Analyzing Core from Two Emerging Tight Oil Plays in Utah: The Uteland Butte Member of the Green River Formation in the Uinta Basin and the Cane Creek Shale within the Paradox Formation in the Paradox Basin

Michael D. Vanden Berg, Craig D. Morgan, and Thomas C. Chidsey, Jr. *Utah Geological Survey, Salt Lake City, Utah*

ABSTRACT

Two emerging tight oil plays in Utah have gained significant traction in the past few years, renewing interest in two historically productive basins. The Utah Geological Survey is conducting a multi-year, U.S. Department of Energy-funded study of these two distinct tight oil plays, utilizing newly acquired core and associated data.

The lacustrine Uteland Butte Member of the Green River Formation records the first major transgression of Eocene Lake Uinta after the deposition of the alluvial Colton Formation in the Uinta Basin. The main horizontal drilling objective, as analyzed in several cores, is a 2- to 7-foot-thick interval of fractured dolomite, with porosities between 14 and 30%, interbedded with organic-rich limestone and shale. TOC values in the adjacent rocks range between 2 and 5%, while Ro values range between 0.7 and 1.1%, indicating the reservoir is most likely self-sourcing.

The Cane Creek shale is a transgressive-regressive marine sequence in the lower portion of the Pennsylvanian Paradox Formation, Paradox Basin. The Cane Creek is tens of feet to nearly 200 feet thick, over- and underlain by beds of salt, and divided into A, B, and C intervals (in descending order). The B interval is the primary hydrocarbon source rock and productive zone, consisting of black organic-rich shale, dolomite, dolomitic siltstone, very fine sandstone, and some anhydrite. Significant porosity (up to 15%) is found in the dolomitic siltstone and sandstone, but permeability is generally low (roughly 0.1 mD); naturally occurring fractures are necessary for economic production. The A and C intervals, mostly dolomite and anhydrite, are the seals for the B interval, helping prevent fracture communication with the adjacent salt beds.

A refined geological and reservoir characterization study of these two tight oil plays, using newly acquired core and geophysical logs, is currently underway to help delineate play boundaries, guide resource estimates, and inform recovery methods.

Project funded by: U.S. Department of Energy - National Energy Technology Laboratory and Utah Geological Survey

Project website:
http://geology.utah.gov/resources/energy/oil-gas/shale-oil

Bill Barrett Corporation — *Core and data provided by Bill Barrett Corporation*

UTELAND BUTTE MEMBER, GREEN RIVER FORMATION

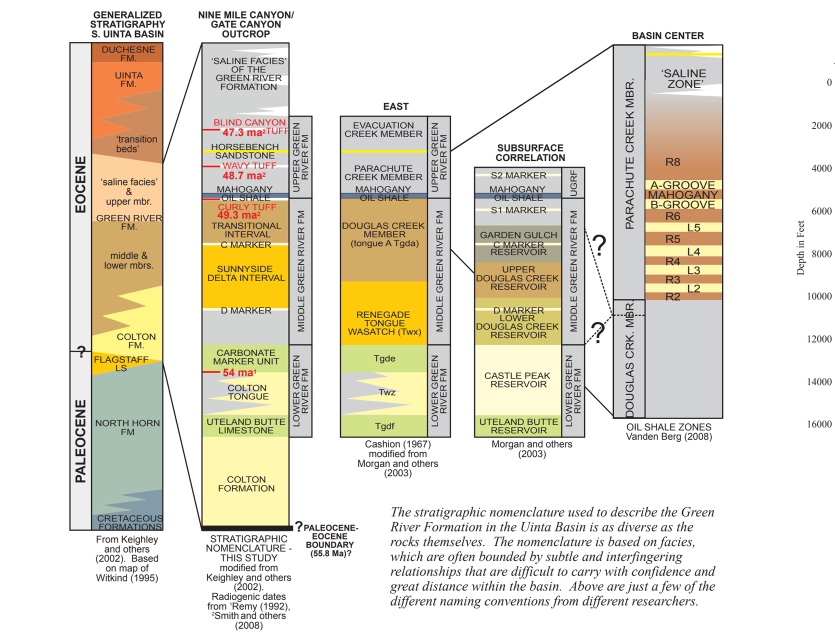
BACKGROUND

Uinta Basin Geology and Green River Formation

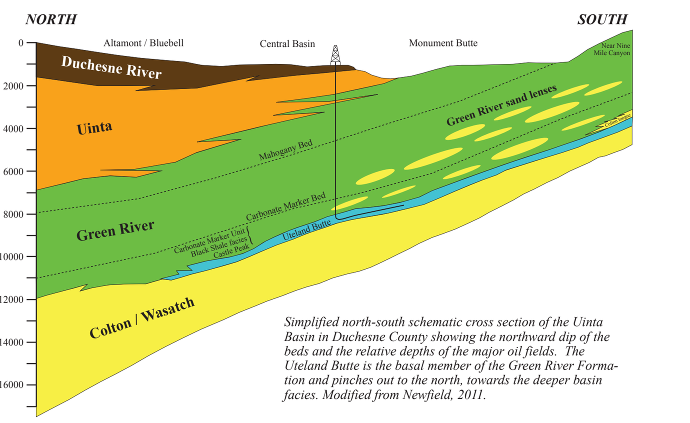
The Uinta Basin is a topographic and structural trough encompassing an area of more than 9300 square miles (14,900 km^2) in northeast Utah. The basin is sharply asymmetric, with a steep north flank bounded by the east-west trending Uinta Mountains and a gently dipping south flank.

The Uinta Basin formed in the Late Cretaceous Maastrichtian time, creating a large area of internal drainage that was filled by ancestral Lake Uinta during the Paleocene and Eocene. Deposition in and around Lake Uinta consisted of open- to marginal-lacustrine sediments that make up the Green River Formation (GRF). Alluvial red-bed deposits that are laterally equivalent to, and intertongue with, the GRF make up the Colton (Wasatch) Formation. The southern shore of Lake Uinta was often very broad and flat, which allowed large transgressive and regressive shifts in the shoreline in response to climatic and tectonic-induced rise and fall of the lake. The cyclic nature of the GRF deposition in the southwest Uinta Basin resulted in numerous stacked deltaic deposits. Distributary-mouth bars, distributary channels, and nearshore bars are the primary producing sandstone reservoirs in the area. Recently, companies have targeted the thinner carbonate layers, such as the Uteland Butte Member, as horizontal drilling targets.

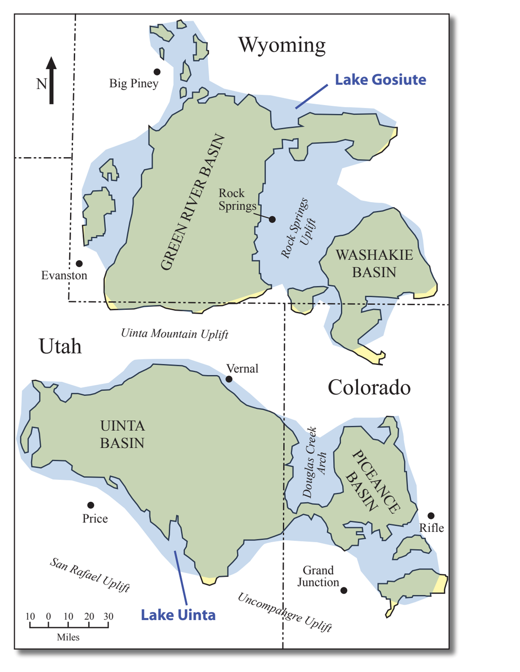
Uinta Basin Stratigraphy



The stratigraphic nomenclature used to describe the Green River Formation in the Uinta Basin is as diverse as the rocks themselves. The nomenclature is based on facies, which are often bounded by subtle and interfingering relationships that are difficult to carry with confidence and great distance within the basin. Above are just a few of the different naming conventions from different researchers.



Simplified north-south schematic cross section of the Uinta Basin in Duchesne County showing the northward dip of the beds and the relative depths of the major oil fields. The Uteland Butte is the basal member of the Green River Formation and pinches out to the north, towards the deeper basin facies. Modified from Newfield, 2011.



Conceptual map of ancient Lake Uinta, which coverd the present day Uinta and Piceance Basins, and ancient Lake Gosiute, which covered the Green River and Washakie Basins.

Uteland Butte Member

The Uteland Butte reservoir is the first major transgression of ancient Lake Uinta after deposition of the fluvial Colton (Wasatch) Formation. The Uteland Butte ranges in thickness from less than 60 feet to more than 200 feet in the southwest Uinta Basin. The Uteland Butte is equivalent to the first lacustrine phase of Bradley (1931), black shale facies of Picard (1955), lower black shale facies of Abbott (1957), basal limestone facies of Little (1988) and Colburn and others (1985), the Uteland Butte limestone of Osmond (1992), and the basal limestone member of Crouch and others (2000).

