# Tight-Oil Plays in Utah

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The high price of crude oil, coupled with lower natural gas prices, has generated renewed interest in exploration and development of liquid hydrocarbon reserves in Utah. Following on the success of the recent shale gas boom and employing many of the same well completion techniques, petroleum companies are now exploring for liquid petroleum in shale formations in the state. In fact, many shales or low-permeable ("tight") carbonates recently targeted for natural gas include areas in which the zones are more prone to liquid production. Organic-rich shales in the Uinta and Paradox Basins have been the source for significant hydrocarbon generation, with companies traditionally targeting the interbedded sands or porous carbonate buildups for their conventional resource recovery. With the advances in horizontal drilling and hydraulic fracturing techniques, operators in these basins are now starting to explore the petroleum production potential of the shale and interbedded tight units themselves.

## Uinta Basin

### Overview

The Uinta Basin is the most prolific petroleum province in Utah. It is a major depositional and structural basin that subsided during the early Cenozoic along the southern flank of the Uinta Mountains. Lake deposits filled the basin between the eroding Sevier highlands to the west and the rising Laramide-age Uinta Mountains, Uncompahgre uplift, and San Rafael Swell to the north, east, and south, respectively. The southern Eocene lake, Lake Uinta, formed within Utah's Uinta Basin and Colorado's Piceance Creek Basin.

The Green River Formation consists of as much as 6000 ft of sedimentary strata (Hintze and Kowallis, 2009; Sprinkel, 2009) and contains three major depositional facies associated with Lake Uinta sedimentation: alluvial, marginal lacustrine, and open lacustrine (Fouch, 1975). The marginal lacustrine facies, where most of the hydrocarbon production is found, consists of fluvial-deltaic, interdeltaic, and carbonate flat deposits, including microbial carbonates. The open-lacustrine facies is represented by nearshore and deeper water offshore muds, including the famous Mahogany oil shale zone, which represents Lake Uinta's highest water level.

The Uinta Basin is asymmetrical, paralleling the east-west trending Uinta Mountains. The north flank dips 10-35º southward into the basin and is bounded by a large north-dipping, basement-involved thrust fault. The southern flank gently dips between 4-6º north-northwest.

### Activity

Recent tight-oil drilling and exploration activities in the Uinta Basin are targeting relatively thin porous carbonate beds of the Uteland Butte Limestone Member of the lower Green River Formation (figures 1 and 2), particularly in an area referred to as the "Central Basin

