Oil & Natural Gas Technology

DOE Award No.: DE-FE0010667

Research Performance Progress Report

Quarterly Report: January 2016 to March 2016

Liquid-Rich Shale Potential of Utah's Uinta and Paradox Basins: Reservoir Characterization and Development Optimization

Project period: October 1, 2012 to September 30, 2015 (extended to September 30, 2016)

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Office of Fossil Energy

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EXECUTIVE SUMMARY

As the project progresses through its one-year no-cost extension, several different research activities are still on track to help better characterize Utah's tight oil plays. Core analysis, outcrop examination, and regional mapping activities are helping to create a clearer understanding of the Uteland Butte tight oil play and several research projects on the Cane Creek shale are nearing completion. For example, geomechanical data measured on cores from both the Uteland Butte and Cane Creek are currently being analyzed by collaborators at the Energy & Geoscience Institute (EGI), University of Utah. These data will be vital in helping inform better well completion strategies and potentially improve production.

Technology transfer remains a vital tool for communicating the project results with interested stake holders. An abstract on the dolomites of the Uteland Butte was accepted for presentation at the 2016 AAPG meeting to be held in Calgary, Alberta in June, as well as an abstract on the Uteland Butte outcrops on the eastern side of the Uinta Basin.

PROGRESS, RESULTS, AND DISCUSSION

Task 1.0: Project Management Plan

During the month of January 2016, the PI wrote and submitted the project's 13th quarterly report for October to December 2015. This report was subsequently sent via email to all interested parties and posted on the UGS project website.

Task 2.0: Technology Transfer

- The UGS project website was updated with new information - http://geology.utah.gov/emp/shale_oil
- The PI completed the 13th quarterly report and emailed it to all interested parties. The report is also available on the UGS project website.
- An abstract was accepted for a poster presentation at the 2016 AAPG Annual Meeting to be held in Calgary, Alberta, from June 19-22, 2016. University of Alberta M.S. student, Federico Rueda, submitted the paper titled *Dolomitization in the Uteland Butte Member of the Eocene Green River Formation, Uinta Basin, Utah: Implications for Petroleum Production.*
- A second abstract was accepted for a poster presentation at the 2016 AAPG Annual Meeting. Colorado School of Mines M.S. student, Katie Logan, submitted the paper titled *Lacustrine Lithofacies, Depositional Processes and Diagenesis of the Uteland Butte Member, Uinta Basin.*
- An article on our Cane Creek shale epifluorescence study was published in the current issue of GEO ExPro (article is attached below).

Tasks 3.0 and 4.0: Data Compilation and Core-Based Geologic Analysis

Uteland Butte Member: Various projects are still underway on the Uinta Basin portion of the project. A paper by Dr. Rick Sarg and Katie Logan (M.S. student), with the PI as third author, on the eastern outcrops of the Uteland Butte is currently in review and is planned to be published as a UGS Open-File Report in spring 2016. Our collaboration with USGS is ongoing. Recently, USGS researchers extensively sampled several Uteland Butte cores for detailed mineralogy and organic geochemistry analyses. Research at the University of Alberta is ongoing, including detailed thin section petrography and mineralogy focused on the dolomites of the Uteland Butte. Over the duration of the no-cost extension, the PI will work to finalize all core descriptions, regional mapping, and facies analyses and synthesize collaborator research into a comprehensive final report.

Cane Creek Shale: Research on the Cane Creek shale in the Paradox Basin is essentially finished and the focus has shifted to preparing a comprehensive final report.

Task 5.0: Outcrop Examination and Characterization – Uinta Basin

An important collaboration was set up with Dr. Rick Sarg, prominent carbonate geologist at the Colorado School of Mines (CSM). UGS partially funded a CSM graduate student, S. Katie Logan, to research the Uteland Butte on the eastern side of the Uinta Basin. Logan measured several Wasatch-Green River-transition outcrop sections on the western flank of the Douglas Creek arch and compared them to the Anadarko Uteland Butte cores from the Natural Buttes gas field. A publication based on her thesis is currently in review and should be published as a UGS Open-File Report in spring 2016.

