Kinematics and Growth of Supra-Salt Systems: A Field and Subsurface Analysis, Paradox Basin

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Abstract

Salt can provide the structure and seal necessary for hydrocarbon entrapment, however, it may lead structural complexities, such as compartmentalizing a hydrocarbon reservoir through supra-salt faulting. Outcrop analog studies provide exceptional opportunities to observe how salt-influenced fault geometries evolved spatially and temporally. The Paradox Basin in southeastern Utah is an example of a salt-influenced petroleum basin where the petroleum system is directly associated with evaporites. Decades of petroleum exploration in the region have yielded a broad subsurface dataset (e.g. seismic reflection data and well penetrations), with close proximity to world-class outcrops. Exposed supra-salt fault scarps have preserved kinematic evidence which provide tangible evidence to populate kinematic models that quantify the temporal and spatial evolution of this fault system.

This study focuses on the Salt Valley salt wall, the northernmost and largest salt structure within the northern Paradox Basin. A 40 km long supra-salt fault array trends parallel to and detaches downward onto the NW-plunging salt wall. Through the use of 3D seismic reflection data, wells, published maps, satellite imagery, and a collection of structural field measurements, we are able to build a database that was used to make an integrated interpretation of the spatial and temporal evolution of the fault array.

Several kinematic analyses coupled with detailed geometric fault descriptions were used to determine the growth history of the studied fault array that consists of a series of overlapping fault segments up to 12.5 km long, with throws of hundreds of meters, defining a series of crestal grabens and half-grabens. Secondary faults of similar length are present on the flanks of the salt wall. Along the strike of the fault array, there are notable changes in the dip direction of the half-graben master faults and regions of varying fault strikes. These changes reflect heterogeneities of the top-salt geometry.

Fault linkage analyses such as: fault throw-length (T-L); throw-distance (T-x); throw-depth (T-z), as well as qualitative distribution of fault throws from map and strike views show that these segments are over-displaced, with a complex fault segment linkage history. We hypothesize that these over-displaced faults evolved with a hybrid fault growth model, where they initiated as isolated fault model but spent the majority of their growth history through coherent fault growth.
Abstract
Salt can provide the structure and seal necessary for hydrocarbon entrapment. However, it may also act as a source for migration, as a conduit for diagenetic alteration through space and salt facility. Outcrop analog studies provide reservoir analogs for interbeds to observe how salt and reservoir rock properties can affect reservoir properties and fluid migration and accumulation. The stratigraphy of the Salt Valley anticline, a well-known salt tectonic province, is characterized by an interbedded sequence of amines, sandstones, and shales. The interbeds are characterized by their thickness, lateral extent, and diagenetic alteration, which can affect fluid migration and deposition.

The stratigraphy of the Salt Valley anticline is characterized by a vast volume of evaporites that were deposited over millions of years. The evaporites consist of a variety of minerals, including halite, sylvite, and carnallite, which can affect the mechanical properties of the rock and its ability to act as a seal for hydrocarbons. The salt can also act as a conduit for diagenetic alteration, which can affect the reservoir properties and fluid migration.

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Research Objectives
1. Produce a detailed geologic map of the Salt Valley basin.
2. Build a watertight 3D structural framework of the subsurface Salt Valley basin.
3. Identify geometric similarities between surficially-mapped and subsurface faults.
4. Contact three distribution locations of the subsurface fault zones to determine the fault evolution.
5. Advance understanding of the spatial and temporal evolution of the supra-salt fault array.
6. Conduct an integrated analysis of the collected field data with a variety of field techniques.

Motivation
Many of the world’s major hydrocarbon provinces are characterized by evaporite deposits. These deposits are unique due to their physical and chemical properties, which can affect the creation of reservoirs and seals. The evaporites consist of a variety of minerals, including halite, sylvite, and carnallite, which can affect the mechanical properties of the rock and its ability to act as a seal for hydrocarbons. The salt can also act as a conduit for diagenetic alteration, which can affect the reservoir properties and fluid migration.

