Structurally Controlled Fluid Migration Through Thrusts of the Stewart Peak Culmination in Northern Salt River Range, Wyoming*

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Abstract

The Stewart Peak Culmination (SPC) is a topographic and structural culmination of the Absaroka thrust sheet in western Wyoming that lies structurally up dip from known subsurface accumulations of CO₂ in southeast Idaho. It is likely that the SPC was also a CO₂ trap prior to Neogene Basin-and-Range extension. The SPC has been uplifted and breached, exposing the structural and lithologic elements analogous to the CO₂ traps in SE Idaho. Investigation of this exposed trap allows for characterization of migration pathways and determination of the relative timing of fluid migration episodes.

Paleozoic-Mesozoic rocks have been highly deformed by movement of the Absaroka thrust sheet and its associated imbricate thrusts. Faulting led to extensive fracturing and brecciation that locally enhanced porosity and permeability. Brecciated fault zones are up to 4 m thick. Highly fractured damage zones extend for tens of meters into the hanging walls of large-displacement thrust faults. Fractures that developed in the culmination are the cumulative result of multiple slip events and aseismic processes. Fractures measured in the field have systematic geometric patterns associated with faulting and folding. The dominant fracture set consists of vertical to sub-vertical, ENE striking fractures that generally parallel the direction of thrust transport (Mode I dilational fractures). Crack-seal vein textures and multiple overprinting breccia textures suggest episodic seismic rupture. Fluid migration in the culmination was focused through faults, fractures, and breccia zones. Hydrothermal fluids likely enhanced these conduits via the processes of dolomitization, dissolution, fracturing, and brecciation.

Late-stage breccia bodies form discrete pipes that cross-cut stratigraphy and sometimes fault damage zones. Some breccia pipes developed by dissolution and collapse along tectonic fractures. These breccia bodies are linear in map view and parallel the main thrust transport direction (ENE). Other pipes exhibit dilational, ‘floating clast’ breccia that likely developed by isothermal boiling of CO₂, which lead to hydro-fracturing of host rocks. Secondary mineralization (saddle dolomite and disseminated sulfides) and related rock fabrics suggest a low temperature hydrothermal origin for most breccia pipes. Hydrothermal dolomitization of carbonate reservoir rocks is evident in the field.
area, and the extent and location of dolomitized bodies appear to be controlled by thrust-related fractures. Fieldwork and petrographic evidence suggest that fracture sets kinematically associated with thrusting served as conduits for multiple episodes of fluid flow including CO$_2$-charged hydrothermal brines and hydrocarbons.

References


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Introduction

- The Stewart Peak Culmination – a structural culmination in the Absaroka thrust sheet of western Wyoming
- Exhumed duplex fault zone breached by erosion

- Up-dip from known CO2 reservoirs in SE Idaho and therefore can be used as a surface analogue for potential CO2 storage sites including the proximal Moxa Arch, a naturally occurring CO2 reservoir and an excellent hydrocarbon trap

- Understanding fluid migration is critical for evaluating CO2 storage sites and potential oil and gas reservoirs

- Structural diagenesis faults, fractures and breccia zones can facilitate fluid migration, create secondary porosity in tight reservoirs, compartmentalize reservoirs, and create anisotropy in fluid flow systems; the diagenetic products of fluid/rock interactions can both enhance and hinder fluid flow
The Northern Salt River Range, Wyoming

The Stewart Creek Recess

Absaroka Thrust

Stewart Thrust

Prater Mountain

Structural map of the field Area (Lageson 1984)
• Collection of fracture data from fracture stations in each of the 4 structural domains
• Sample collection
• Characterization of fault zones, breccia pipes, fracture swarms, and reservoir rocks
• Geometric and kinematic analysis of fracture data
• Spatial and statistical studies of fracture attributes
• Sample stains and peels
• Thin section petrography
• FEM and SEM and CL imaging

• Stable isotope analyses (C, O, Sr)
• Fluid inclusion analyses
Rose Diagrams of Fracture Data

Orientations of Fractures Measured in the Field

Major Fracture Sets
- Group 1: Strike 345-360-005 and 165-185
- Group 2: Strike 030-045 and 210-225
- Group 3: Strike 050-080 and 230-260
- Group 4: Strike 090-120 and 270-300
- Group 5: Strike 140-160 and 320-340

Hinge of the Culmination 338

Stewart Creek Recess

Absaroka Thrust

Fracture Stations

Prater Mountain Area

Stewart Thrust

Fracture Stations
Fractures geometrically fit with Sevier deformation and are consistent with the regional tectonic fabric.

What is the relationship between deformation, and fluid migration in the Culmination?

**Structural Controls, Timing, Diagenesis**
Group 3 fractures in the Cambrian Gros Ventre in the hanging wall of the Absaroka thrust served as conduits for multiple episodes of fluid migration.
Linear breccia bodies in the Jurassic Twin Creek trend parallel to group 2 fractures.

Dissolution by acidic hydrothermal brines migrating along group 2 fractures may have lead to collapse.
Fracture Swarms and Fault Damage Zones

Subvertical fracture swarm cuts through strata of the Madison Formation, south Prater Mountain cirque.

Saddle Dolomite lining the walls of a dissolution cavity, note the curving crystal faces.

Fault Breccia made up of Cambrian limestone in the hanging wall of the Absaroka Thrust.

Dilational strain creates fluid migration pathways.
FEM image of saddle dolomite from the Madison fracture swarm
Funnel shaped Breccia Pipe in the Cambrian Gros Ventre formation, the Hanging Wall of the Absaroka Thrust, Stewart Creek Recess.

Breccia pipe in the Jurassic Nugget formation, footwall of the Absaroka Thrust.
Vein filled with course saddle dolomite from the Gros Ventre breccia pipe in the Hanging wall of the Absaroka Thrust

Floating-clast breccia fabric indicative of CO2 boiling

Herkimer Quartz crystals in the Nugget breccia pipe
Outcrop-Scale Alteration of Siliciclastic Rocks

Bleached Nugget Formation with spotty hydrocarbon staining and bitumen residue

Bleached Wells Formation with extensive alteration and recrystallization of host rock and numerous herkimer quartz crystals

Footwall of the Absaroka Thrust

Footwall of a major hanging wall imbricate of the Absaroka Thrust
Conclusions

- Geometry of most fractures fit with Sevier tectonic deformation:
  - Group 3 ⇒ mode I extension fractures parallel to thrust tectonic transport
  - Group 3 ⇒ parallels the SE Idaho Lineament and Stewart Peak Ramp
  - Groups 2 and 4 ⇒ conjugate shear set (mode II)
  - Group 5 ⇒ parallel to the hinge of the culmination
  - Group 1 ⇒ youngest, related to regional extension & unloading
- Groups 2, 3, and 4 ⇒ Linked, open fractures with crack-seal textures, and multiple generations of cement were likely the best fracture controlled fluid conduits.
- Displacement transfer zones also made good fluid conduits
- Episodic faulting maintained fluid flow conduits and enhanced fault fracture permeability
- Multiple episodes of fluid flow via fractures (mostly vertical) and breccia zones (including breccia pipes and fault damage zones)
- Late dolomitization hydrothermal fluids ⇒ saddle dolomite, sulfide minerals, herkimer quartz
- Hydrothermal breccia pipes cut through the Absaroka thrust
- Fracturing and brecciation were likely driven by the ascent of hydrothermal brine+CO₂+hydrocarbon solutions through the thrust sheets
- Active travertine springs ⇒ still an active fracture controlled CO₂ system!
Questions?