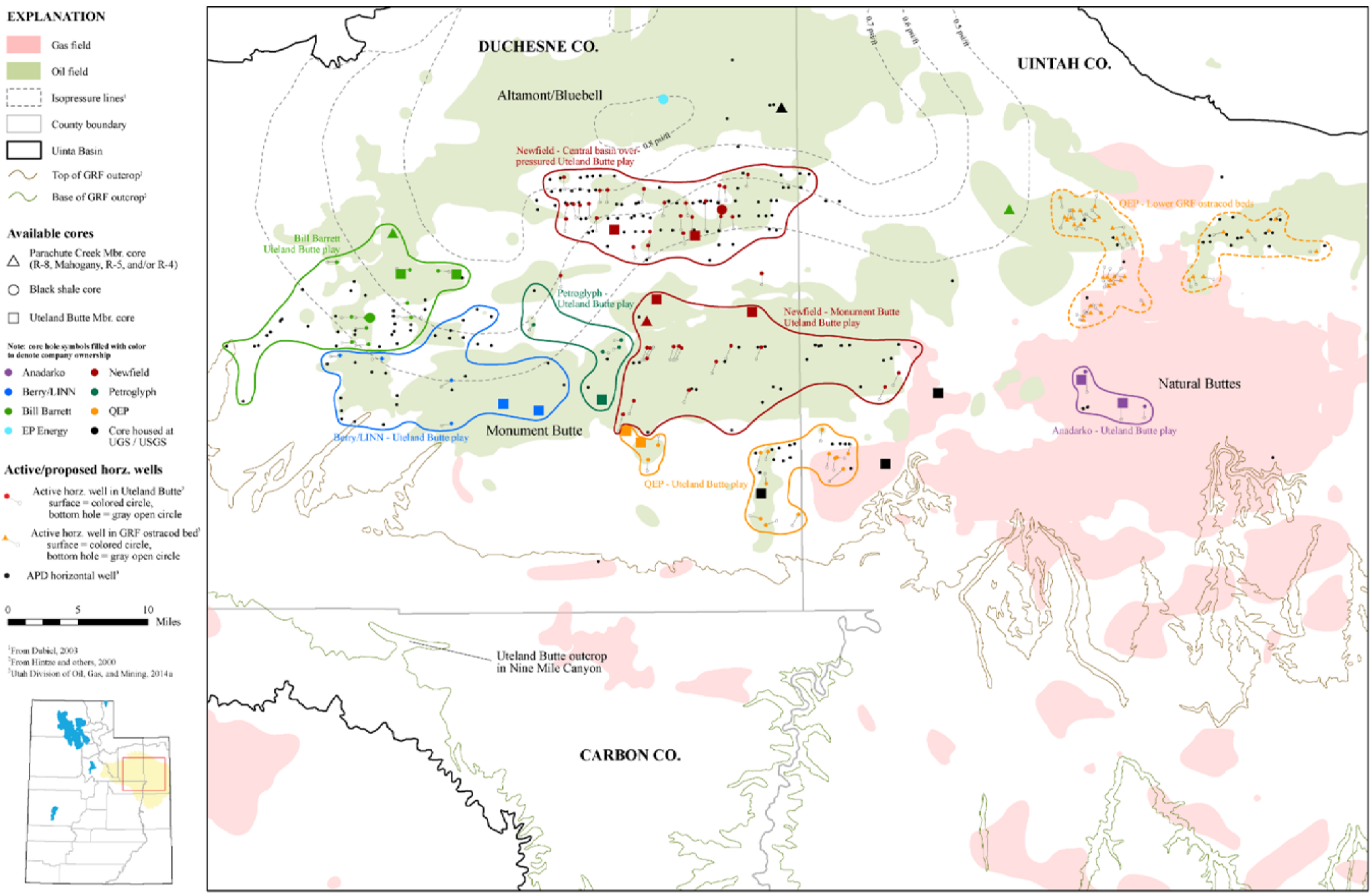


*Figure 1. Map of the Uinta Basin, Utah, showing play areas for the Uteland Butte Limestone Member of the Tertiary Green River Formation, APD horizontal well locations, and active horizontal wells by operators.*


***Figure 2. Uteland Butte core from the Bill Barrett 14-1-46 well. The horizontal drilling target is the roughly 5-ft light brown dolomitic interval. Porosity in this interval ranges from 15-30% and permeability averages 0.06 mD. The dolomite is interbedded with organic-rich mudstones and limestones averaging between 1% and 3% TOC. Note the abundant shell fragments indicating deposition in a freshwater lacustrine environment.***

region” between Altamont-Bluebell field to the north and Monument Butte field to the south. The Uteland Butte has historically been a secondary oil objective of wells tapping shallower overlying Green River reservoirs and deeper fluvial-lacustrine Colton Formation sandstone units in the western Uinta Basin.

The Uteland Butte records the first major transgression of Eocene Lake Uinta after the deposition of the alluvial Colton Formation, and thus it is relatively widespread in the basin (figure 3). The Uteland Butte ranges in thickness from less than 60 ft to more than 200 ft and consists of limestone, dolomite, organic-rich calcareous mudstone, siltstone, and rare sandstone (figures 2, 4, and 5). The dolomite (figure 2), the new horizontal drilling target, often has more than 20% porosity, but is so finely crystalline that the permeability is very low (single mD or less).

Several companies (Berry/LINN, Bill Barrett Corporation, EP Energy, Newfield, QEP Resources, Devon, and Petroglyph) have had recent and continued success targeting the Uteland Butte with horizontal wells in both the central, normally pressured part of the basin near Greater Monument Butte field, and farther north in the overpressured zone in western Altamont field (figure 1). There are over 50 active horizontal wells producing from the Uteland Butte. Production from these wells averages 500-1500 BOE per day from horizontal legs up to 4000 ft in length. However, at the end of 2013, Newfield Production Company announced the completion of three high-volume producers in the Central Basin region with initial rates of 1213-1337 barrels per day (IHS Inc., 2013d). As of January 2014, there were over 200 APDs for horizontal wells targeting the Uteland Butte and other potential Green River tight-oil zones (figure 1) (Utah Division of Oil, Gas, and Mining, 2014a).

