Characterizing Outcrop Growth Faults, Slump Blocks, Mud Volcanoes and Other Sedimentary Deformation Features for use as Reservoir Analogues for Observed Features in Targeted Reservoirs in the Green River Formation, Uinta Basin, Utah*

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Abstract

Sand dominated clastic deposits form an important component of the rapidly developing Green River horizontal play in the Uinta Basin of NE Utah. Reservoir quality within the Green River is highly variable, with one cause being sedimentary deformation compartmentalizing clastic reservoirs, creating discontinuities and degrading intergranular porosity and permeability values. This occurs within fluvial and marginal lacustrine sandstone facies of the Flagstaff, Castle Peak and Douglas Creek Members of the Green River Formation. In many cases, well and seismic data demonstrate stratigraphic discordance that is interpreted to be related to sedimentary deformation shortly after burial. Evidence includes sudden thickening or thinning of reservoir units with undeformed strata above and below these features, stratigraphic zones of pervasive deformation (seismites?) and proximity to concurrently active faulting. These features appear to partition these sandstone reservoirs, making their characterization important for operators in the Uinta Basin. On the eastern flank of the Uinta Basin, there exists a large series of growth faults, slump blocks, mass transport deposits, mud volcanoes and diapirs, all related to fluvial sandstone deposits in a near shore settings of ancient Lake Uinta. Studied intervals include the Uinta A, Douglas Creek and Lower Black Shale informal members of the Green River Formation. The deformed sandstone blocks exhibit brittle deformation in the form of micro faults and minor brecciation, with limited ductile deformation. Dark oil shales acted as undeformed glide planes on which these blocks moved. These blocks range in size from 100 yards to nearly a quarter mile across and display everything from gently dipping rotations to being nearly overturned. Mud volcanoes and diapirs are often in close spatial association to the blocks, and deformed intervals will sometimes stack vertically, with undeformed lacustrine mudstones in between. Geographically, the deformed blocks appear to cluster in paleo valleys and along main-stem fluvial deposits. It is expected that a better characterization of these deformed deposits will allow for more accurate modeling of similarly deformed reservoirs within the active Green River oil play.

References Cited


Characterizing outcrop growth faults, slump blocks, mud volcanoes and other sedimentary deformation features for use as reservoir analogues for observed features in targeted reservoirs in the Green River Formation, Uinta Basin, Utah

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Problem

Some Green River Formation Sandstones produce much more poorly than they should based on:

- Offset production
- Pay encountered/OOIP
- Initial production volumes
- Completion practices (frac size)
Study Location

- Study involves production anomalies in the West Myton oil field in Duchesne County
- Deformation in Uinta ‘A’ outcrops in Uinta County
- Core in the Gusher oil field in Uinta County
Vertical wells were commonly drilled ~300’ into the Wasatch, then every sand and porous carbonated from the TGR-3 to TD would be completed.
Cumulative Oil Production of All Green River Wells

Note that the West Myton wells are underperforming versus offset wells.
Initial Oil Production (IP’s) of Green River Wells

At IP, these wells were doing about average or better than offset wells.
Gas/Oil Ratio (GOR) of All Wells

Finally, note that the GOR’s for West Myton are much higher than average for the area.
West Myton’s Early Achievement of Bubble Point

• Bubble point is the pressure at which gas begins to come out of solution within the reservoir

• When a well reaches bubble point much earlier than is normal for the area, it typically indicates the well is only producing from a limited reservoir

A Typical West Myton Well
For Myton, Production Statistics are

- Average IP’s
- Smaller cumulative oil production than surrounding areas
- Reach bubble point much earlier than surrounding wells
- Higher GOR’s

- Production removes volume, decreasing pressure
- The greater the pressure decline per given volume, the smaller the reservoir
Why Are Reservoirs in West Myton So Limited?

• Stratigraphic controls are unlikely as offset fields with very similar geology are not similarly affected

• Structural controls are possible
  • No faulting with significant vertical offset are present
  • Are there other possible structures?

Maybe something we could see in outcrop?
Rapidly Prograding Sandstone Deposits

• The Uinta A consists of deltas quickly spreading south and west over shallow lacustrine deposits

• The lake gradually becomes more restricted on the western portion of the Basin
  • However, it often transgresses over recently deposited deltaic sediments during wetter periods
  • Interbedded sandstones and lacustrine shales are a common feature of the lower Uinta A

Vanden Berg and Birgenheier, 2017
Deformation in the Uinta A Sandstone (West Myton Analogue?)

- The Uinta A is justifiably famous for its fossils and soft sediment deformation
  - SSD is pervasive in the Uinta A
- Flame, ball and pillow, and flow structures are common and represent a degradation of sandstone reservoir quality
- This study focuses on larger block movements that compartmentalize reservoirs

Uinta A sandstone (Wagonhound Member) at its type section
A change in regional drainage trends directed large amounts of sediment into the intermountain lake system.