Task 6.0: Well Completion Optimization

Dr. John McLennan, Energy and Geoscience Institute, University of Utah, and Task 6 team leader, provided an extensive update to this portion of the project in the October-December 2015 quarterly report. Research is ongoing and will continue throughout the no-cost extension.

CONCLUSION

The project has now transitioned into a one-year no-cost extension, however, the PI recently requested another 6-month extension to give graduate students working on the project more time to finish their theses. This would put the project ending date at March 31, 2017. The PI and other UGS geologists are currently finalizing research tasks and synthesizing collaborator research into a comprehensive final report.

COST STATUS

Table 1. *Project costing profile for one-year no-cost extension.*

	Jan 2016		Feb 2016		Mar 2016	
	Plan	Actual	Plan	Actual	Plan	Actual
UGS-personnel		$1,867		$5,834		$4,143
Travel Expenses[1]				$434		
Analyses						
Miscellaneous						
SUBTOTALS		$1,867		$6,268		$4,143
UGS OVERHEAD (34.44%)		$643		$2,159		$1,427
SUBCONTRACTS						
EGI						$16,683
Eby[2]				$2,625		
CSM						
EGI - Moore						
U. of Alberta						
GRAND TOTALS		$2,510		$11,051		$22,252

[1]Feb – Plane ticket for AAPG in Calgary in June
[2]Feb – Includes $525 in cost share