Geologic Context
The Paradox Basin is an important stratigraphic unit that developed during the Cretaceous Epoch. It is characterized by a vast volume of evaporites that were deposited over millions of years. The evaporites consist of a variety of minerals, including halite, sylvite, and carnallite, which can affect the mechanical properties of the rock and its ability to act as a seal for hydrocarbons. The salt can also act as a conduit for diagenetic alteration, which can affect the reservoir properties and fluid migration.

Tectonic Evolution of the Paradox Basin
The Paradox Basin is an important stratigraphic unit that developed during the Cretaceous Epoch. It is characterized by a vast volume of evaporites that were deposited over millions of years. The evaporites consist of a variety of minerals, including halite, sylvite, and carnallite, which can affect the mechanical properties of the rock and its ability to act as a seal for hydrocarbons. The salt can also act as a conduit for diagenetic alteration, which can affect the reservoir properties and fluid migration.

Field Mapping
Field photographs highlighting various outcropping structures. Maps and cross-sections of the Paradox Basin showing the distribution of evaporites and salt lenses. Field mapping of the salt wall and evaporite bodies in both map and cross-section.
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Surface Structure Maps

Supra-Salt Fault Array

Strike Orientations

Dip Angles

Throw Distribution

Fault Throw Analyses Results

Throw Distribution within Fault Zones

East-Dipping Fault Zone

West-Dipping Fault Zone

Seismic Profiles along East-Dipping Array

Segment E1 Throw Distribution

Segment E2 Throw Distribution

Segment E3 Throw Distribution

Seismic Profiles along West-Dipping Array

Segment W1 Throw Distribution

Segment W2 & W3 Throw Distribution

Segment W4 Throw Distribution

East-Dipping Fault Zone

West-Dipping Fault Zone

Numbers displayed are included in Western Array
Numbers displayed are not included in Eastern Array

Map shows location of fault segments analyzed in this study. Four seismic inlines were analyzed to capture the geometric heterogeneities of the west-dipping fault zone. Each figure contains three segments: E1, E2, and E3. The southeastern tip of the fault is the shortest segment in the fault, followed by the second shortest segment, E1, and then E2. This suggests that the fault is growing in a stepwise manner, with the southernmost fault segment growing faster than the others. The cumulative maximum throw for all three segments is approximately 3.2 km.

In general, the strike values are dominantly northwest-southeast with some variability along the faults length. Maximum throw within the fault array (640m) occurs on a NW-E dipping fault zone. This fault surface connects the southern fault, E1 to the northern fault, E3. The southeastern tip of the fault is the shortest segment in the fault, followed by the second shortest segment, E1, and then E2. This suggests that the fault is growing in a stepwise manner, with the southernmost fault segment growing faster than the others. The cumulative maximum throw for all three segments is approximately 3.2 km.

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**Field Results**

**Synthesis of Field and Subsurface Results**

**Regional Observations**

**Fault Statistics**

**Fault Growth**

**Role of Inherited Structures**

**Conclusions**

Research conducted on the Salt Valley supra-salt fault array have resulted in:

- The identification of four dominant fault orientations, present throughout the entirety of the research area.
- The generation of a 3D structural framework of the Salt Valley's supra-salt fault system constrained by 3D seismic reflection survey and borehole penetrations.
- The execution of quantitative analyses (e.g., fault throw-length (T-L); throw-distance (T-D); throw-depth (T-D)); and throw variation along strikes and between stratigraphic intervals) to determine the complex fault segment linkage history of the supra-salt fault system.
- The construction of a more-accurate sub-regional geologic contact map of the northwestern Salt Valley, which incorporates published data points, digitally-collected field measurements, as well as the creation several small-scale inset maps highlighting fault zones studied in advanced analyses.
- The completion of kinematic analyses of digitally-collected outcropping faults.
- The interpretation for the nucleation, fault growth evolution, and mechanism of formation for the supra-salt fault system, based on observations from both field and subsurface results.
- The northwestern tip of the Salt Valley salt wall likely coincides with the location of an underlying ENI-SWSS Trending basement fabric, similar to other salt wall terminations mapped in the Paradox Basin.

References