The Uteland Butte consists of limestone, dolostone, calcareous mudstone and siltstone, and rare sandstone. Most of the limestone beds are ostracodal grain-supported or mud-supported grainstone, packstone, or wackestone. Grainstone is more common near the shallow shoreline of the lake, whereas deeper distal deposits are commonly argillaceous limestone. A cryptocrystalline, dolomitized, compacted wackestone with ostracods has been found near the top of the Uteland Butte in some core. The dolomite often has more than 20 percent porosity, but is so finely crystalline that the permeability is low (single millidarcy or less).

The Uteland Butte reservoir was deposited during a rapid and extensive lake-level rise. The Uteland Butte is distinctive in the abundance of carbonate and the lack of sandstone, which could have been caused by one or both of the following situations: (1) the rapid lake-level rise caused siliciclastic sediments to be deposited in the proximal alluvial channels, or (2) the main inflow into the lake was far from the southwest Uinta Basin area, perhaps flowing into the southern arm of the lake south and west of the San Rafael uplift.

The Uteland Butte reservoir is oil productive throughout most of the southwest Uinta Basin. The Uteland Butte was a secondary objective in most vertical wells and was usually perforated along with beds in the Castle Peak, lower Douglas Creek, and upper Douglas Creek reservoirs.

The cryptocrystalline dolomitic wackestone has only recently been extensively explored. This bed, widely distributed throughout the central and southern Uinta Basin, has become a recent target for extensive horizontal drilling, with limited success in the southern part of the basin, but more success in the over-pressured central basin area.

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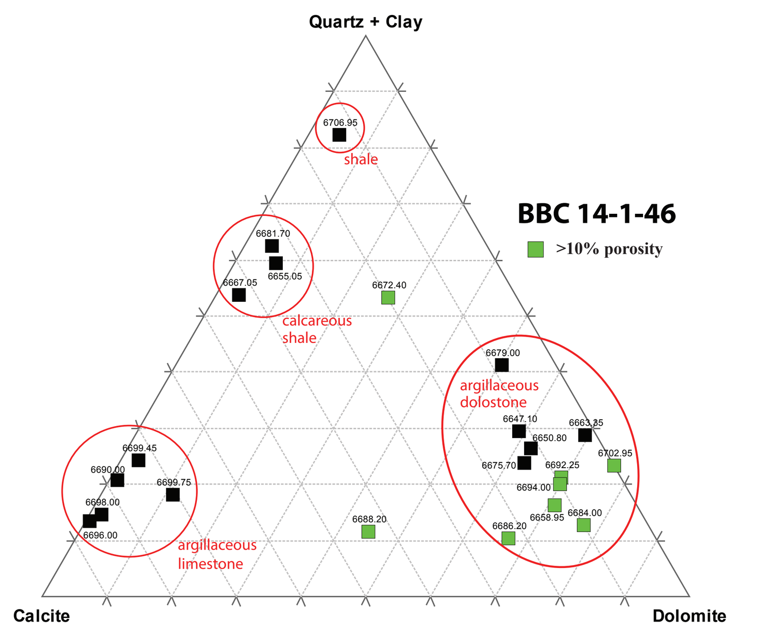
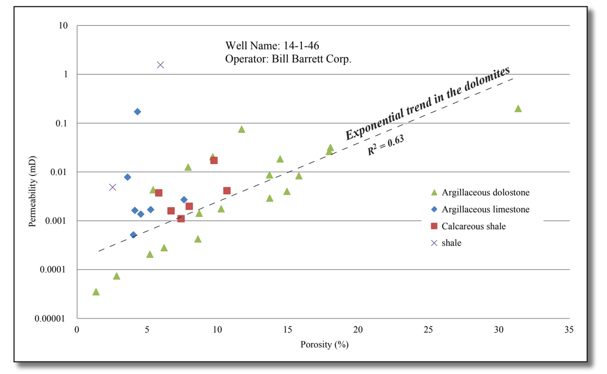
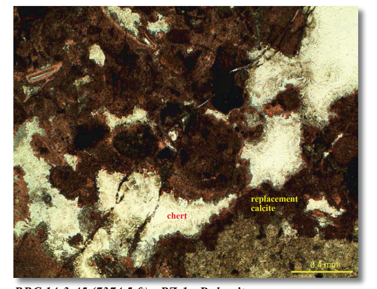
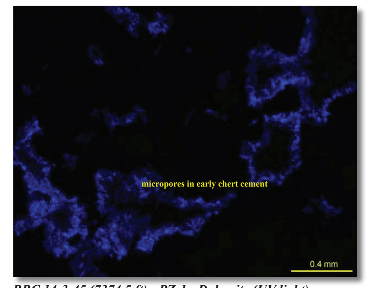
MINERALOGY AND GEOCHEMISTRY



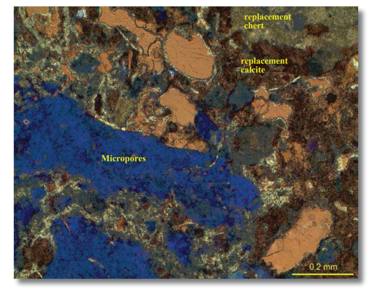




BBC 14-3-45 (7374.5 ft) - PZ-1 - Dolomite



BBC 14-3-45 (7374.5 ft) - PZ-1 - Dolomite (UV light)



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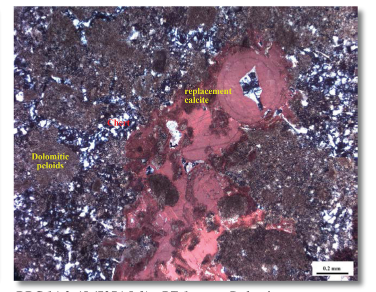

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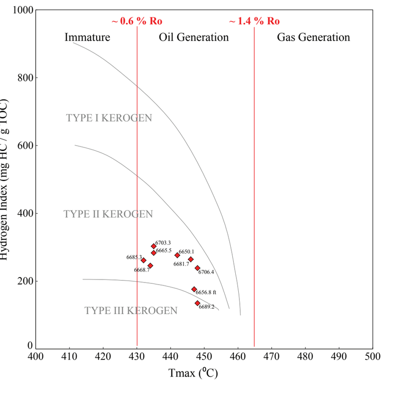
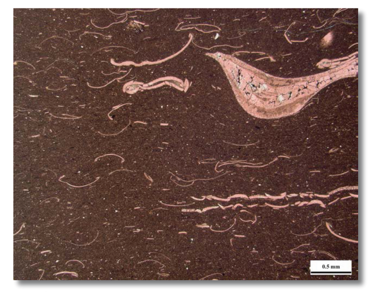




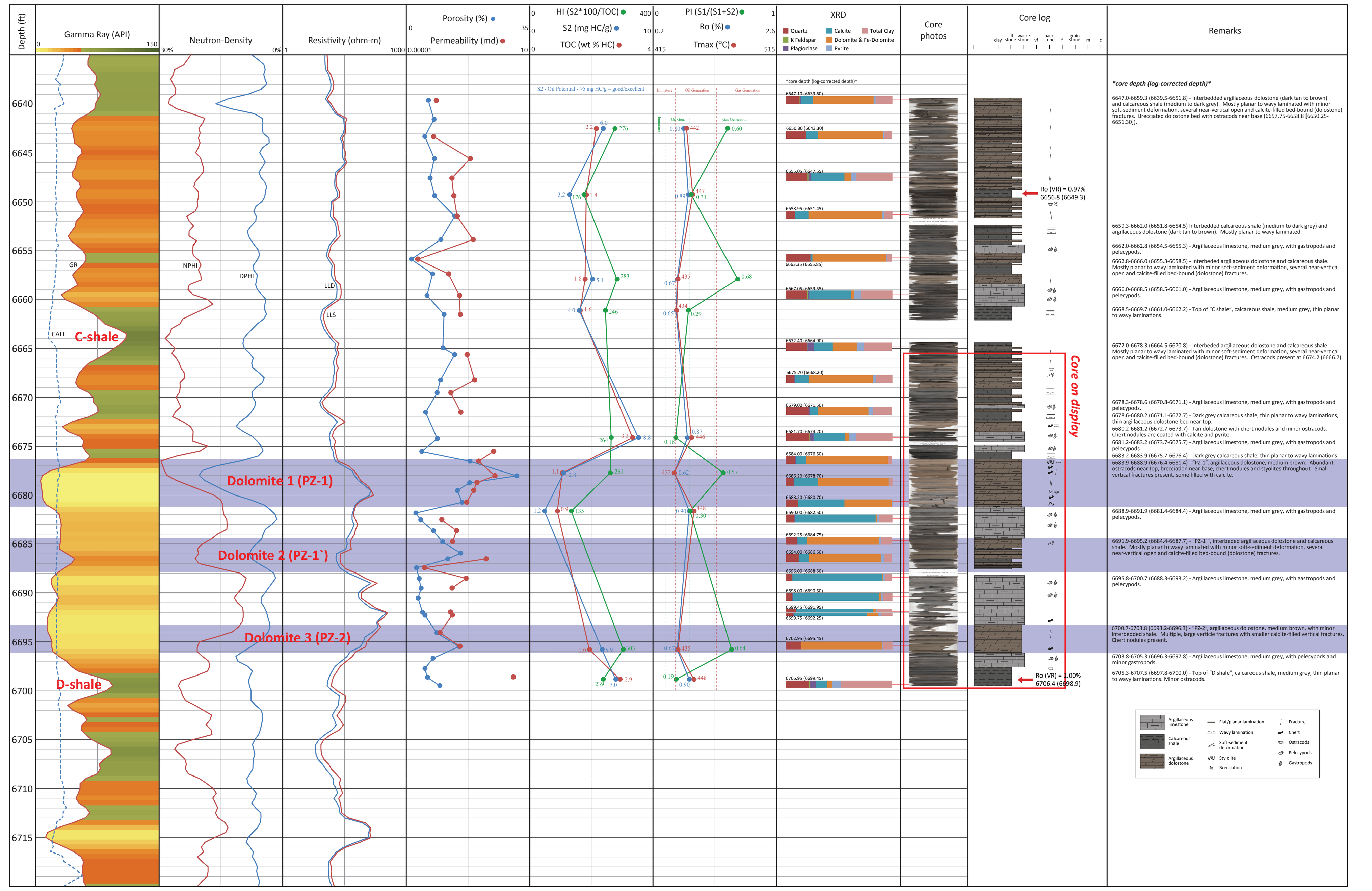
BBC 14-3-45 (7365.1 ft) - Limestone w/ bivalves