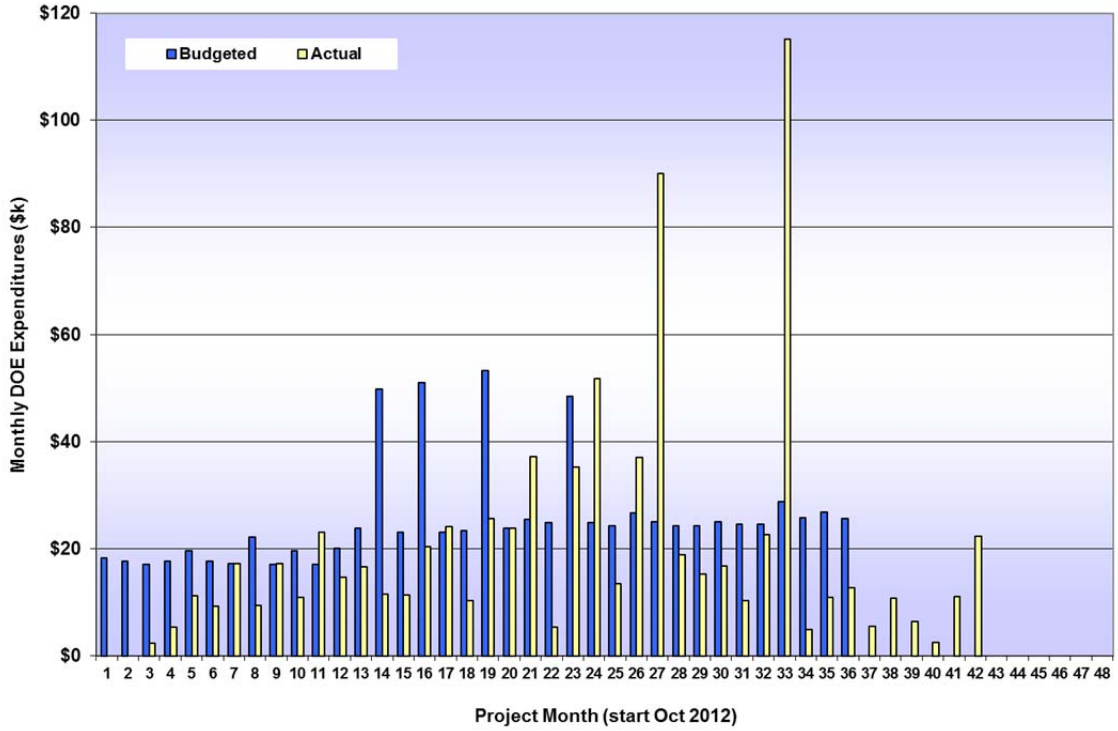


Figure 1. *Project costing profile.*

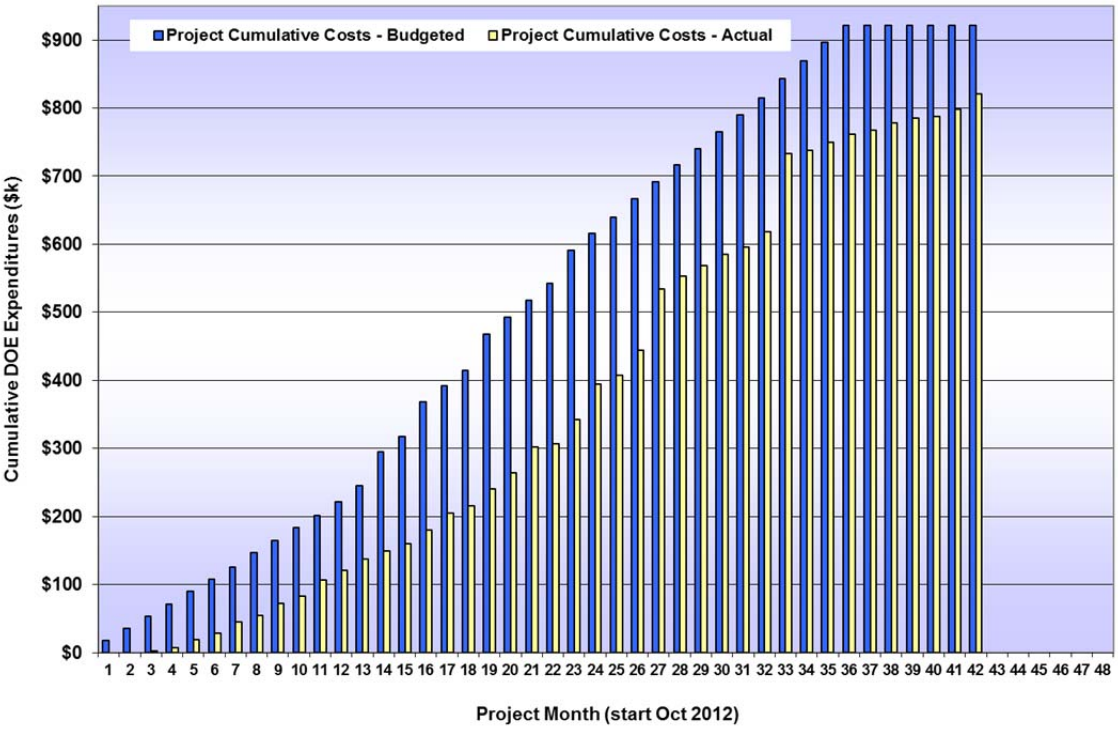


Figure 2. *Project cumulative costs.*

MILESTONE STATUS

Table 2. *Milestone log for one-year no-cost extension*

	Title	Related task or subtask	Completion Date	Update/comments
Milestone 32	Quarterly updates of website	Subtask 2.1	Quarterly	Ongoing, 1-year extension
Milestone 33	Quarterly reports	Subtask 2.2	Quarterly	Ongoing, 1-year extension
Milestone 34	Profiles of mechanical stratigraphy	Subtask 6.5	31-Mar-15	Ongoing, 1-year extension
Milestone 35	Regional correlation and mapping	Subtask 7.1	31-Mar-15	Ongoing, 1-year extension
Milestone 36	Regional cross sections	Subtask 7.2	31-Mar-15	Ongoing, 1-year extension
Milestone 37	Sweet spot maps	Subtask 7.3	31-Mar-15	Ongoing, 1-year extension
Milestone 38	Technical presentations at National AAPG	Subtask 2.4 & 5	Apr-15	1 abstract accepted at AAPG 2016
Milestone 39	Core workshop and/or field trip	Subtask 2.7	Jul-15	Delayed until summer 2016
Milestone 40	Locating completions	Subtask 6.4	30-Sep-15	Ongoing, 1-year extension
Milestone 41	Stimulation diagnostics modeling	Subtask 6.6	30-Sep-15	Ongoing, 1-year extension
Milestone 42	Reservoir simulations/stimulation locating	Subtask 6.7	30-Sep-15	Ongoing, 1-year extension
Milestone 43	Final publications	Subtask 2.6	30-Sep-15	1-year extension
Milestone 44	Final interpretation	Task 8	30-Sep-15	1-year extension