## Paradox Basin

### Overview

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado with small portions in northeastern Arizona and the northwestern corner of New Mexico. The Paradox Basin is an elongate, northwest-southeast-trending, evaporitic basin that predominately developed during the Pennsylvanian, about 330 to 310 Ma. The basin was bounded on the northeast by the Uncompahgre Highlands as part of the Ancestral Rockies. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest—the Paradox Basin. Rapid basin subsidence, particularly during the Pennsylvanian and continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast. Deposition in the basin produced a thick cyclical sequence of carbonates, evaporites, and organic-rich shale of the 500- to 5000-ft-thick Pennsylvanian Paradox Formation (Hintze and Kowallis, 2009).

Rasmussen (2010) divided the middle part of the Paradox Formation in the evaporite basin into as many as 35 salt cycles, some of which onlap onto the basin shelf to the west and southwest (figure 6). Each cycle consists of a clastic interval/salt couplet. The clastic intervals are typically interbedded dolomite, dolomitic siltstone, anhydrite, and black, organic-rich shale—the sources of the petroleum in the basin. The clastic intervals typically range in thickness from 10 to 200 ft and are generally overlain by 200 to 400 ft of halite.

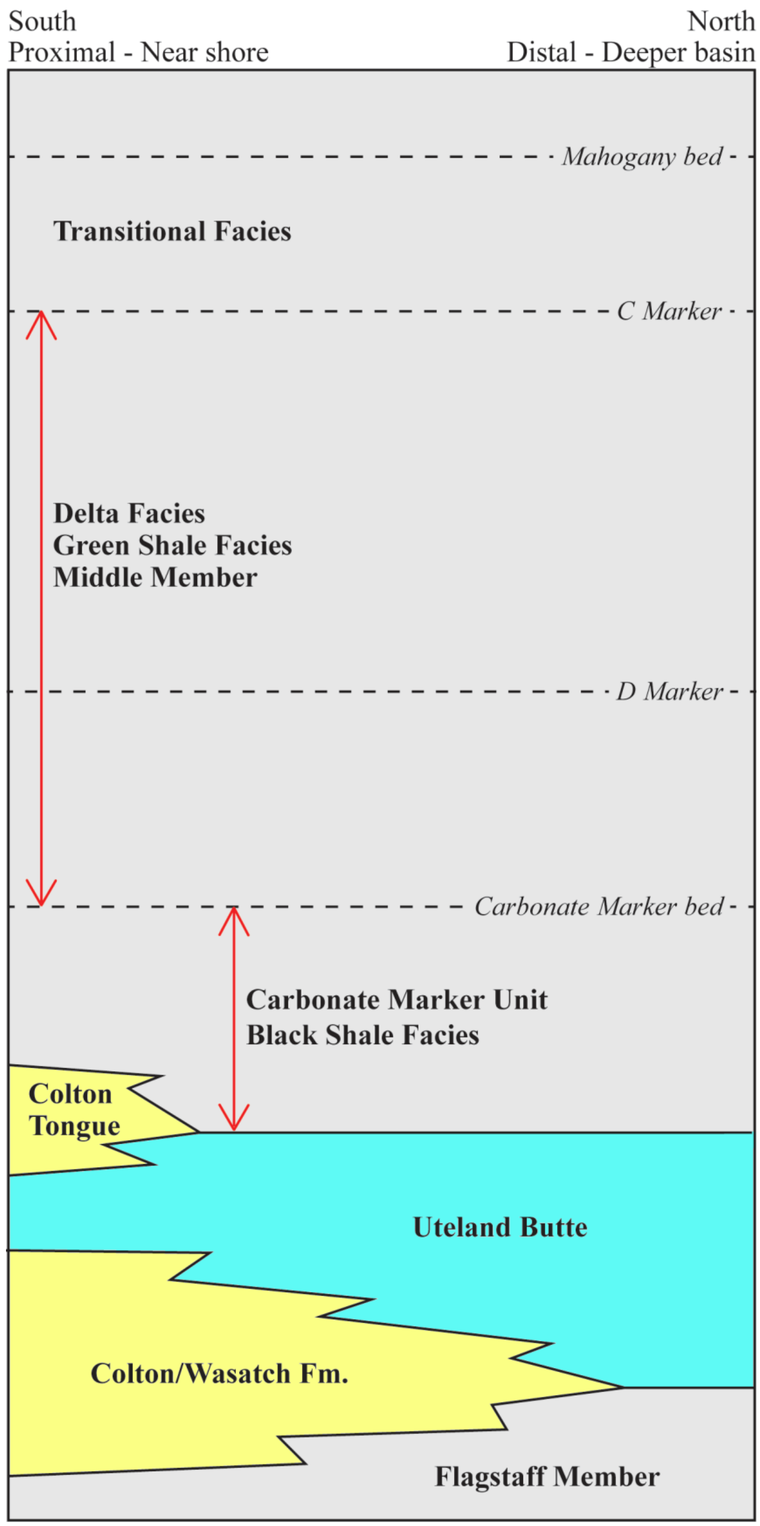


***Figure 3. General stratigraphy of the lower to middle Green River Formation in the western Uinta Basin (not to scale).***