Thin section micrographs from adjacent Bill Barrett core (14-3-45). Photos and interpretations from Core Lab.

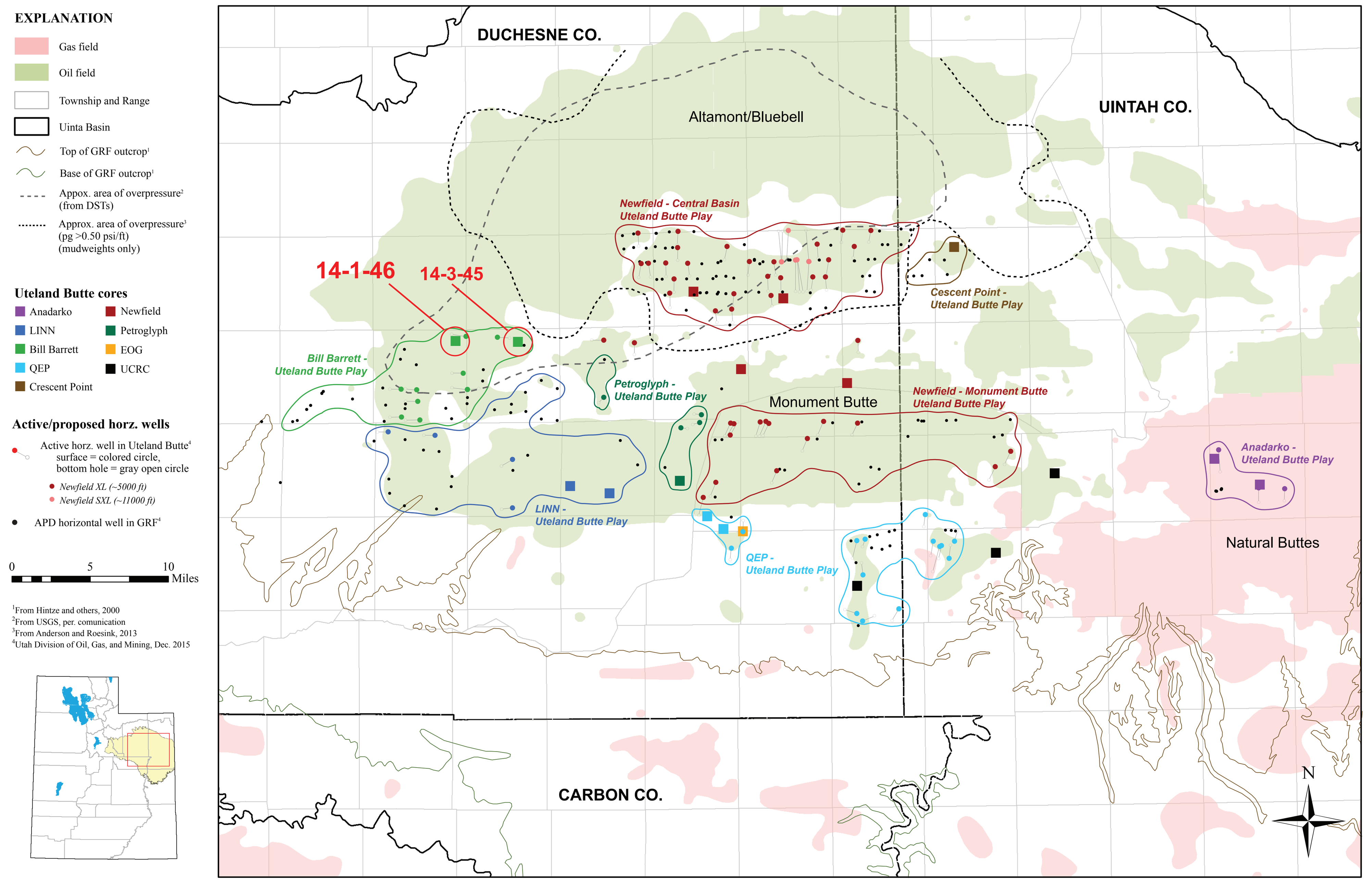
Well name: 14-1-46 (4301334113)

Operator: Bill Barrett Corp.
Location: T4S, R6W, Sec. 1, Duchesne County, UTM E 541444, UTM N 4445336

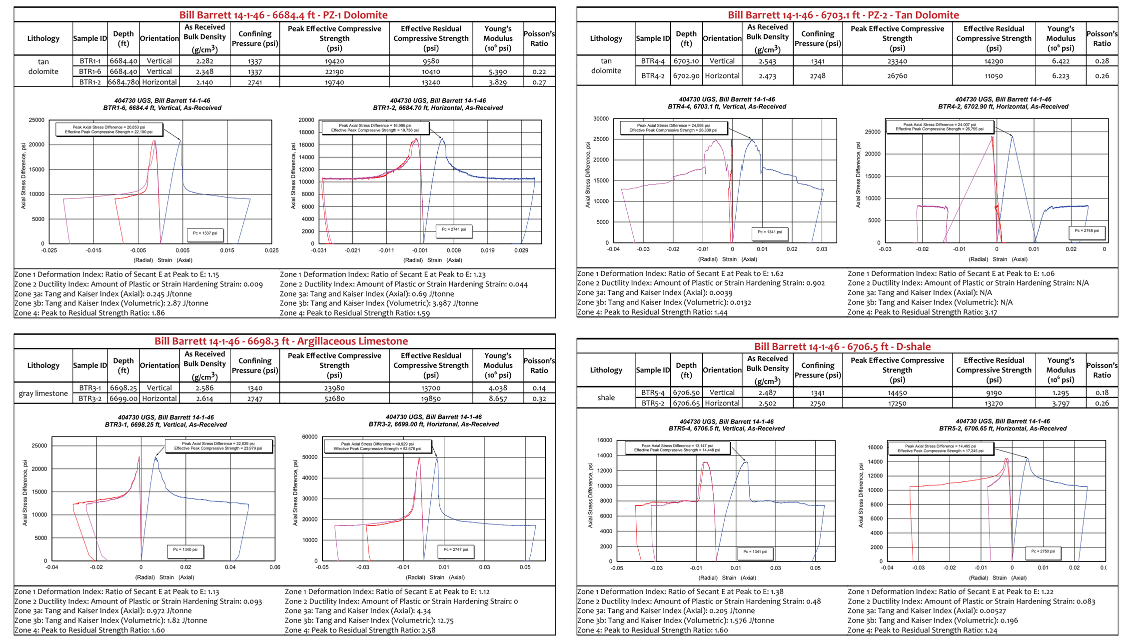
Cored interval: 6647-6669.7, 6672-6707 ft (core shifted up ~7.5 ft to match logs)
Core location: Utah Core Research Center



