Oil & Natural Gas Technology

DOE Award No.: DE-FE0010667

Research Performance Progress Report

Quarterly Report: April 2015 to June 2015

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)

Submitted by:
Utah Geological Survey
1594 W. North Temple, Suite 3110
Salt Lake City, UT 84114
DUNS # 176871572

Principal Investigator: Michael D. Vanden Berg
michaelvandenberg@utah.gov, 801-538-5419

Prepared for:
United States Department of Energy
National Energy Technology Laboratory

Submitted: July 31, 2015

Office of Fossil Energy

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EXECUTIVE SUMMARY

As the project progresses through Budget Period 3, several different research activities are 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. For instance, a Utah Geological Survey (UGS) funded study on the "shale oil" potential of the Green River Formation in the Uinta Basin, including the Uteland Butte, was recently published as UGS Open-File Report 639. Several research projects are also underway looking at the Cane Creek shale. Epifluorescence analysis on Cane Creek cuttings has been completed and results were presented at the May 2015 AAPG annual meeting in Denver, Colorado. This extensive study will be published in the coming months. Geomechanical data measured on cores from both the Uteland Butte and Cane Creek are currently being analyzed by collaborators at the Energy & Geoscience Institute, University of Utah. This 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. Two presentations were given at the 2015 AAPG annual meeting in Denver, Colorado: a core poster highlighting both the Uteland Butte and Cane Creek plays, and a poster presentation on the aforementioned epifluorescence analyses. In addition, the PI lead a core workshop and field trip in April 2015 for several industry geologist highlighting the petroleum geology of the Green River Formation in the Uinta Basin.

PROGRESS, RESULTS, AND DISCUSSION

Task 1.0: Project Management Plan

During the month of April 2015, the PI wrote and submitted the project's tenth quarterly report for January to March 2015. This report was subsequently sent via email to all interested parties and posted on the UGS project website. The PI also requested, and DOE approved, a one-year no-cost extension to the project, pushing the contract ending date to September 30, 2016.

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 tenth quarterly report and emailed it to all interested parties. The report is also available on the UGS project website.
- Two posters were presented at the AAPG annual meeting in Denver, May/June 2015: a core poster that included discussions of both the Uteland Butte and Cane Creek, and a poster detailing the completed epifluorescence analyses on the Cane Creek.
- Project team member Tom Chidsey wrote an article summarizing the geology, current drilling, and research activities of the Uteland Butte and Cane Creek tight oil plays for the AAPG-EMD (Energy and Minerals Division) Shale Gas and Liquids Committee 2015 Annual Report.
- UGS funded and recently published a report titled *Shale Oil Resource Play Potential of the Green River Formation, Uinta Basin, Utah* (Open-File Report 639), written by Steve Schamel, GeoX Consulting, Inc.
- The PI led a core workshop and field trip for several oil and gas industry geologists in April 2015, highlighting the petroleum geology of the Green River Formation in the Uinta Basin, Utah, including the unconventional Uteland Butte member.
- Project team member, Craig Morgan, wrote an article on the Cane Creek tight oil play for the May 2015 issue of *Survey Notes*, the UGS newsletter.

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

Uteland Butte Member: The UGS funded Dr. Steven Schamel (GeoX Consulting, Inc.) to investigate the "shale oil" resource play potential of the Green River Formation, including the Uteland Butte, in the Uinta Basin, Utah. After extensive review by the PI, the study was recently published as UGS Open-File Report 639. The abstract of the publication is included below and the publication is available on the UGS project website.

