Outcrop Analogs in Utah: Templates for Reservoir Characterization and Modeling

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Abstract

Utah is unique in that representative outcrop analogs are present for the thrust belt, Uinta Basin, and Paradox Basin for each major oil play. Production-scale outcrop analogs serve as "templates," often in 3D, of reservoir-facies characteristics and boundaries that determine the overall reservoir rock heterogeneity, and can be applied to reservoirs worldwide. Examples include the Mississippian Madison Limestone, Pennyslvanian Paradox Formation, Jurassic Navajo Sandstone and Twin Creek Limestone, and Tertiary Green River Formation for carbonate shallow shelf, bioherm, eolian, fractured, and fluvial-deltaic lacustrine reservoirs, respectively.

The shallow-marine shelf, Mississippian Leadville Limestone is a major oil and gas reservoir in the Paradox Basin of Utah and Colorado. Hydrocarbons are produced from basement-involved, northwest-trending structural traps with closure on both anticlines and faults. Excellent outcrops of Leadville-equivalent rocks are found along the south flank of the Uinta Mountains, Utah. For example, like the Leadville, the Mississippian Madison Limestone contains zones of solution breccia, fractures, and facies variations. Hydrocarbons are stratigraphically trapped in heterogeneous bioherms (mounds) of the Pennsylvanian Paradox Formation, which includes Utah's largest oil field, in the Paradox Basin. Exposures of the Paradox Formation along the San Juan River of southeastern Utah display mounds and intermound troughs to off-mound detrital wedges or fans bounded by flooding surfaces. These facies also show flow conduits for secondary/tertiary recovery projects, and various horizontal-drilling targets.

In the Utah-Wyoming thrust belt, hydrocarbons are produced from traps formed by discrete subsidiary closures on ramp anticlines along major thrust faults. The most prolific oil reservoir is the eolian Jurassic Nugget Sandstone. Outcrop analogs in the stratigraphically equivalent Navajo Sandstone of southern Utah display large-scale dunal cross-strata and interdunal lithofacies such as oases and playas. These outcrops illustrate how eolian facies might effect petroleum movement and production rates. The low-porosity Jurassic Twin Creek Limestone produces in the thrust belt where extensive fractures are sealed by overlying argillaceous and clastic beds, and non-fractured units within the Twin Creek. The best outcrop analogs for Twin Creek reservoirs are found at Devils Slide and near the town of Peoa, Utah, 20 miles (32 km) west and 9 miles (15 km) southwest, respectively, of producing fields. Closely spaced rhombic and rectilinear fracture patterns developed on bedding planes and within dense, homogeneous non-porous (in terms of primary porosity) limestone beds of the Rich and Watton Canyon Members.

The Tertiary Green River Formation is the primary oil reservoir in the Uinta Basin. Outcrop analogs in Nine Mile Canyon, just 15 miles (24 km) south of producing fields, display distributary-channel and interdistributary mud-flat deposits. These outcrops show that potential reservoirs can form laterally continuous flow units or pinch out to form flow barriers, all within 40 acres, a common well spacing interval in the basin.

Acknowledgments

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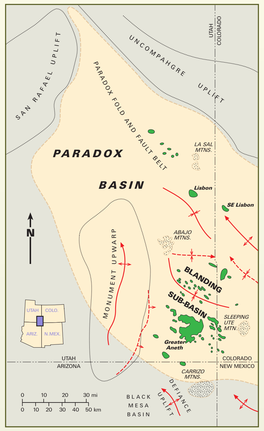
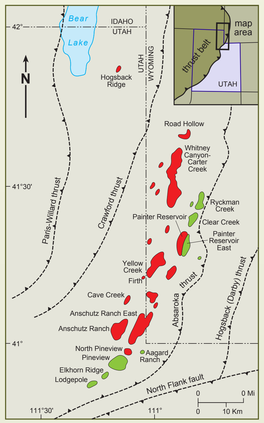
Geologic outcrop interpretations were also contributed by Douglas A. Sprinkel, Grant C. Willis, and Hellmut H. Doelling, UGS; David E. Eby, Eby Petrography & Consulting, Inc.; Lisë Brinton, LithoLogic, Inc.; and Stanley and Collinson (1979). Reservoir descriptions incorporated information from Baars (1966), Imlay (1967, 1980), Picard (1975), Maher (1976), Conner and Covlin (1977), Babcock (1978), Cargile (1978), Clarke (1978), Dunn (1978), Latch (1978), Mecham (1978), Norton (1978), Miesner (1978), Wold (1978), Parker (1981), Brown (1983), Kocurek and Dott (1983), Lindquist (1983), Petroleum Information (1984), Bruce (1988), Peterson (1992), Hill and Bereskin (1993, 1996), Smouse (1993), Fouret (1996), Parra and Collier (2000), and Dubiel (2003). Production and well data as of December 1, 2003, were provided by the Utah Division of Oil, Gas and Mining. Vicky Clarke, Cheryl Gustin, and Jim Parker of the UGS drafted figures and designed displays.