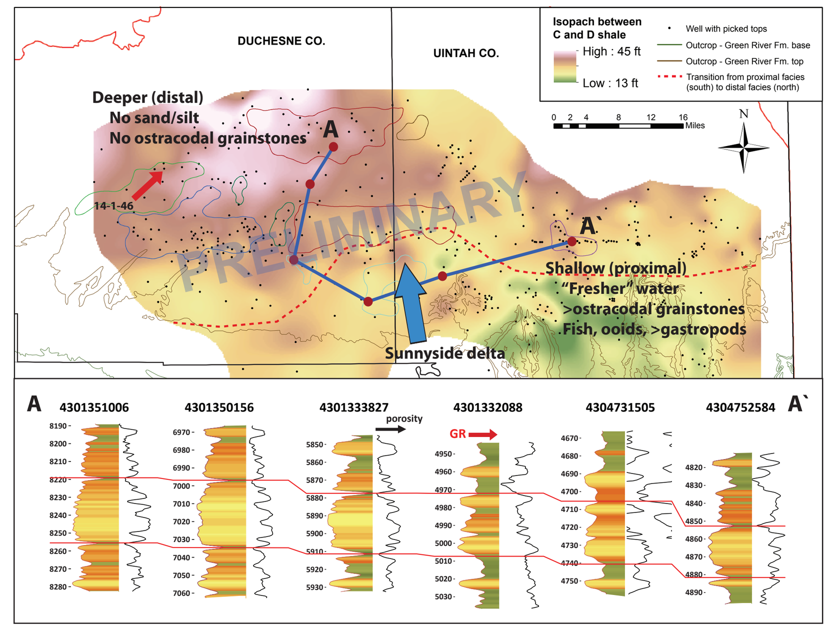
UTELAND BUTTE PLAY MAP



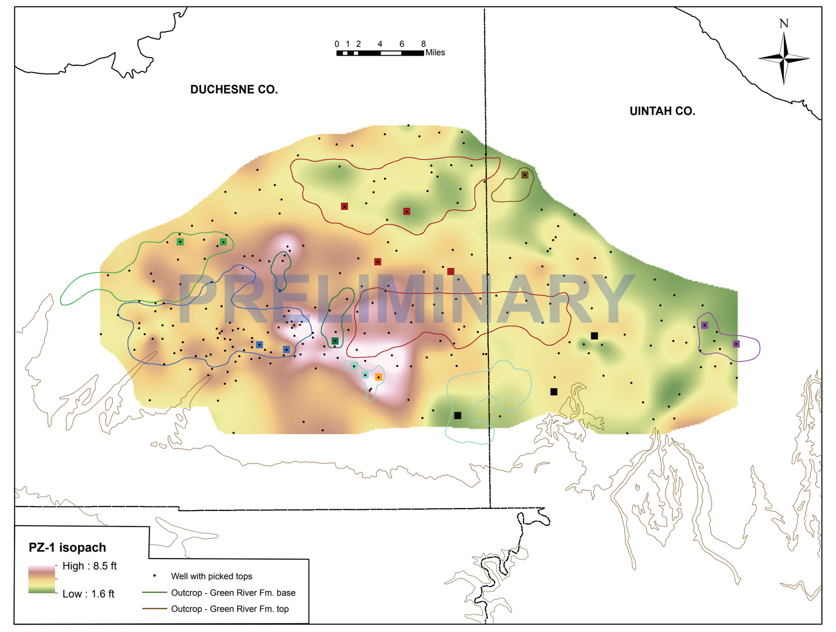
GEOMECHANICS



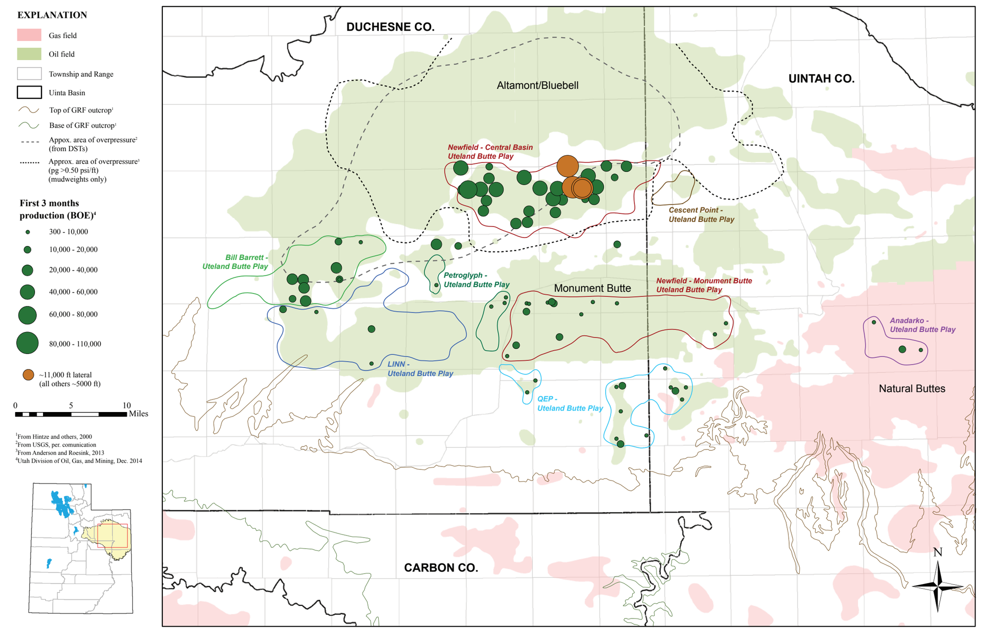
UTELAND BUTTE - C-SHALE TO D-SHALE THICKNESS

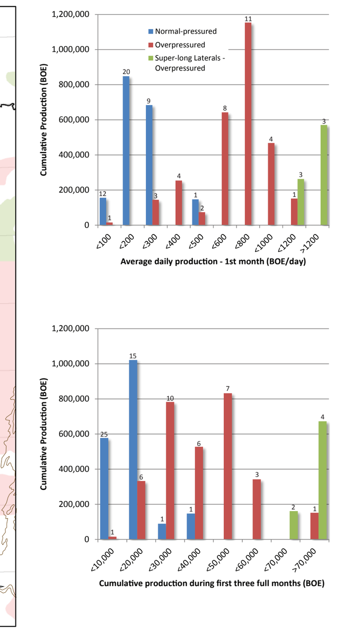


UTELAND BUTTE - PZ-1 THICKNESS



UTELAND BUTTE PRODUCTION MAP





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Project website: http://geology.utah.gov/resources/energy/oil-gas/shale-oil

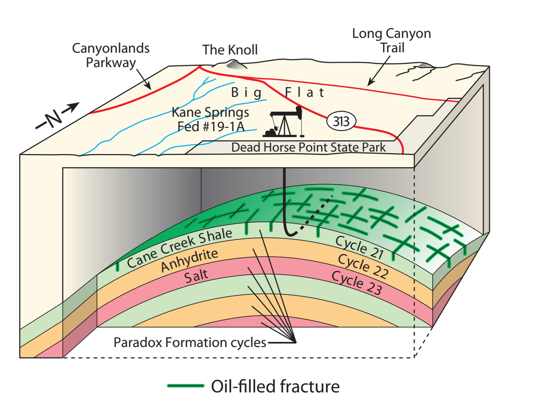
Thanks to Fidelity Exploration and Production Company for sharing their core and data.

CANE CREEK SHALE, PARADOX FORMATION

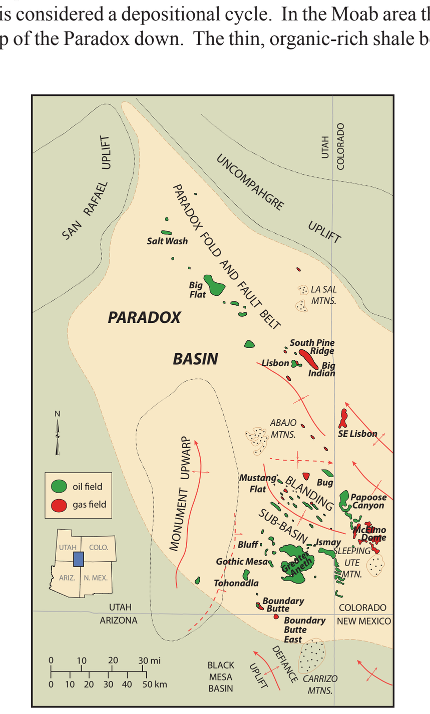
BACKGROUND

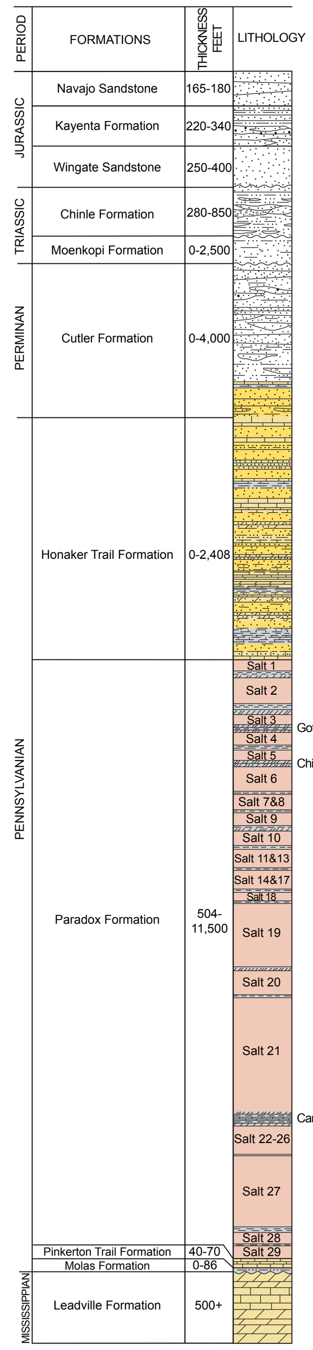
Paradox Basin Geology and Paradox Formation

The Moab area is part of the Pennsylvanian-aged Paradox Basin. About 307 million years ago, the region was a highly restricted marine bay. Sea level rose and fell during global greenhouse (interglacial) and icehouse (glacial) periods, respectively. Low sea level resulted in evaporation of sea water and extensive, thick deposits of halite as well as minor amounts of potassium and magnesium salts. High sea level resulted in deposition of carbonates and siltstones interbedded with thin, organic-rich shales (collectively referred to as shale) such as the Cane Creek shale. A shale and overlying thick salt bed is considered a depositional cycle. In the Moab area there are as many as 29 cycles in the Paradox Formation; the Cane Creek shale is in cycle 21, with the cycles numbered from the top of the Paradox down. The thin, organic-rich shale beds in the Cane Creek are the source of the oil produced from the unit's adjacent fractured siltstones and carbonates.