> The Green River Formation in the Uinta Basin has many characteristics typical of an ideal shale oil resource play. It is a world-class oil-prone source rock. In nearly all parts of the basin there are many thousands of net feet of Type-I and Type-II kerogen-rich calcareous mudstones, many intervals of which have average total organic carbon (TOC) of 5-10% or greater. In the north-central and western parts of the basin a substantial part of the formation is in the oil-generative window. A large volume of the formation has reached "peak oil". Furthermore, organic maturation simulations done in this study using PRA BasinView-3D™ indicates early entry into the oil-generative window. In the northwest parts of the basin the lower Green River Formation was generating oil even before the end of the Eocene and slowing of sediment accumulation in the basin. Anomalous formation pressures are observed in the lower Green River Formation across much of the basin. In the area of the greater Altamont-Bluebell field in the northwest of the basin, the abnormal pressures are nearly lithostatic (0.6 to 0.8 psi/ft). The Green River Formation is unquestionably a superb petroleum system responsible for very large cumulative production of oil and associated natural gas, and an even larger potential oil sand resource.
>
> This assessment of the shale oil resource play potential of the Green River Formation is based on the integration of:
>
> - Basin-wide stratigraphy and facies distributions;
> - Programmed pyrolysis and other geochemical data from organic-rich calcareous mudstone in fourteen wells, most of which are in the northern and western quadrants of the basin;
> - New basin-wide BasinView 3D™ numerical modeling of thermal maturation at a 1.0 kilometer resolution;
> - The known distribution of oil and oil sand accumulations in Green River Formation and age-equivalent reservoirs; and
> - The current revitalization of oil production from Green River-Wasatch reservoirs.
>
> Typical shale oil resource plays are self-contained petroleum systems having ineffective carrier systems that severely restrict migration of oil generated in the source rocks from migrating outward or upward into traps in reservoirs marginal to the oil kitchens. Consequently, the oil backs up into any and all pore space in the source rock succession, even creating fracture storage space where anomalous pressures occur. Relatively tight rocks that would normally never be considered reservoirs can have very high oil saturations and oil-in-place. In a shale oil resource play these are what are exploited by horizontal wells and hydraulic fracture stimulation.
>
> As more of the shale oil plays receive close scrutiny, it is becoming clear that no two are the same with regards to character of source rock or reservoir. What they all have in common, however, is (1) an organic -rich source rock capable of generating large volumes of oil, (2) interbedded or proximal reservoir intervals that, although tight, have sufficient porosity and/or natural fractures to be capable of hosting commercially significant volumes of the producible oil, and (3) inefficient carrier systems resulting in the oil generated remaining in proximity to the oil-generative source rock. The presence of anomalous formation pressures appears necessary to drive the oil from reservoir to well bore, even when fracture stimulated. These are "self-sourcing" petroleum systems only when viewed on a scale that encompasses the entire source rock formation and its immediately adjacent strata, or a significant portion thereof. And so it is with the Green River Formation, which has both an internal "self-sourcing" continuous oil play within the oil generative window and conventional oil accumulations on its periphery. Due to the lenticular character of the sandstone and carbonate beds in

the Green River Formation and the underlying Wasatch Formation, some beds trap oil locally, while others carry the oil up-dip into traps at a distance from the oil generative window.

Only a few years after the discovery of the Altamont field, it was described as an "*oil accumulation near the center of a deep basin*", an example of a then newly-recognized "*group of deep-basin, organic-shale-related, overpressured accumulations*" having significant hydrocarbon potential. Altamont-Bluebell field characteristics subsequently have come to identify a basin-centered, continuous resource play. These characteristics include:

- Difficulty in defining field limits laterally and vertically because the trap is stratigraphic with no simple down-dip water levels or facies boundaries to the productive horizons.
- Multiple thin productive zones with abnormally high fluid pressures.
- Very low matrix porosities enhanced by post-lithification fractures.

The companies now using fracture stimulation and horizontal wells to produce oil from Green River-Wasatch sandstone and carbonate reservoirs have merely *rediscovered* this basin-centered, continuous shale oil resource play.

Cane Creek Shale: Potential oil-prone areas in the Cane Creek shale were identified in the Paradox Basin based on hydrocarbon shows recognized using low-cost epifluorescence (EF) microscope techniques on cuttings, core chips, and thin sections. The Cane Creek has produced over 5 million barrels of oil (MMBO) and 4 billion cubic feet of gas from naturally fractured and overpressured dolomitic sandstones/siltstones and dolomites interbedded with anhydrite and organic-rich marine shales. Since the 1990s, horizontal drilling has been used to successfully develop the Cane Creek tight oil play.