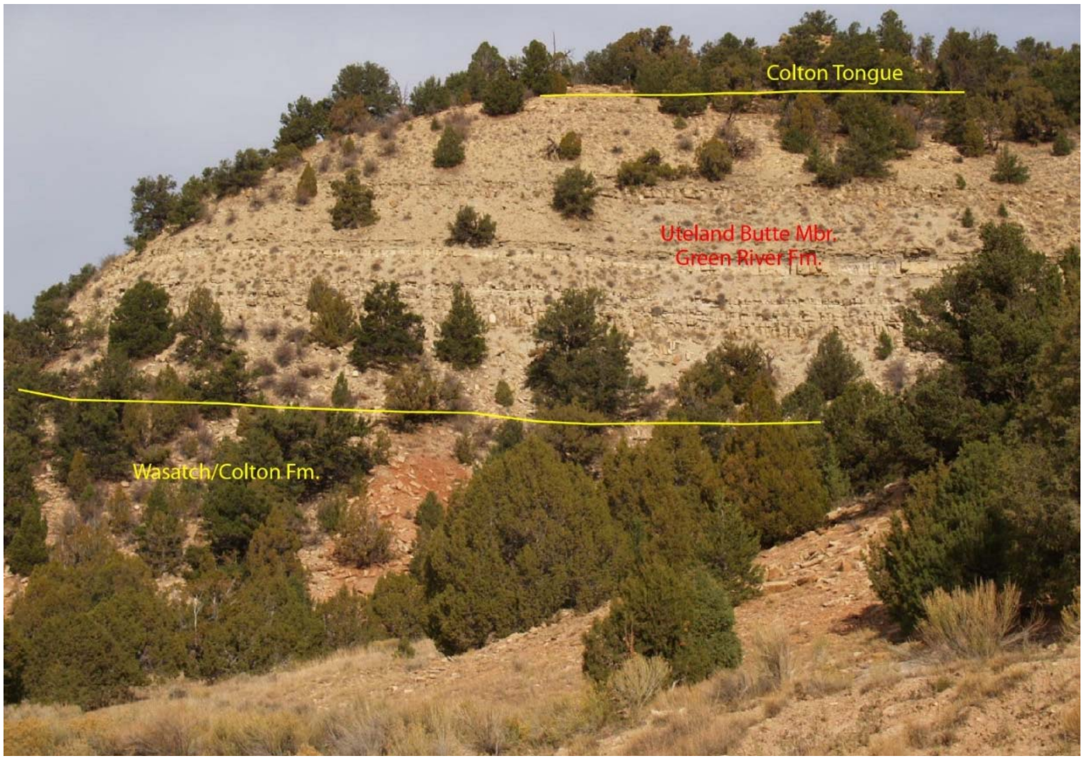


***Figure 4. Outcrop of the Uteland Butte Member of the Green River Formation, Nine Mile Canyon, central Utah.***

***Figure 5. Fresh road cut exposure of Uteland Butte Member of the Green River Formation consisting of interbedded dolomite and mudstone/limestone, Nine Mile Canyon, central Utah.***

The Paradox Basin can generally be divided into three areas: the Paradox fold and fault belt in the north, the Blanding sub-basin in the south-southwest, and the Aneth platform in the southernmost part in Utah. The area now occupied by the Paradox fold and fault belt was the site of greatest Pennsylvanian/Permian subsidence and salt deposition. Folding in the Paradox fold and fault belt began as early as the Late Pennsylvanian as sediments were laid down thinly over, and thickly in areas between, rising salt. Spectacular salt-cored anticlines extend for miles in the northwesterly trending fold and fault belt. Reef-like buildups or mounds of carbonates consisting of algal bafflestone and oolitic/skeletal grainstone fabrics in the Desert Creek and Ismay zones of the Paradox Formation are the main hydrocarbon producers in the Blanding sub-basin and Aneth platform. Oil in these zones is sourced above, below, or within the organic-rich Gothic, Chimney Rock, Hovenweep, and Cane Creek shales (figure 6).