Schematic of horizontal drilling targets along the Cane Creek anticline, Big Flat field, next to Dead Horse Point State Park





Cane Creek Shale Drilling History

Over the past decade, the Moab area of the Paradox Basin has seen a large increase in drilling and subsequent oil production. The first oil discovery in the area occurred in the 1920s from the 300-million-year-old (Pennsylvanian aged) Paradox Formation. Drilling equipment and building materials were loaded onto barges and floated down the Colorado River to where the first discovery was drilled on the axis of the Cane Creek anticline near the current site of the Moab potash mine. While drilling, the well first blew out at a depth of 2028 feet and the rig was destroyed by the resulting fire. Several additional wells were drilled on the anticline but only a minor amount of oil was produced. Later, the equipment was floated farther down the river to Shafer dome, where drilling resulted in a dry hole.

In 1957, drilling at Big Flat, near present-day Dead Horse Point State Park, resulted in the discovery of oil in the Mississippian Redwall Limestone. This was the first discovery of oil from Mississippian-aged rocks in Utah. Ultimately, three oil wells and four dry holes were drilled in the Big Flat field, which was abandoned in 1971 after producing more than 83,000 barrels of oil (BO).

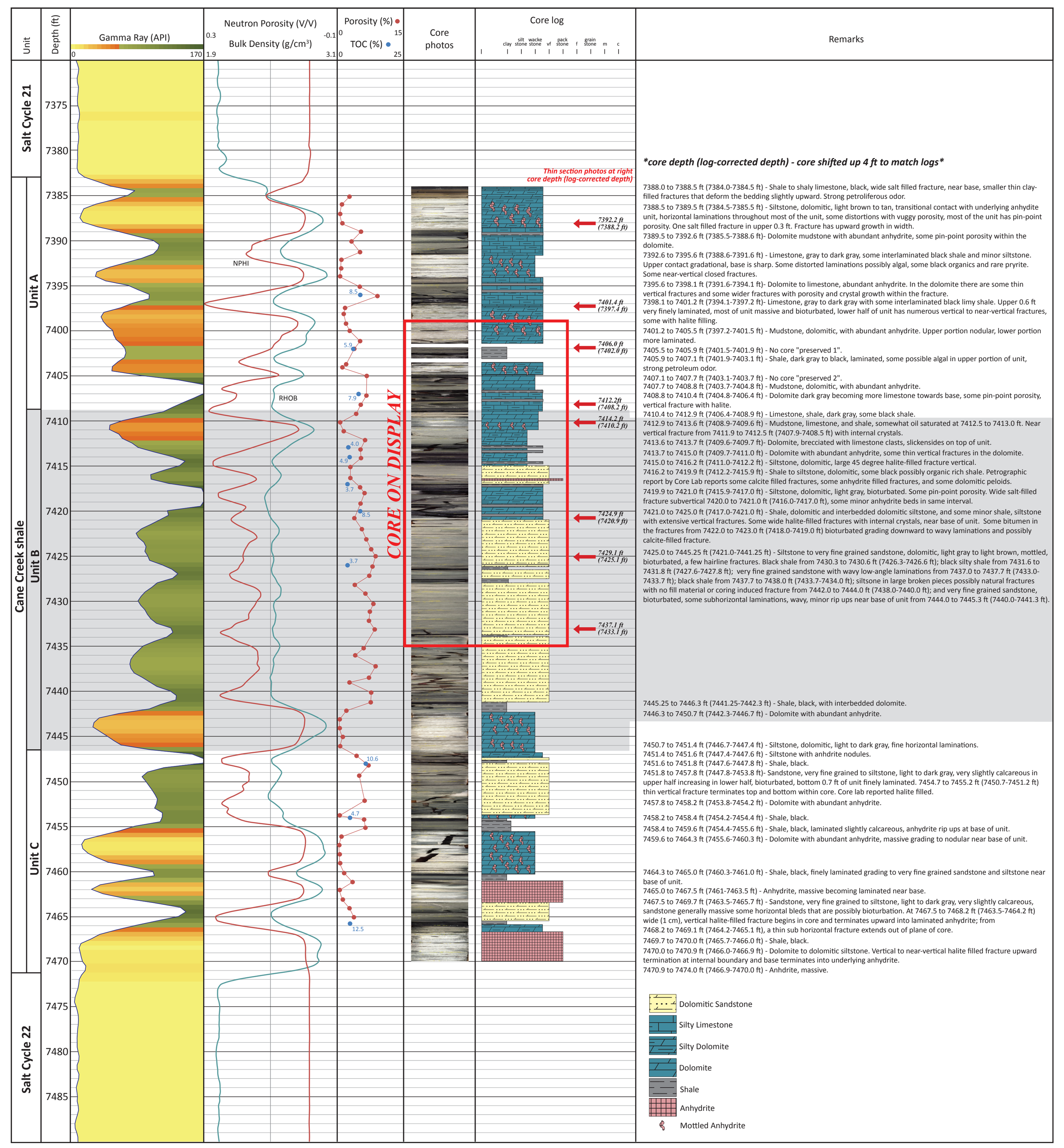
In the early 1960s, the Shafer Canyon, Bartlett Flat, and Long Canyon fields were discovered. The Shafer Canyon field consisted of two wells, one on each side of Dead Horse Point State Park, which produced from the Cane Creek shale. The wells were plugged and abandoned in 1969 after producing over 67,000 BO, mostly from one well. Bartlett Flat (Big Flat 5 well) and Long Canyon (Long Canyon 1 well) fields (both one-well fields) also produced from the Cane Creek shale. The casing collapsed in the Big Flat 5 well and the field was abandoned after producing 39,000 BO. The Long Canyon well was the most successful well in the area drilled during the 1960s. The well has produced more than 1 million BO and is still producing. Lion Mesa field was discovered in 1980, but has only produced a minor amount of oil from the Cane Creek shale.