After filling the Green River and Piceance Basins, this massive flow of sand dominated sediment was directed into the eastern Uinta Basin.

These rapidly deposited sandstones are the Uinta A and B.
Type Section of the Uinta A (Wagonhound Member)

Channels flow from east to west (Stagner, 1941)

Transgressive Lacustrine Shale (15’ thick)

Amalgamated Fluvial Sandstones

Rippled, Planar Bedded Deltaic Sandstones

Growth Fault

Rippled, Planar Bedded Deltaic Sandstones
Parachute Creek Shale (Grease for the System)

Three factors combine to make Parachute Creek shales particularly weak

- Medium to high total organic carbon (TOC)
- High smectite percentage in the clays
- Claystone fabric disrupted by evaporite crystals

- Very low shear strength
- **Loads easily slip down-slope**

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Slide Blocks

Evaporite Pseudomorphs

Vanden Berg’s (2017) “Phase 2 Hypersaline Zone”
Parachute Creek shales are weak enough to flow in response to lateral loads.

Movements are typically tightly stratabound.
Growth Faulting

- Growth faults are the most common type of block movement observed
- Syndepositional
- Serves to sever or baffle adjacent sandstone reservoirs

Modified from http://homepage.ufp.pt/biblioteca/WebBasPrinTectonics/BasPrincTectonics/Page9.htm
Growth Faults

- Growth fault with evaporites deposited along fault trace
- Evidence for the impermeability of the fault

- Uinta A growth faults lay directly on either the main body of the Parachute Creek or on thin tongues of lacustrine shale interbedded with the deltaic sandstones
  - Tightly stratabound with stratigraphic growth within the involved block
  - Evidence of syndepositional character and repeated movement
Rotated Blocks

- Large (100’s of yards across) slide blocks are found rotated 40°-90°
- Undeformed shale at their bases
- Tool marks at the base of the blocks show they slid down slope (into the lake)
Internally Deformed

- Unsurprisingly, the rotated blocks suffer significant internal deformation
  - Micro faults
  - Folding
  - Mud injections and dikes
Foundered Blocks

• In areas where Parachute Creek shales are thick enough some detached blocks founder into and are partially encased by shale.
Late Eocene Uinta Basin Tectonics

- During the deposition of the Uinta A sandstones, the Basin was surrounded by actively moving uplifts.
- Large earthquakes were recurrent events in the Basin.
- It is assumed that shocks associated with these quakes activated movement on the observed large slump blocks.

Study Area
Uinta A Outcrop

Modified from Dickinson and others (1988)
What are Sand Boils?

- Sand boils can occur anytime that buried, saturated sandstones are loaded beyond their containment pressure
  - Flooding
  - Construction
  - Earthquakes

- The vast majority of sand boils or “blows” occur during the liquefaction of sediments during earthquakes

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Fossil Sand Boils

Large scale sand boils are observed frequently in association with slide blocks, growth faults and diapirs in the Uinta Formation.
Fossil Sand Boils

In outcrops they appear as circular or elongated zones of concentrically upturned strata.
Fun, But How Does this Relate to Production?

Uinta A Sandstones

Growth fault separating blocks of opposing dips

Parachute Creek Shales

Block rotated 90° and broadly deformed

Slump block sliding down slope into the lake
Interpreted

- Slumping of large blocks of Uinta A sandstones compartmentalized individual reservoirs
- Blocks that are not hydraulically isolated by slumping still experience significant baffling

Vertical wells will not access reserves in blocks not penetrated by the wellbore
Isolated?

The Gusher 1 core shows Uinta A sandstones as a rotated block.

Rotated block in the Lower Black Shale

The core begins in the rotated block, so it is unknown how large the block is.
Terminal Deltas and the Duchesne Fault Zone

- The Duchesne Fault Zone acted as a point of structural rotation, marking the southern limit of the deep basin.
- The change of structural dip focused deltaic sediments at the fault zone.
  - Meaning that large volumes of terminal deltaic sediments were deposited on thick lacustrine shales in a zone with a high potential for earthquakes.

Brinkerhoff and Woolf, 2018
Observed Blocks Near West Myton

For much of the stratigraphic section in the West Myton area, the lack of markers makes identifying structured blocks difficult.

Fortunately, these two blocks occurred in a zone with frequent markers.
Conclusions

• Production anomalies in West Myton likely related to limited reservoir extents
• Outcrop examples of synsedimentary and early post sedimentation block movements are plentiful, particularly in the Uinta A in the eastern Uinta Basin
• Similar large slump blocks are observed in other portions of the basin and near West Myton
  • It is very possible that features similar to those observed in the Uinta A contribute to West Myton’s limited reservoir extents
References

• Reduction of reservoir quality
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