**Activity**

The Cane Creek shale zone of the Paradox Formation has been a target for tight-oil exploration on and off since the 1960s and produces oil from several small fields (figure 7). The play generated much interest in the early 1990s with the successful use of horizontal drilling. Currently, eight active fields produce from the Cane Creek in the Paradox Basin fold-and-fault belt, with cumulative oil production over 5 million barrels and 4 billion cubic feet of gas (Utah Division of Oil, Gas, and Mining, 2014b). Once again, the Cane Creek and other Paradox zones are being targeted for exploration using horizontal drilling.

The Cane Creek shale zone records an early stage of a transgressive-regressive sequence (cycle 21) in the Paradox Formation and consists of organic-rich marine shale with interbedded dolomitic siltstone and anhydrite (figure 8). The unit is up to 160 ft thick and areally extensive within the Paradox Basin. It is divided into the A, B, and C zones, with the shale and silty carbonates of the B zone considered both the source rock and reservoir. The A and C zones are anhydrite rich and provide an upper and lower seal to the B zone. The unit is highly overpressured, with measurements ranging between 5000 and 6200 psi, which is probably the result of hydrocarbon generation between very impermeable upper and lower anhydrite seals. The B zone is naturally fractured, and oriented cores show that fractures trend northeast-southwest, matching the regional structural trend.

Two new Cane Creek shale horizontal well discoveries were announced in 2013 (figure 7): Fidelity Exploration & Production Company's 17-1 Cane Creek Unit (SWSE section 17, T. 26 S., R. 20 E., Salt Lake Basin Line & Meridian [SLBL&M], Grand County) just east of Park Road field, and Southwestern Energy Production Company's 1-16H SEPCO-State 30-23 (SESE section 16, T. 30 S., R. 23 E., SLBL&M, San Juan County). The 17-1 well was drilled in a south-southeast direction and averaged 524 BOPD and 242 MCFGPD in June 2013. Fidelity completed additional wells in Big Flat and Park Road fields in 2012 and 2013. The 36-1 Cane Creek Unit well (SWSW section 36, T. 25 S., R. 19 E., SLBL&M, San Juan County) in Big Flat field flowed over 1250 BOPD (IHS Inc., 2013b). The company has identified 50 to 75 Cane Creek locations with an estimated recovery of 250,000 to 1 million bbls of oil per well (IHS Inc., 2013a). The 1-16H well was drilled in a northwest direction and in October 2013 was testing oil into onsite production facilities. It is located 5 miles south of Stone Energy Corporation's 2011 29-28 La Sal Unit Cane Creek discovery (SESE section 29, T. 29 S., R. 23 E., SLBL&M, San Juan County). That well initially flowed 248 BOPD and 320 MCFGPD from a northeast-