EF microscopy enables better imaging of poorly preserved grains and textures in carbonate rocks. In addition, EF provides 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 Hg-vapor lamp, and appropriate filtering. Samples from four cores (a producer and three dry holes) provide a template for selection of drill cuttings and calibration of EF shows. Approximately 2650 cuttings samples and core chips were evaluated from 31 wells penetrating the Cane Creek shale throughout the region. The wells include four producers, one with cumulative production of >1 MMBO from the Cane Creek since its completion in 1962. The dolomites in these cuttings (generally 10 representative samples per depth interval from each well) display intercrystalline porosity, microporosity, and microbial constructional pores. A qualitative visual rating (a range and average) based on EF evaluation was applied to the group of cuttings or core chips (when available) from each depth interval in each well. The highest average and maximum EF rating from each well were plotted and mapped (figures 1 and 2).

As expected, productive wells (fields) are distinguished by their generally higher EF ratings (figures 1 and 2). However, an area of moderate to good fluorescence (indicating probable capacity of some oil production if there is adequate porosity and permeability) is indicated within a northwest to southeast oriented curvilinear fairway in the Cane Creek shale of the Paradox fold and fault belt whereas the northeastern part shows a regional trend of low EF. This implies that hydrocarbon migration in Cane Creek dolomite beds was along regional northwest-trending folds, faults, and fracture zones, and created a potential oil-prone area that to date is relatively untested.

This research was recently presented as a poster at the 2015 AAPG meeting; the poster is available on the UGS project website. In addition, a final written report on the Cane Creek epifluorescence analyses is being prepared and will be published in the coming months.