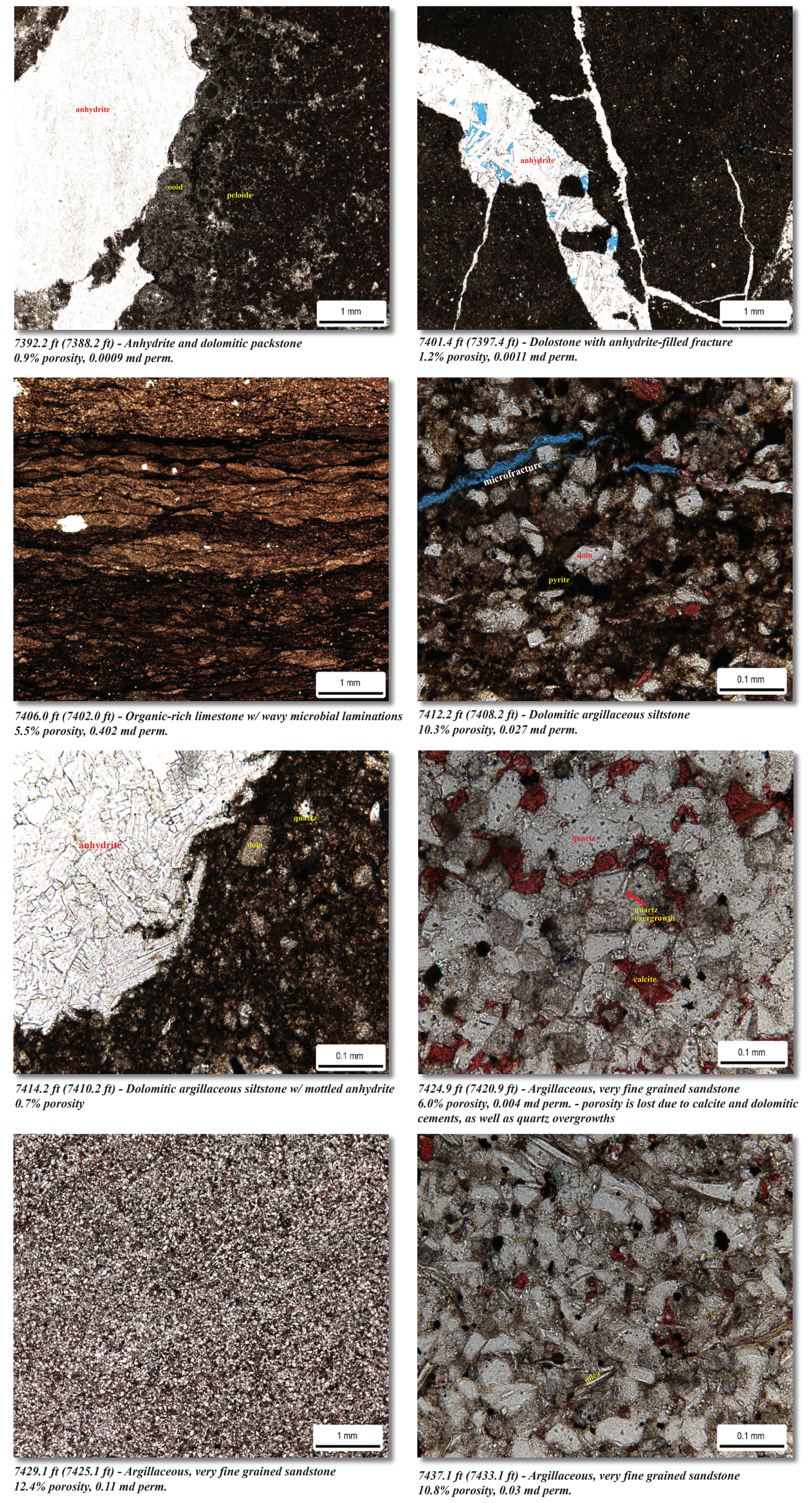
Exploration continued in the Moab area, but significant success did not occur until Columbia Gas Development Corporation formed the Cane Creek Federal unit in 1991 and drilled a horizontal well (1-27) in the Cane Creek shale in the abandoned Bartlett Flat field. This was the first long-reach horizontal well drilled in Utah. Drilling horizontally in the Cane Creek shale allows wells to penetrate 1000+ feet of reservoir rock, versus 10 to 30 feet in a vertical well, and greatly increases the probability of encountering natural fractures essential to economic production. Columbia drilled six horizontal wells that are still producing and are now operated by Fidelity Exploration & Production Company. The six wells drilled by Columbia have produced more than 1.4 million BO.

Fidelity Exploration & Production Company took ownership of the Cane Creek unit in 2007 and began drilling additional wells. Fidelity has drilled 17 horizontal wells in the unit, many of which have horizontal legs exceeding 5000 feet in length. Total production from the Cane Creek unit as of September 1, 2014 exceeds 2.9 million BO, with 91,836 BO produced during the month of August 2014. Many of the wells have multiple horizontal laterals and some drill pads contain two wells, which reduces the surface footprint of development. Drilling and completion costs are typically $8 to $14 million per well and the best wells are expected to ultimately produce about 1.7 million BO.

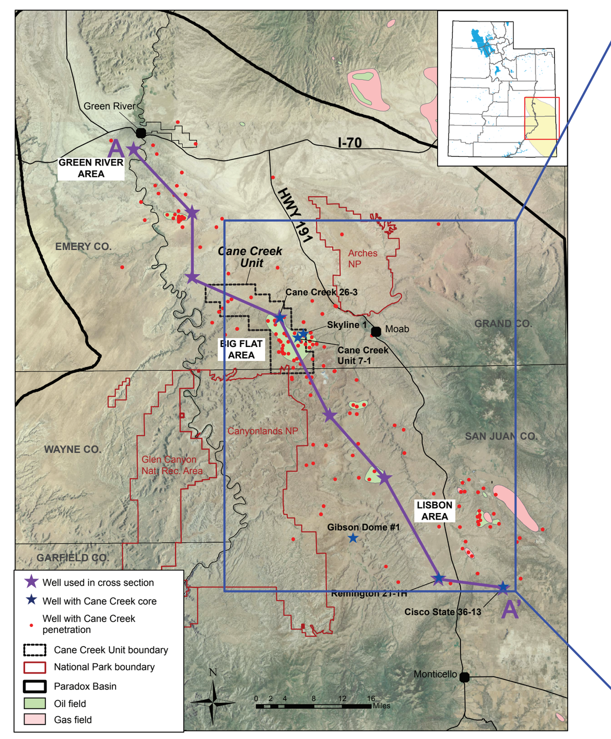
Cane Creek anticline, near Moab, UT

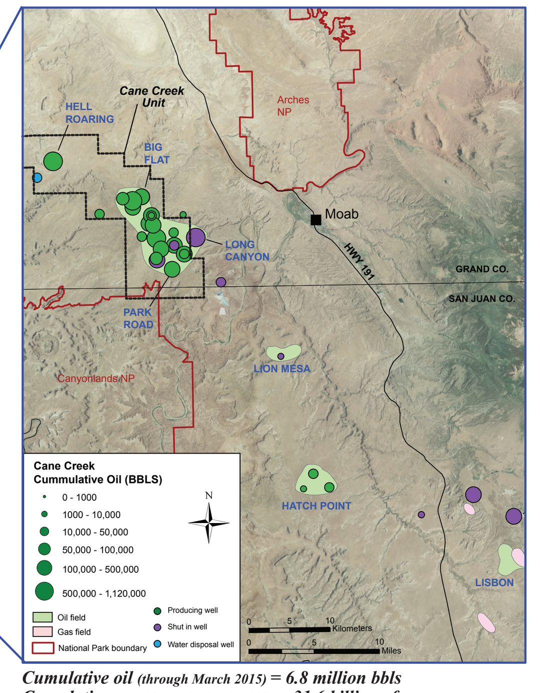
Cane Creek Unit 26-3 (4301950019)