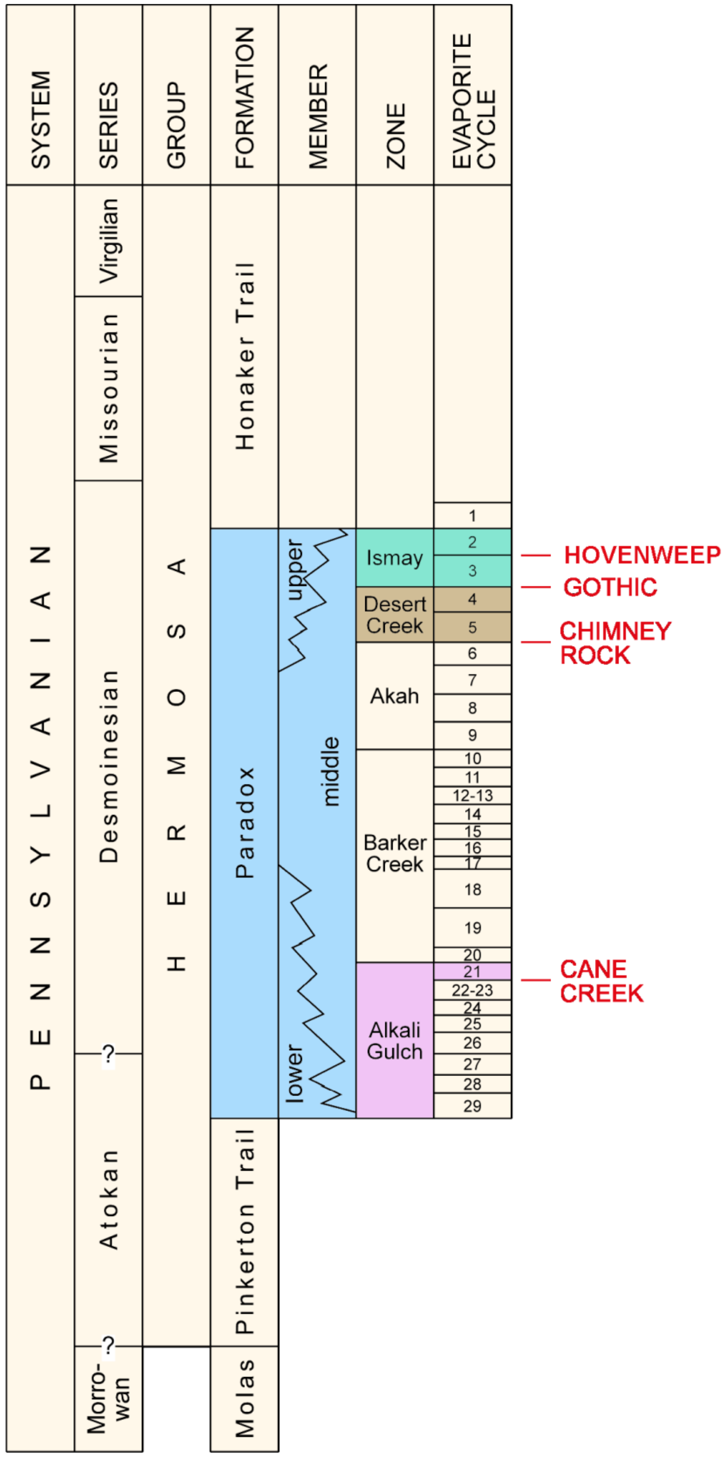


***Figure 6. Pennsylvanian stratigraphic chart for the Paradox Basin, informal organic-rich shale units are highlighted. Modified from Hite (1960), Hite and Cater (1972), and Reid and Berghorn (1981).***