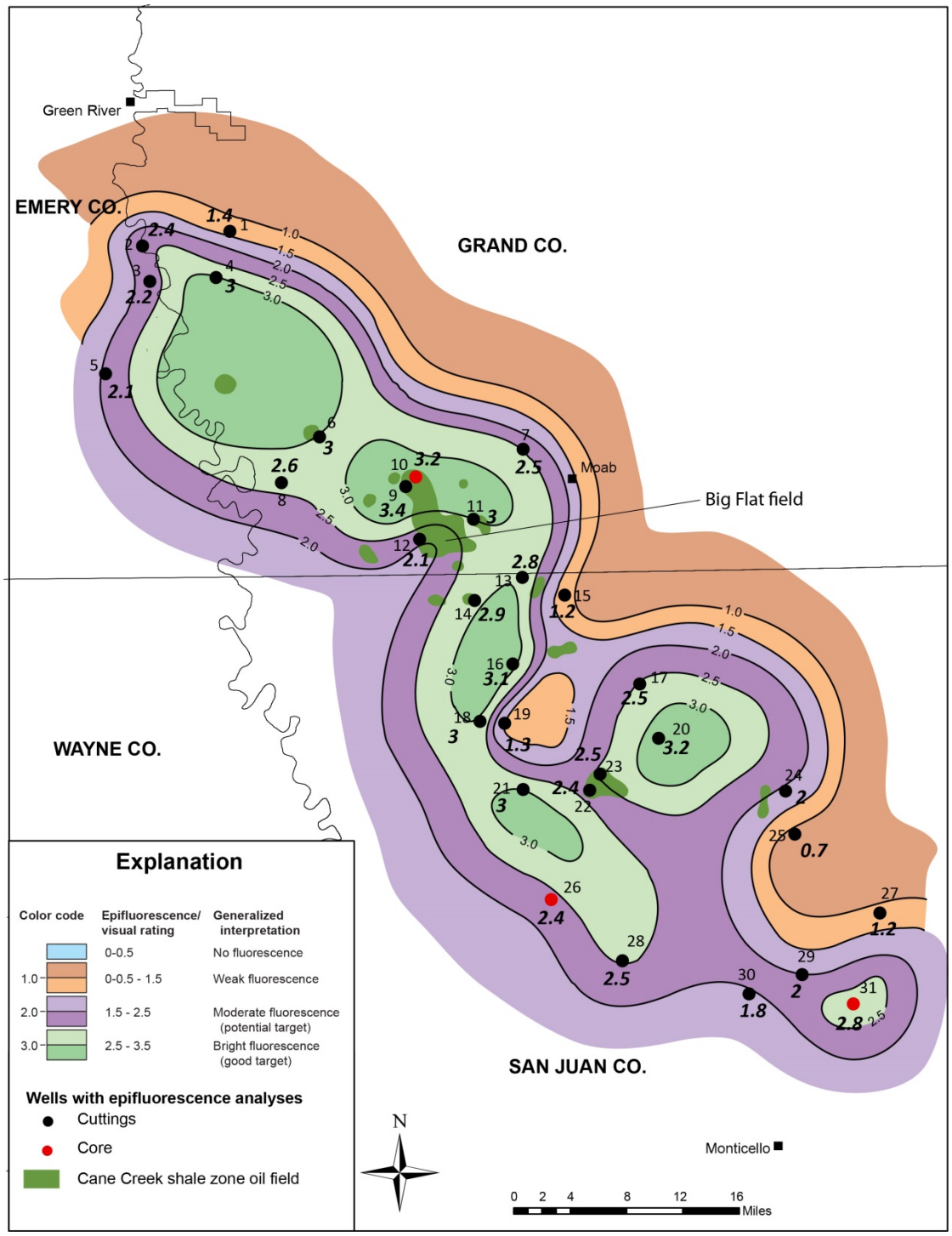

Figure 1. *Map of the highest maximum epifluorescence based on visual rating of Cane Creek well cuttings and core chips. Mapped ratings that are considered highly prospective for oil are shown in dark purple (rating of 2.0 - 2.5) and green (rating higher than 2.5). There is a pronounced curvilinear fairway of very high (in green) maximum ratings that trends from northwest to southeast. Note the lobes of high maximum ratings that occur both northwest and southeast of the biggest Cane Creek field (Big Flat). The regions within these oil prospective lobes are sparsely explored. Areas to the northeast and southwest of fairway defined in the map are characterized by relatively low maximum fluorescence ratings (in orange and blue), and thus have a much higher risk for finding new oil reserves in the Cane Creek Shale.*