ACCOMPLISHMENTS

- Two major publications are currently under review and should be published in the next few months:
    - Logan, S.K., Sarg, J.F., and Vanden Berg, M.D., in prep, Lithofacies, Deposition, Early Diagenesis, and Porosity of the Uteland Butte Member, Green River Formation, Eastern Uinta Basin, Utah and Colorado. UGS Open-File Report.
    - Chidsey, T.C., and Eby, D.E., in prep, Potential Oil-Prone Areas in the Cane Creek Shale Play, Paradox Basin, Utah, Identified by Epifluorescence Microscopy Techniques. UGS Special Study.

PROBLEMS OR DELAYS

The project is two quarters into the one-year no-cost extension, but the PI recently requested a second no-cost extension taking the project to March 2017. This second extension is mostly to give graduate students working on the project enough time to finish and publish their thesis research. The PI did not project expenditures for each month of the extension, but sufficient funds remain to take the project to March 2017. The project is currently 89.0% of total budget.

PRODUCTS AND TECHNOLOGY TRANSFER ACTIVITIES

- Project website
    - The project website has been updated with new reports and abstracts.
    - http://geology.utah.gov/emp/shale_oil

- Quarterly Report – October to December 2015
    - Completed late January and is available on the project website.
- Poster presentation – 2016 AAPG Annual Meeting, Calgary, Alberta, Canada, June 19-22, 2016
    - Rueda, F. (M.S. student at the University of Alberta), Vanden Berg, M.D., and Machel, H.G. (Professor at the University of Alberta) - *Dolomitization in the Uteland Butte Member of the Eocene Green River Formation, Uinta Basin, Utah: Implications for Petroleum Production.*
    - The poster will be presented on Monday, June 20, 2016, in the Modeling of Carbonate and Evaporite Systems session.
    - The abstract has been uploaded to the UGS project website.
- Poster presentation – 2016 AAPG Annual Meeting, Calgary, Alberta, Canada, June 19-22, 2016
    - Logan, K. (M.S. [graduated] student Colorado School of Mines) and Sarg, R. (Professor at Colorado School of Mines) – *Lacustrine Lithofacies, Depositional Processes and Diagenesis of the Uteland Butte Member, Uinta Basin.*
    - The poster will be presented on Tuesday, June 21, 2016, in the Advances in Carbonate Diagenesis session.
- Article – GEO ExPro magazine – Volume 13, Number 2, 2016
    - Identifying Potential Oil Zones in Tight Reservoirs: Low-cost epifluorescence microscope techniques have delineated a prospective, relatively untested oil-prone fairway in the Cane Creek shale play, Paradox Basin, Utah.
    - Written by Thomas Smith with help from project team member Thomas Chidsey.
    - Article is attached below and is available on the project website.

Technology Explained

Identifying Potential Oil Zones in Tight Reservoirs

THOMAS SMITH

Low-cost epifluorescence microscope techniques have delineated a prospective, relatively untested oil-prone fairway in the Cane Creek shale play, Paradox Basin, Utah.

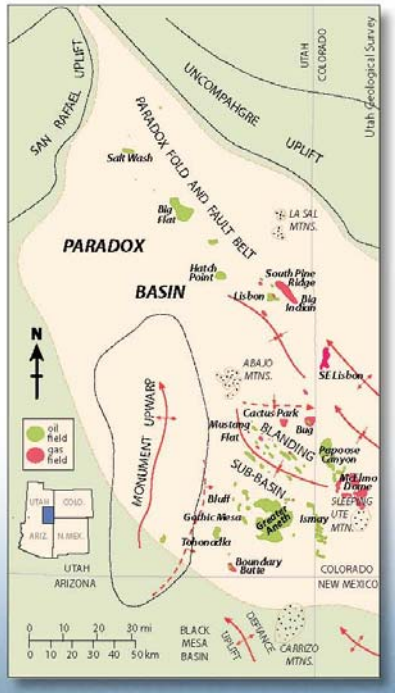
When it comes to liquid-rich shale production and potential, the Bakken in North Dakota, Eagle Ford, and the Permian Basin shales of Texas have grabbed all the attention. However, the Cane Creek shale in south-eastern Utah has huge overall potential and may, on a per well basis, outdo those well-known areas. The US Geological Survey says there is a 95% confidence that it holds at least 103 MMbo and a 50% confidence rate of at least 198 MMbo. As for well production, a Fidelity E&P well in the Big Flat field produced about 700,000 barrels of oil in its first year, free-flowing to the surface.