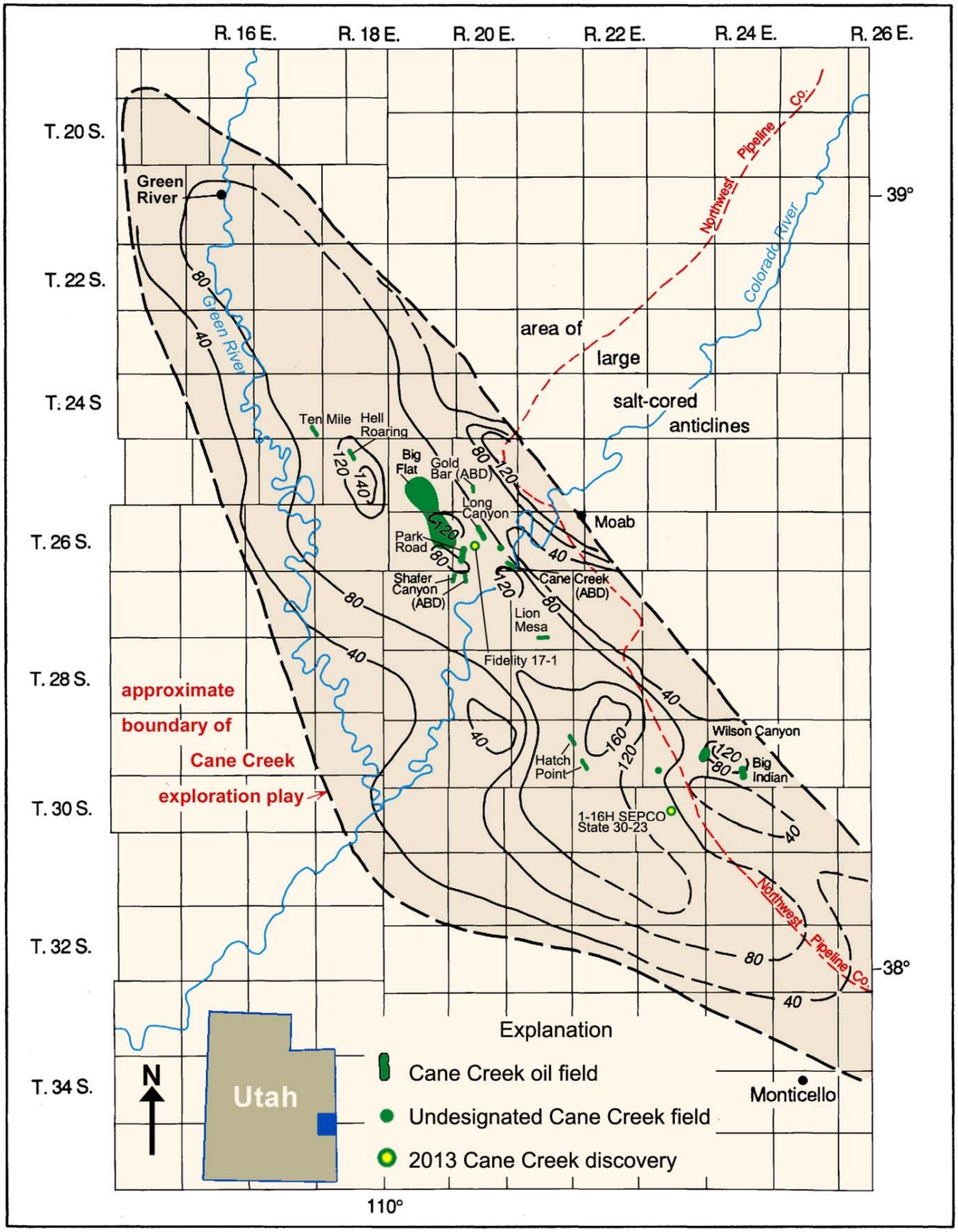


*Figure 7. Thickness map and exploration play area of the Cane Creek shale zone of the Pennsylvanian Paradox Formation, northern Paradox Basin, Utah, showing Cane Creek fields and 2013 discoveries. Contour interval = 40 ft.*


***Figure 8. Cane Creek core from the Union Pacific Resources Remington 21-1H well (section 21, T. 31 S., 23 E., SLBL&M, San Juan County, Utah) displays interbedded medium gray dolomite with organic-rich dark gray/black shale. Also present is mottled light gray to white anhydrite.***

directed horizontal lateral. At the end of 2013, Fidelity staked horizontal wells targeting the Cane Creek, one northeast of Hell Roaring field and two west of Big Flat field.

The U.S. Geological Survey (2012), Whidden and others (2014), and Anna and others (2014) re-assessed the undiscovered oil resource in the Cane Creek at 103 million barrels at a 95% confidence level and 198 million barrels at a 50% confidence level. In addition to the Cane Creek, several other organic-rich shale zones are present in the Paradox Formation, creating the potential for significant reserve base additions. The Gothic, Chimney Rock, and Hovenweep shales (figure 6) in the Blanding sub-basin and Aneth platform are estimated to hold an undiscovered oil reserve of 126 million barrels at a 95% confidence level and 238 million barrels at a 50% confidence level (U.S. Geological Survey, 2012; Whidden and others, 2014; and Anna and others, 2014). These zones are also actively being evaluated for tight oil potential and several wells were staked in 2013. Anadarko E&P Onshore LLC drilled a horizontal well, the 3424-2-1H Lewis Road-Fee (SWSW section 2, T. 34 S., R. 24 E., SLBL&M, San Juan County), targeting the Gothic shale; no information has been released (IHS Inc., 2013c). Anadarko has three additional horizontal Gothic wells staked 5, 8, and 17 miles to the south, southwest, and southeast, respectively, from the Lewis Road well.

## New Research

The Utah Geological Survey has been awarded funding from the National Energy Technology Laboratory, U.S. Department of Energy for a three-year project titled "Liquid-Rich Shale Potential of Utah's Uinta and Paradox Basins: Reservoir Characterization and Development." The overall goal of this study is to provide reservoir-specific geological and engineering analyses of the (1) emerging Green River Formation tight oil plays (such as the Uteland Butte Limestone Member, Black Shale facies, deep Mahogany zone, and other deep Parachute Creek member high-organic units) in the Uinta Basin, and (2) the established, yet understudied Cane Creek shale (and possibly other shale units such as the Gothic and Chimney Rock shale zones) of the Paradox Formation in the Paradox Basin. To accomplish this goal, the project will:

- Characterize geologic, geochemical, and petrophysical rock properties of target zones in the two designated basin areas by compiling various sources of data and by analyzing newly acquired and donated core, well logs, and well cuttings.
- Describe outcrop reservoir analogs of Green River Formation plays and compare them to subsurface data (not applicable in the Paradox Basin since the Cane Creek shale is not exposed).
- Map major regional trends for targeted liquid-rich intervals and identify "sweet spots" that have the greatest oil production potential.
- Suggest techniques to reduce exploration costs and drilling risks, especially in environmentally sensitive areas.
- Improve drilling and fracturing effectiveness by determining optimal well completion design.
- Suggest techniques to reduce field development costs, maximize oil recovery, and increase reserves.