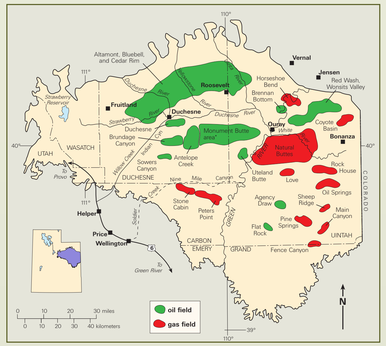
Overview of Utah's Major Oil-Producing Provinces



Oil and gas fields in the Paradox Basin of Utah and Colorado.



Oil and gas fields, uplifts, and major thrust faults in the Utah-Wyoming thrust belt.



Oil and gas fields in the Uinta Basin of Utah.

PARADOX BASIN

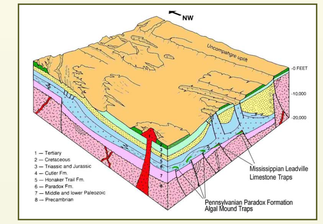
- Major Oil Reservoirs: Mississippian Leadville Limestone, shallow-shelf marine dolomite and limestone; Pennsylvanian Paradox Formation, shallow-shelf marine limestone and dolomite
- Trapping Mechanisms: stratigraphic – carbonate buildups (algal mounds, shoals, islands) sealed by anhydrite, salt, or organic-rich shale; structural – basement-involved faulted asymmetrical anticlines
- Source Rocks: black, organic-rich marine shale within the Pennsylvanian Paradox Formation
- First Commercial Discovery: Boundary Butte field, 1947
- Number of Active Fields/Wells: 63 fields/803 wells
- Recent Monthly Production: 353,000 bbls of oil, 1.6 BCF of gas
- Cumulative Production: 538 million bbls of oil, 1.3 TCF of gas
- Best Practices: waterflood, carbon-dioxide flood, waterflood, gas injection, horizontal drilling

THRUST BELT

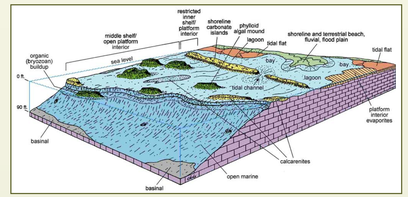
- Major Oil Reservoirs: Jurassic Nugget Sandstone, eolian dune sandstone; Jurassic Twin Creek Limestone, shallow marine limestone
- Trapping Mechanisms: anticlines in the hanging walls of detached (not involving basement rocks) thrust systems, and untested subthrust structures (beneath detached and basement-cored faults)
- Source Rocks: Cretaceous Mowry Shale; possibly Permian Phosphoria Formation
- First Commercial Discovery: Pineview field, 1975
- Number of Active Fields/Wells: 7 fields/85 wells
- Recent Monthly Production: 62,100 bbls of oil, 2.4 BCF of gas
- Cumulative Production: 165 million bbls of oil, 3.1 TCF of gas
- Best Practices: gas re-injection to maintain pressure, horizontal drilling

UINTA BASIN

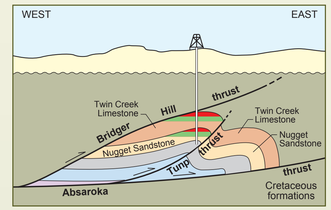
- Major Oil Reservoirs: Eocene Green River and Wasatch (Colton) Formations, lacustrine to alluvial channel and bar sandstone
- Trapping Mechanisms: anticlinal at Ashley Valley field, stratigraphic conventional (fluvial-deltaic pinchouts) and basin centered
- Source Rocks: Cretaceous coals and shale, Eocene lacustrine shale
- First Commercial Discovery: Gas at the Ashley Valley field, 1925, and oil at Roosevelt field, 1949
- Number of Active Fields/Wells: 65 fields/4,290 wells
- Recent Monthly Production: 624,000 bbls of oil, 10.2 BCF of gas
- Cumulative Production: 520 million bbls of oil, 2.2 TCF of gas
- Best Practices: waterflood in the Green River Formation



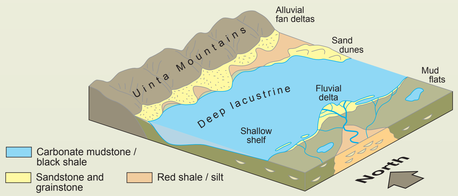
Schematic block diagram of the Paradox Basin showing trapping mechanisms for the Mississippian Leadville Limestone and Pennsylvanian Paradox Formation reservoirs. Modified from Petroleum Frontiers, 1984.



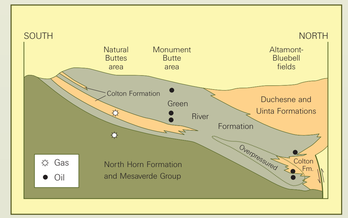
Block diagram displaying major depositional facies for the Pennsylvanian Paradox Formation, Paradox Basin.



Diagrammatic west-east structural cross section showing typical hanging-wall anticline trap.



Block diagram displaying major depositional facies for the Tertiary Green River Formation, Uinta Basin.



South-north cross section through Uinta Basin.

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