The Utah Geological Survey (UGS) has an ongoing basin-wide research project, part of a three-year US Department of Energy funded study. Their scientists are analysing the geological, geomechanical and geochemical properties of the Cane Creek shale across the Paradox Basin to provide improved reservoir characterisation. The goals of this research are to identify potential exploration areas outside the current Cane Creek unit and to improve drilling and production techniques. The epifluorescence (EF) study is part of that research; most of the operators in this area are small independents not in a position to undertake such an extensive regional study.

Paradox Basin

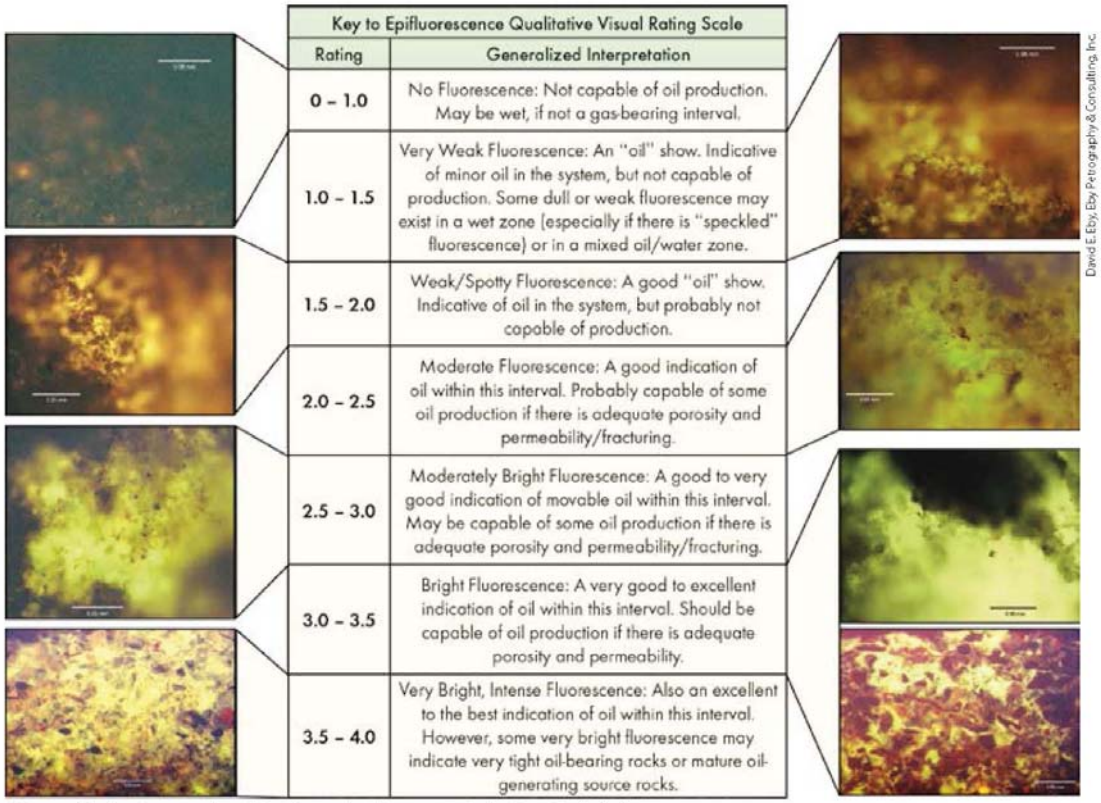
The 'paradox' originated in Paradox Valley in south-western Colorado. In 1875, geologist Albert Peale noted that the Dolores River had a "desire to perform strange and unexpected things". Instead of flowing down the valley, the river emerges from a narrow gap, cuts perpendicularly across the centre of the valley and exits through another gap. This oddity or paradox was caused by the basin's unique geology. The Paradox Valley occupies an eroded, salt-cored anticline and the river maintained its previously ancient course that was cut into the overlying bedrock.