The project will therefore develop and make available geologic and engineering analyses, techniques, and methods for exploration and production from the Green River Formation tight oil zones and the Paradox Formation shale zones where operations encounter technical, economic, and environmental challenges.

In addition to a thorough geologic characterization of the target zones, tests will be performed to characterize the geomechanical properties of the zones of interest to inform/guide well completion strategies. The brittle characteristics of the target intervals will be studied in detail using energy-based calculations. This approach acknowledges both mechanical properties and in-situ stress conditions, as well as geometric lithologic constraints and the mineralogy that regulates fracturing. The study will establish a template for more effective well planning and completion designs by integrating the geologic characterization and formation evaluation with state-of-the-art rock mechanical analyses. This will help companies access oil they know is present, but technically difficult to recover.

To aid in the identification of hydrocarbon "sweet spots," novel concepts for exploration will be employed such as the use of low-cost, low-environmental impact, epifluorescence analysis of regional core and well cuttings. Epifluorescence microscopy is a technique used to provide information on diagenesis, pore types, and organic matter (including "live" hydrocarbons) within sedimentary rocks. It is a rapid, non-destructive procedure that uses a petrographic microscope equipped with reflected-light capabilities, a mercury-vapor light, and appropriate filtering. Epifluorescent intensities obtained from core and cuttings will be mapped to help identify areas with potential for significant hydrocarbon production. The detailed reservoir characterization and rock mechanics analyses will provide the basis for identification of "sweet spots" and improve well completion strategies for these undeveloped and under-developed reservoirs.

For more information about this ongoing project, including available posters and talks (in pdf), refer to the Utah Geological Survey's project website: http://geology.utah.gov/emp/shale_oil.

## Recent Presentations

"Liquid-Rich Shale Potential of Utah's Uinta Basin: Reservoir Characterization and Development," by Michael D. Vanden Berg, January 10, 2013, quarterly Uinta Basin Oil and Gas Collaborative Group Meeting, Vernal, Utah.

"The Uteland Butte Member of the Eocene Green River Formation: An Emerging Unconventional Carbonate Tight Oil Play in the Uinta Basin, Utah," by Michael D. Vanden Berg, Craig D. Morgan, Thomas C. Chidsey, Jr., and Peter Nielsen, May 19-20, 2013, AAPG Annual Convention, Pittsburgh, Pennsylvania.

"Current Understanding of the Sedimentology, Stratigraphy, and Liquid-Oil Potential of the Pennsylvanian Cane Creek Shale of the Paradox Formation, Southeastern Utah," by Peter Nielsen, Craig D. Morgan, and Michael D. Vanden Berg, September 22-24, 2013 AAPG Rocky Mountain Section Meeting, Salt Lake City, Utah.

"Detailed Sedimentology and Stratigraphy of the Remington 21-1H Cane Creek Shale Core, Pennsylvanian Paradox Formation, Southeastern Utah: Implications for Unconventional Hydrocarbon Recovery," by Peter J. Nielsen, Craig D. Morgan, and Michael D. Vanden Berg, September 22-24, 2013 AAPG Rocky Mountain Section Meeting, Salt Lake City, Utah.

“Reservoir Characterization of the Uteland Butte Formation in the Uinta Basin,” by Jason Anderson and John Roesink, September 22-24, 2013 AAPG Rocky Mountain Section Meeting, Salt Lake City, Utah.

“Temporal and Spatial Variations in Lacustrine Depositional Controls from the Middle to Upper Green River Formation, Central and Western Uinta Basin, Utah,” by Leah Toms, Lauren Birgenheier, and Michael D. Vanden Berg, September 22-24, 2013 AAPG Rocky Mountain Section Meeting, Salt Lake City, Utah.

“Geologic Evaluation of the Cane Creek Shale, Pennsylvanian Paradox Formation, Paradox Basin, Southeastern Utah,” by Stephanie M. Carney, Peter J. Nielsen, and Michael D. Vanden Berg, April 9, 2014 AAPG Annual Convention, Houston, Texas.

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