretations have been validated (Fig 5). However, my analysis revealed that some of Schiefelbein's (2002) initial interpretations need to be slightly revised. For instance, I found certain upper horizon lengths to be shorter than lower horizon lengths in Schiefelbein's (2002) cross-sectional interpretations. Once these structural interpretations have been validated across the fault network, future researchers will able to assess fault geometries along the fault zone and limit possible kinematic fault evolution scenarios.

FUTURE WORK

Future work must address the discrepancy in data density between the northern and southern sections of the study area. Specifically, future researchers will need to use surface data to construct more cross-sections in the northern Sevier fault study area. These cross-sections will need to undergo the same validation process that I performed on Schiefelbein's (2002) cross-sections. Additionally, future researchers will need to revise some of Schiefelbein's (2002) structural interpretations. To address discrepancies, researchers may add blind faults at depth, adjust changes in displacement magnitudes/ratios with depth, and/or change fault geometries. This work will allow us to answer the following research questions: 1) Are modeling results consistent with the established ideas about the kinematics of segmented fault zone evolution? 2) How do permeability and fluid flow

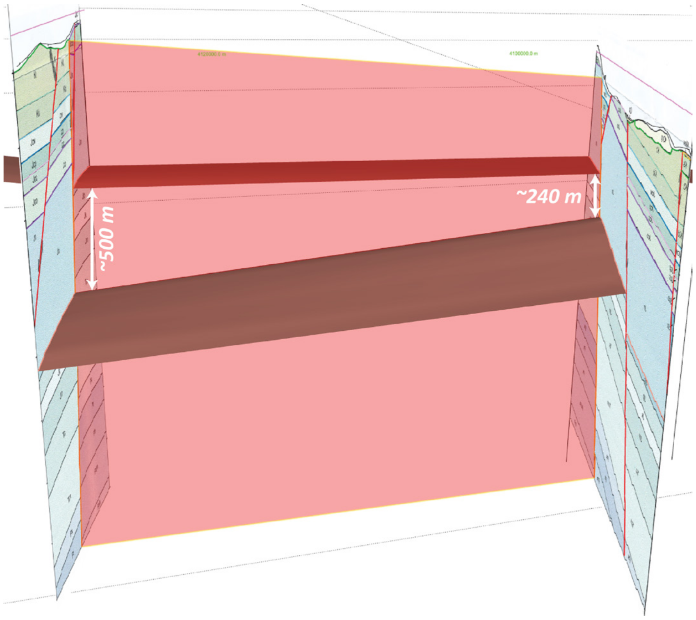

Figure 5. Displacement of a layered horizon (shown in brown in foreground and dark red in background) by a fault surface (shown in transparent light red) along the Sevier fault zone.

pathways change as a segmented fault zone evolves? and 3) How can these results be used to assess the impacts of fault geometry on the propagation of slip during an earthquake?

IMPLICATIONS

The structural geometries and features exposed along the Sevier fault zone are important because they influence deformation within the rock volume, creating fractures that affect permeability and fluid flow within the fault zone. Therefore, the geometry of the system in the subsurface affects groundwater flow. By validating and revising previous interpretations of the Sevier fault zone, researchers will be able to accurately determine the evolution of the fault system and related fluid flow paths. This structural evolution will provide a conceptual framework that other researchers can use to better constrain the evolution of segmented fault zones worldwide.

Furthermore, analysis of the structural geometries and features exposed along the Sevier fault zone may allow for analysis of fault damage zones, best characterized by fracturing. These damage zones absorb some portion of energy related to earthquake slip propagation (e.g., Surpless and McKeighan, 2022). Additionally, segmented portions of major faults impede the propagation of slip due to their complex geometries. If a fully retro-deformable model of the fault zone can be completed, this model would allow for fracture and strain analysis associated with the creation of damage zones. In turn, this model might help researchers better understand how damage zones evolve over time in segmented fault zones, and more specifically might aid in understanding how fault segment geometries impact earthquake slip propagation.

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