Location map for the Paradox Basin showing the Pennsylvanian oil fields.



The Cane Creek Anticline was the location of the first oil discovery in the Moab, Utah area in the 1920s. This feature is just one of many spectacular anticlines that extend for miles in the fold and fault belt portion of the Paradox Basin.

Craig D. Morgan, Utah Geological Survey



Micrographs showing examples of visually rated epifluorescence in the Cane Creek shale zone.

Moab Valley (Spanish Valley) located to the west in Utah has a similar geological history and is bisected by the Colorado River.

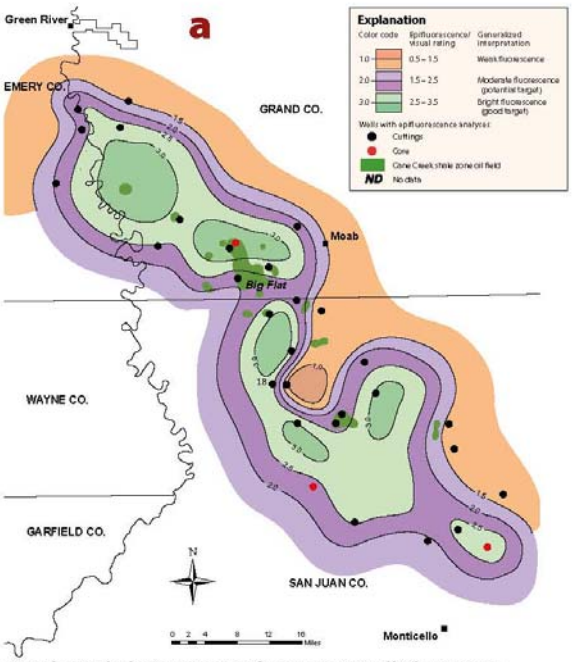
The Paradox Basin covers 85,470 km², primarily in south-east Utah and south-west Colorado, but extends into northern Arizona and New Mexico. The basin formed during Pennsylvanian (Late Carboniferous) time about 330 to 310 million years ago, when a series of fault-bounded uplifts and basins developed from Utah to Oklahoma as a result of continental collisions that formed the Ancestral Rockies. The Paradox Basin received a thick succession of cyclic carbonates, evaporites and organic-rich shales, now known as the Paradox Formation. The basin is divided into three areas: the fold and fault belt in the north, the Aneth platform in the south, and the Blanding sub-basin located between those two areas. Deposition in the northern portion of the basin (the Moab area) was in a highly restricted marine bay. Fluctuations in sea level left alternating thick deposits of halite and minor amounts of potassium and magnesium salts during low sea levels, while carbonates and siltstones with thin organic-rich shales were deposited during the high stands. There are 29 cycles in the Moab area; the Cane Creek shale was deposited in the highstand portion of cycle 21 in the lower Paradox Formation.

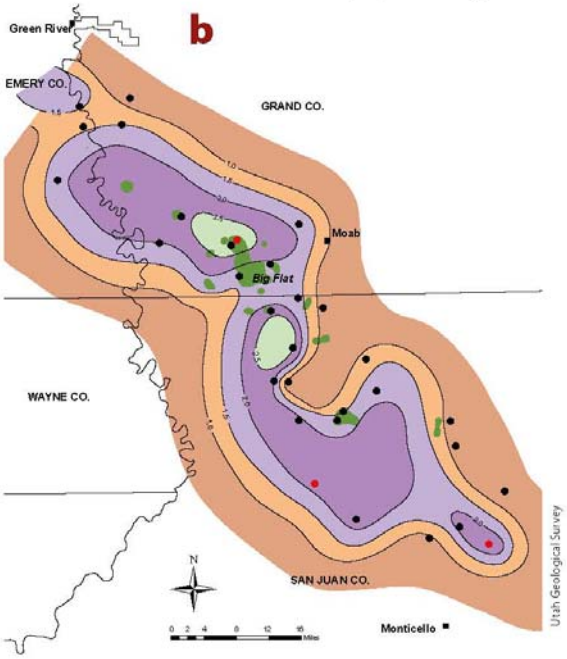
The first well in Utah was drilled in the northern end of the Paradox Basin near the town of Green River in 1891. Greater Aneth, Utah's largest oil field, is located in the southern end of the basin. Discovered in 1956, the field has produced over 470 MMbo.