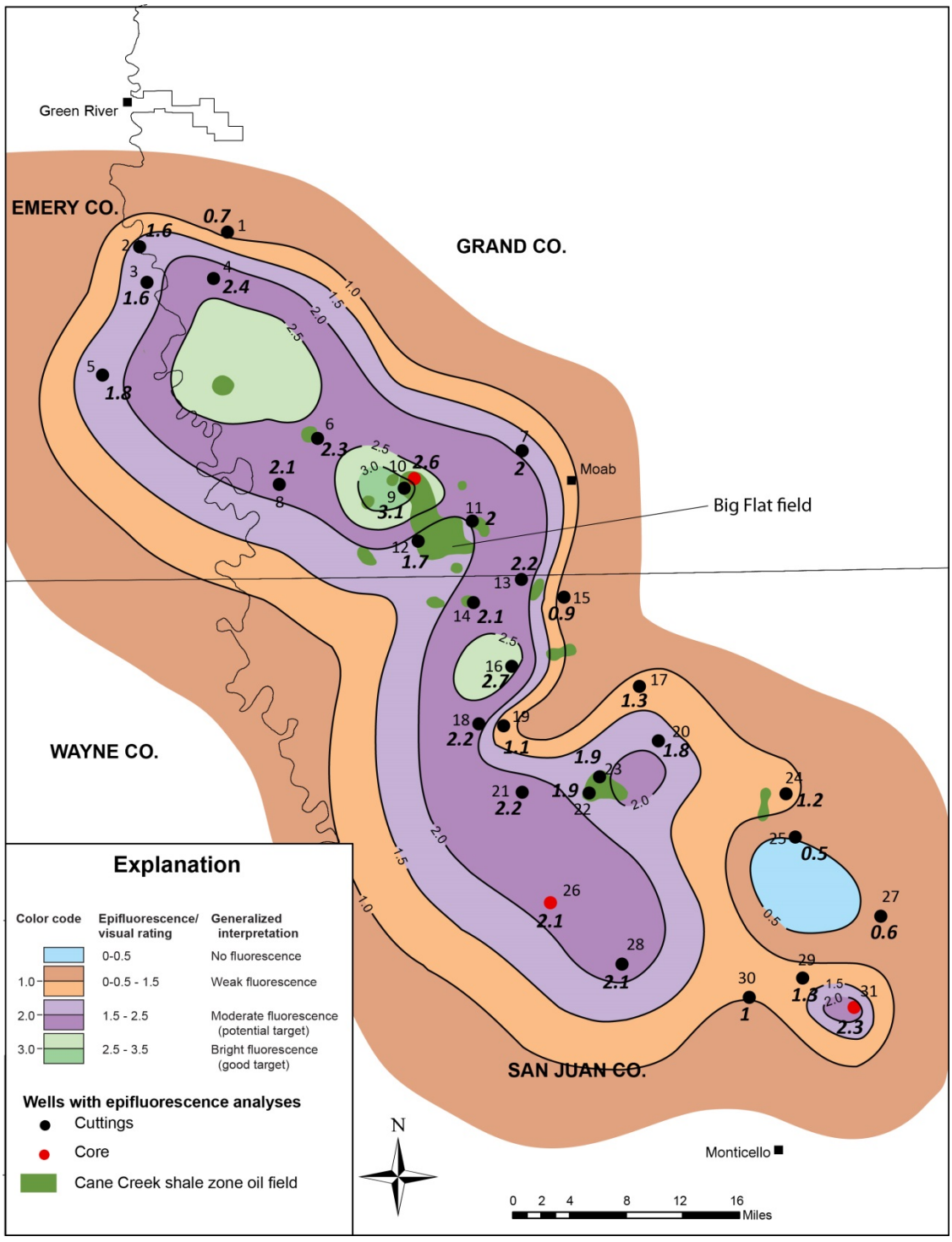

Figure 2. *Map of the highest average epifluorescence based on visual rating of Cane Creek well cuttings and core chips. There is a pronounced curvilinear fairway of anomalous fluorescence ratings that follows the same northwest to southeast trend seen in the "high maximum" map (figure 1). The anomalous trend displays lower average ratings (displayed in both green and purple) than the "high maximum" ratings. The lobes of high average ratings that occur both northwest and southeast of the largest Cane Creek field (Big Flat) are not as pronounced nor are they as large and continuous as those suggested by the "high maximum" map. Some of the smaller fields containing productive Cane Creek wells display high average ratings that are less than the area around and possibly to the northwest of Big Flat field.*

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. Logan recently completed the study and defended her thesis titled *Lacustrine Lithofacies, Depositional Processes, and Diagenesis of the Uteland Butte Member, Green River Formation, Eastern Uinta Basin, Utah & Colorado.* This study will be published as a UGS Open-File Report in the coming months.

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 last quarterly report. Research is ongoing and will continue throughout the no-cost extension.

CONCLUSION

Several technology transfer activities took place this quarter, including presentations at the AAPG annual meeting and the publication of some key reports, including a "shale oil" assessment of the Green River Formation in Utah. Epifluorescence analyses on Cane Creek cores and cuttings are now completed, and a publication detailing the results is being prepared. In addition, research on the eastern outcrops of the lower Green River Formation has been completed by a graduate student at Colorado School of Mines. A paper based on her thesis will be available in the coming months. Due to extensive delays in securing contracts with various collaborators, DOE approved a one-year no-cost extension, pushing the project ending date to September 30, 2016.