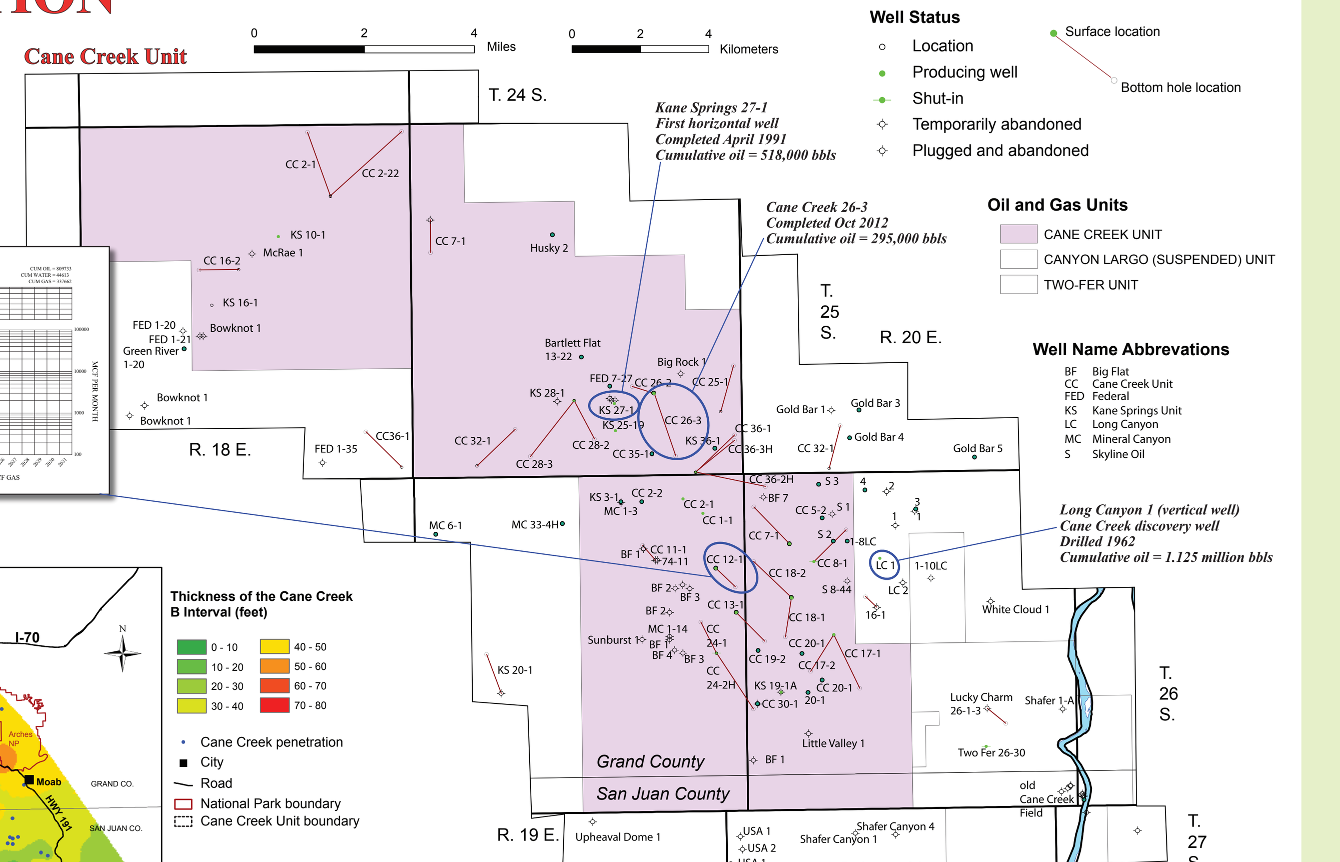
CANE CREEK PRODUCTION AND CHARACTERIZATION

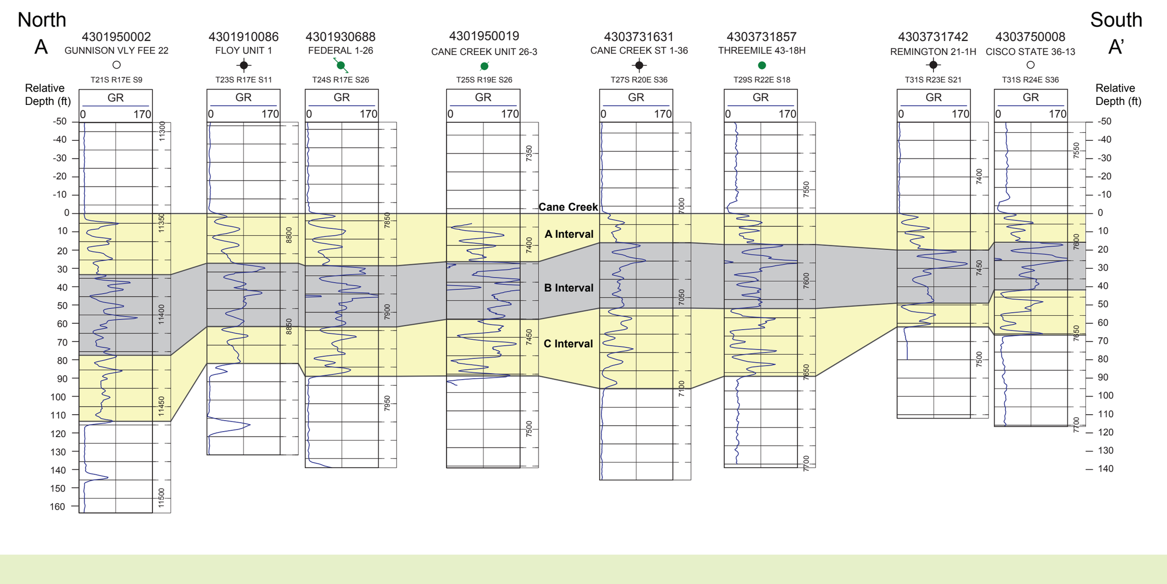


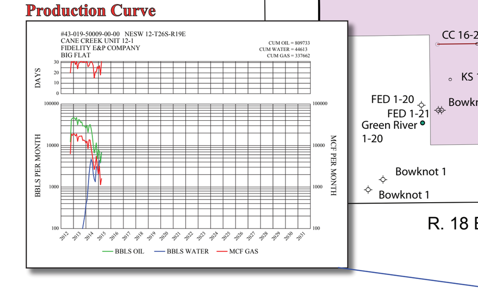


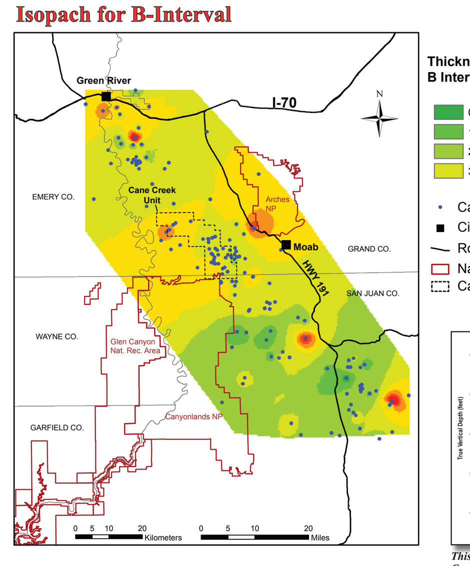
Cane Creek Cumulative Production

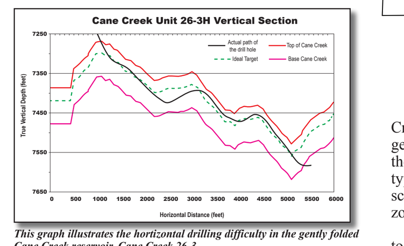
Cumulative oil (through March 2015) = 6.8 million bbls
Cumulative gas (through March 2015) = 31.6 billion cf











This graph illustrates the hortizontal drilling difficulty in the gently folded Cane Creek reservoir, Cane Creek 26-3.

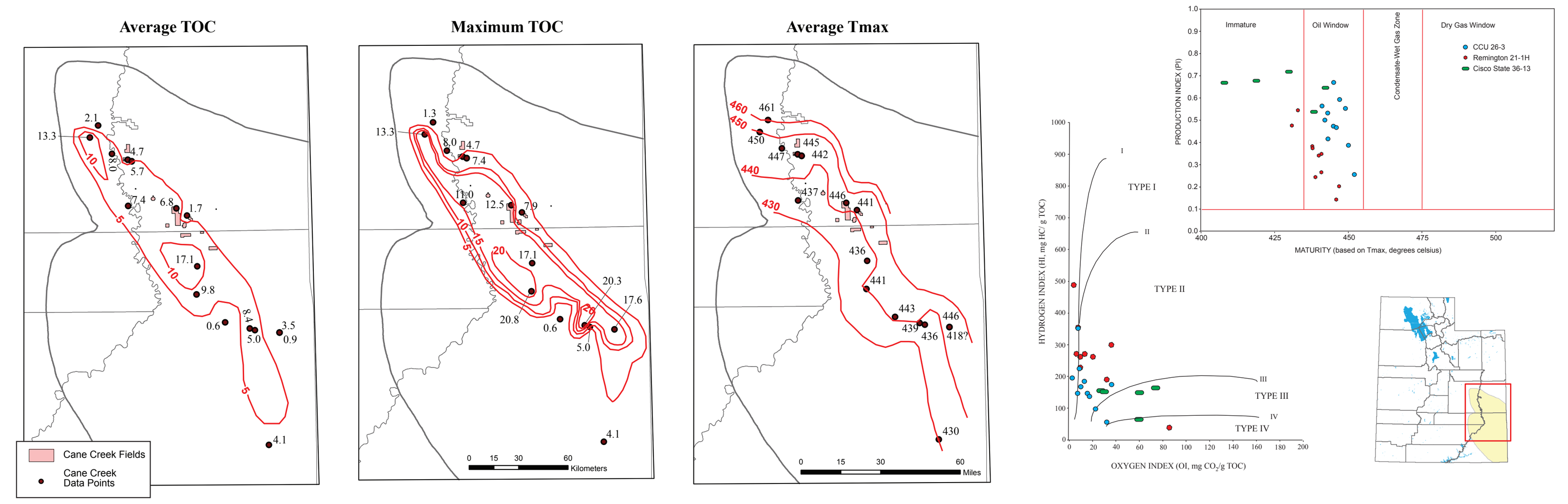
Cane Creek Shale Reservoir Characterization

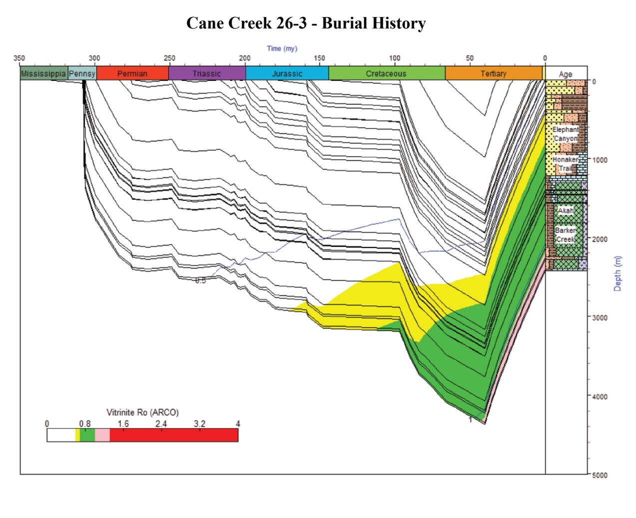
The Cane Creek shale is a difficult oil reservoir to develop. In the Big Flat area, about 3500 feet of interbedded sandstone, shale, and limestone overlie the Paradox Formation. From the top of the Paradox to the Cane Creek, there is about 3500 to 4000 feet of salt with thin, interbedded shale beds. Under the pressure and temperature of deep burial, salt will often flow, like squeezing a tube of toothpaste. Salt flow can ruin a well by collapsing the well casing and plugging well perforations and tubing.