The Study

The first oil discoveries in the Pennsylvanian Cane Creek shale play occurred in the early 1960s. The most successful well drilled during this period was at Long Canyon field, which has produced over 1 MMbo, although most wells produced less than 70,000 bo before being plugged and abandoned. Exploration continued but significant success did not occur until Columbia Gas Development Corporation formed the Cane Creek Federal unit in 1991 and drilled a horizontal well, the first long-reach horizontal well in Utah. The company drilled six horizontal wells that have delivered over 1.4 MMbo and are still producing. Recently, Fidelity Exploration & Production Company took ownership of the field and has drilled 17 additional wells in the Cane Creek Federal unit. Now, with longer laterals and improved completions, well rates have dramatically increased and are expected to ultimately produce about 1.7 MMbo each.

The horizontal target is the B interval where the reservoir is primarily comprised of dolomite, sandstone and siltstone with both intercrystalline and microporosity. This interval is sandwiched by the A and C zones, consisting of organic-rich shale, anhydrite and silty dolomite which serve as both





Maps showing highest maximum epifluorescence (a) and highest average epifluorescence (b) for Cane Creek B interval. A well-defined fairway with ratings 2.0 and higher (purple and greens) follows the same general trend as the total Cane Creek shale highest rating. All existing Cane Creek fields lie within this trend. Very prospective, largely untested B interval sections are present in lobes to the north-west and south-east of the Big Flat field, indicating the interval may not have uniform prospectivity along the favourable fairway. High-risk, less prospective areas occur to the north-east and south-west of the prospective fairway.

the hydrocarbon source and as seals for the B interval. The entire Cane Creek interval is naturally fractured and overpressured. Production occurs in the fractured dolomites, sandstones and siltstones, usually on subtle subsidiary structural noses found associated with the major structures that trend south-east to north-west across the northern portion of the Paradox Basin. This area, known as the Paradox fold and fault belt, is crossed by large spectacular anticlines that are cored by salt.

Locating these subtle traps usually requires expensive, 3D seismic acquisition in often environmentally sensitive areas. To help high grade this large area outside the existing unit for lease acquisition and more detailed seismic mapping that could lead to exploratory drilling, UGS scientists working with Dr. David E. Eby, from Eby Petrography & Consulting, Inc., Denver, Colorado, have used the area's extensive collection of cuttings, core chips and a limited number of thin sections to conduct this study. EF microscope techniques gave them a low-cost, non-destructive way to characterise the reservoir properties and organic matter including live hydrocarbons.

"Approximately 2,650 cuttings samples and core chips from the collection at the Utah Core Research Centre were evaluated from 31 wells penetrating the Cane Creek shale, including several producers," explains Tom Chidsey, senior scientist at the UGS. "Cuttings were examined under a binocular microscope and representative samples were selected over the Cane Creek interval. Four to ten samples were analysed over each depth interval from each well. The cuttings or core chips were placed on Petrologs™, a small plastic, self-adhesive compartmentalised cuttings storage unit that made sample preparation quick and inexpensive for EF examination. All Petrologs used in this study are stored at the Utah Core Research Centre and are available to the public."

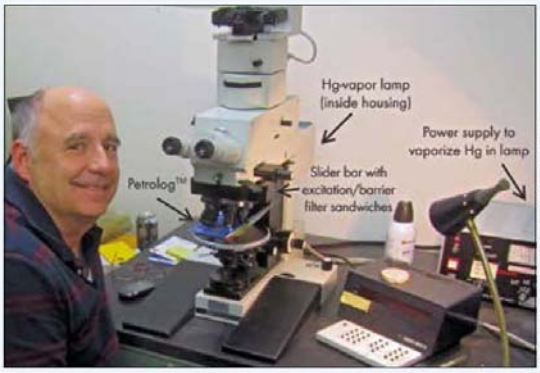
Qualitative Mapping

"EF petrography makes it possible to clearly identify hydrocarbon shows in the Cane Creek cuttings," says Chidsey. "The best images are obtained at relatively high magnifications (greater than 100x). A qualitative visual rating scale (a range and average) based on EF evaluation was applied to the group of cuttings or core chips. Using the qualitative visual rating scale, a variety of EF readings for each well were plotted and mapped. We mapped highest maximum and highest average for the total Cane Creek shale zone and then separated out the A, B, and C intervals. All the maps use the same ratings. Areas considered highly prospective for oil have ratings 2.0 or higher." As expected, the EF ratings for productive Cane Creek wells were generally highest and served as a baseline in identifying potential.

"The Cane Creek interval is a difficult reservoir to explore and develop," explains Chidsey. "Seismic mapping can identify potential drilling targets; however, identifying where good quality reservoirs exist is extremely difficult. Using low-cost EF analysis and

Epifluorescence Microscopy

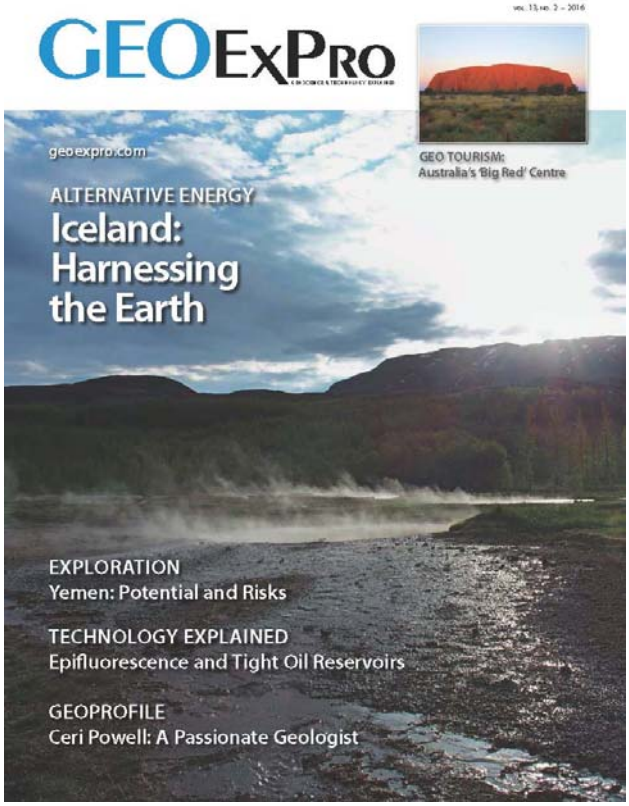
EF microscopy enables better imaging of poorly preserved textures and grains in sandstone, siltstone and carbonate rocks, particularly the type of dolomites encountered in the Cane Creek play. Information on the diagenesis, pore types and organic matter (including 'live' hydrocarbons) within sedimentary rocks are gained using EF microscopy. Samples are analysed using a rapid and non-destructive procedure employing a petrographic microscope equipped with reflected-light capabilities, a high pressure mercury vapour lamp for EF evaluation, appropriate filtering and a film imaging system. For the Cane Creek samples, magnification ranges for examination and image-documentation were between 130 and 320x, and it was found that broad-band, blue-light EF was the most helpful in observational work on the dolomites. The greater depth of investigation into a sample by the reflected fluorescence technique over that provided by either polarised or other forms of reflected light makes it possible to resolve grain boundary and compositional features that are normally not appreciated in cuttings or thin-section petrography.



mapping has identified a prospective north-west to south-east oriented fairway in the Cane Creek shale zone, whereas the north-eastern part of the Paradox fold and fault belt shows low EF values. The implication is that hydrocarbon migration in the Cane Creek dolomite beds was along regional north-west trending folds, faults and fracture zones, creating this relatively untested oil-prone area.

"EF analysis represents a low-cost method that can help quantify and delineate the 'sweet spots' and the potential areas in emerging tight oil plays around the world just as it has in the Cane Creek shale."

The UGS and Eby previously conducted a similar EF study on the Mississippian Leadville Limestone, also in the Paradox Basin, which also showed areas with untested potential. ■



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