Mapping seismic data can identify faults and structural highs at the Cane Creek shale horizon. These deep structures are often the drilling targets, but identifying where good, reservoir-quality, porous beds and natural fractures occur is much more difficult. On the surface the formations are generally flat-lying to gently inclined, but the salt deposits of the Paradox Formation are often highly deformed. Movement of thousands of feet of salt from one location to another formed large salt anticlines; when the salt pushed through or intruded into overlying formations it created salt diapirs. Moab-Spanish Valley, Castle Valley, and Salt Valley in Arches National Park are all examples of large diapiric salt anticlines. The Big Flat area sits atop the Cane Creek anticline, which is the result of more subdued salt movement. The movement of salt formed a broad, gentle anticline but did not penetrate the overlying formations. Additionally, smaller-scale deformation within the individual Paradox salt cycles often resulted in folding the Cane Creek shale into "wavy folds." These folds typically have an amplitude of several feet to tens of feet and are spaced hundreds of feet apart. This smaller-scale folding can make it very difficult to keep the drill bit within the Cane Creek reservoir when drilling a horizontal lateral several thousand feet long.

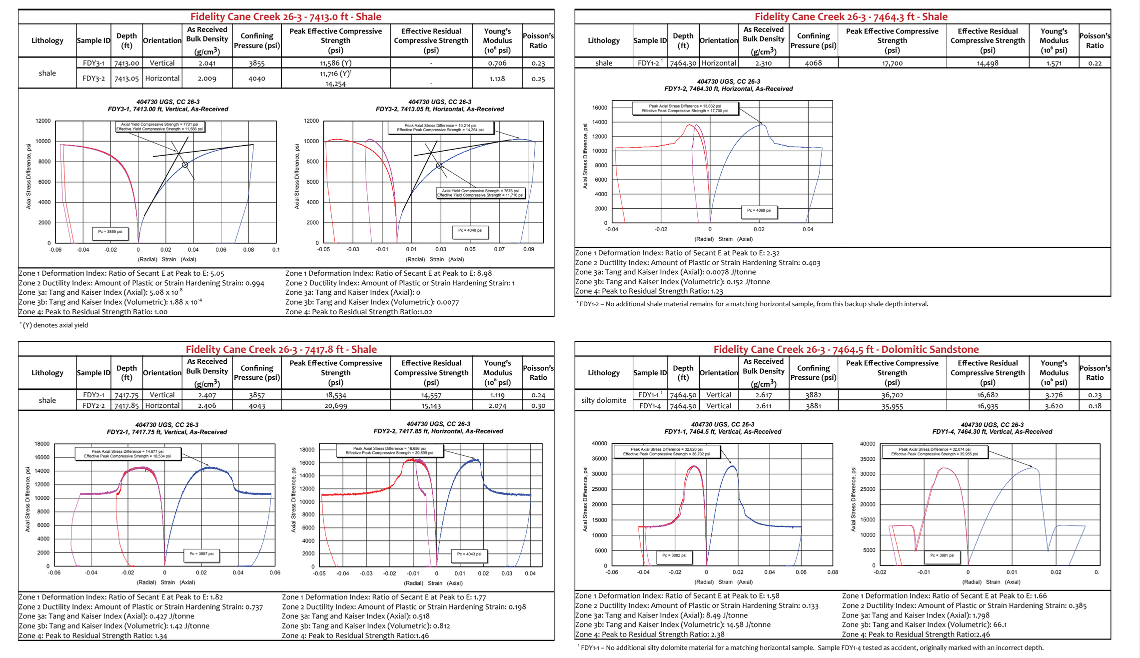
Naturally occurring open fractures in the Cane Creek shale are important permeability pathways for oil to move from the formation into the well bore. Core from the Cane Creek contains many types of fractures; some are thin with limited length and are filled with anhydrite, calcite, or clay, and some are wider and filled with halite. Open fractures tend to be near vertical but are confined to individual brittle sandstone or carbonate beds. An important part of predicting where oil-productive fractures might exist involves understanding when both the filled and open fractures formed, what forces caused the fracturing, and what fluid flow conditions resulted in mineral-filled fractures versus open fractures. Another key exploration element is understanding the timing of oil generation. Were the mineral filled-fractures sealed before or after oil was generated and were the open fractures formed before or during the time of peak oil generation? We are using organic-matter maturity data and burial history studies to determine when, and at what temperature, oil was generated. Also, fluid inclusions found in the fracture-fill minerals are being used to help determine at what temperature, and therefore what time during burial, minerals formed in the fractures. As minerals form within a fracture, microscopic bubbles of liquid and gas can become trapped within the crystal structure. Heating and cooling of the bubbles reveals the composition of the fluids, gases, and the temperature at which they formed. When in geologic history the fractures formed can be determined by comparing temperature data generated from a burial history curve to the fluid inclusion temperatures. Burial history curves also help us determine when oil was generated within the Cane Creek.

GEOCHEMISTRY





GEOMECHANICS



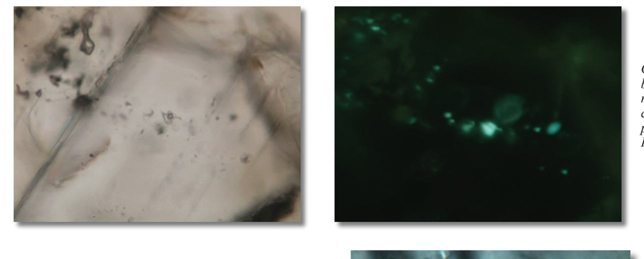
FLUID INCLUSION ANALYSIS

Analyses performed by Dr. Joe Moore, Energy & Geoscience Institute, University of Utah

Fluid inclusion and petrographic studies were conducted on samples from three wells: Cane Creek 26-3, Cisco State 36-13, and Remington 21-1H. The primary objectives were to: 1) characterize the temperatures and salinities of the fluids responsible for mineral deposition; and 2) determine the relative timing of oil migration with respect to the deposition of the vein filling minerals. Both oil and aqueous inclusions were observed in the samples.

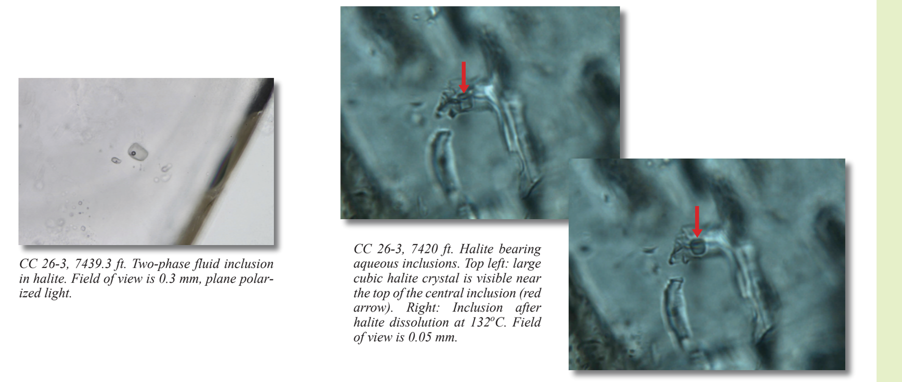
Preliminary conclusions:

1. Fluid inclusions were trapped in fracture filling dolomite, anhydrite, and halite. Anhydrite and dolomite were precipitated before halite.
2. Oil migration occurred during and after vein formation. During vein formation, aqueous and oil inclusions were trapped contemporaneously in dolomite and halite. Healed fractures in dolomite containing oil inclusions suggest oil migration continued after vein formation.
3. The presence of aqueous inclusions containing only liquid suggests that mineral deposition and later fracturing occurred at temperatures of <50°C. The inclusions were subsequently thermally re-equilibrated as the rocks were progressively buried and heated.
4. Oil migration and vein formation must have occurred at relatively shallow depths. Low- to moderate-thermal gradients (<~25°C/km) would imply that mineral deposition occurred at depths of less than approximately 2 km.
5. The majority of the aqueous inclusions contain liquid with a salinity of approximately 30 wt% NaCl + $CaCl_2$ equivalent. These high salinities suggest interactions with evaporites.
6. Fluorescence colors of the oil inclusions indicate they have a moderate API gravity of approximately 35°.



CC 26-3, 7420 ft. Secondary light-brown, oil-bearing inclusions in dolomite. Left: Two-phase oil-inclusions containing oil and a gas bubble, plane polarized light. Right: ultraviolet light. Field of view is 0.3 mm.

CC 26-3, 7439.3 ft. Two-phase fluid inclusion in halite. Field of view is 0.3 mm, plane polarized light.



CC 26-3, 7420 ft. Halite bearing aqueous inclusions. Top left: large cubic halite crystal is visible near the top of the central inclusion (red arrow). Right: Inclusion after halite dissolution at 132°C. Field of view is 0.05 mm.