COST STATUS

Table 1. *Project costing profile for Budget Period 3.*

	Apr 2015		May 2015		Jun 2015	
	Plan	Actual	Plan	Actual	Plan	Actual
UGS-personnel	$11,027	$5,624	$11,027	$7,240	$11,027	$13,601
Travel Expenses[1]		$210		$232	$3,334	$3,287
Analyses						
Miscellaneous[2]	$225	$13	$200	$392		$508
SUBTOTALS	$11,252	$5,846	$11,227	$7,864	$14,361	$17,397
UGS OVERHEAD (34.44%)	$3,875	$2,013	$3,867	$2,708	$4,946	$5,991
SUBCONTRACTS						
EGI	$6,771		$6,771		$6,771	$82,487
Eby[3]	$2,724		$2,724	$4,120	$2,724	$2,469
CSM		$2,505				$1,578
EGI - Moore				$7,000		
U. of Alberta						$5,139
GRAND TOTALS	$24,622	$18,913	$24,589	$22,626	$28,802	$115,061

[1]Apl – Trip to Denver to look at core; May – Trip to Price, UT to look at outcrop; Jun – travel to Denver for AAPG
[2]Apl – Shipping samples; May – AAPG exhibit booth and poster lamination; Jun – software and other supplies
[3]May – Includes $638 in cost share; June – includes $494 in cost share

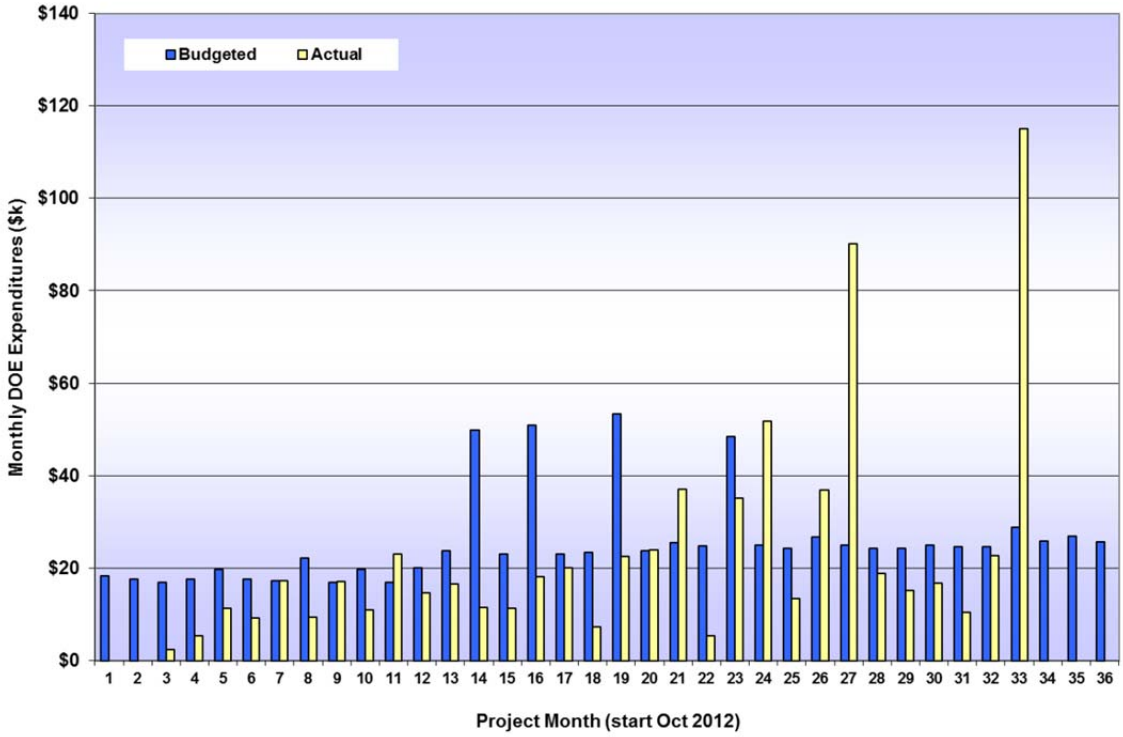

Figure 3. *Project costing profile.*

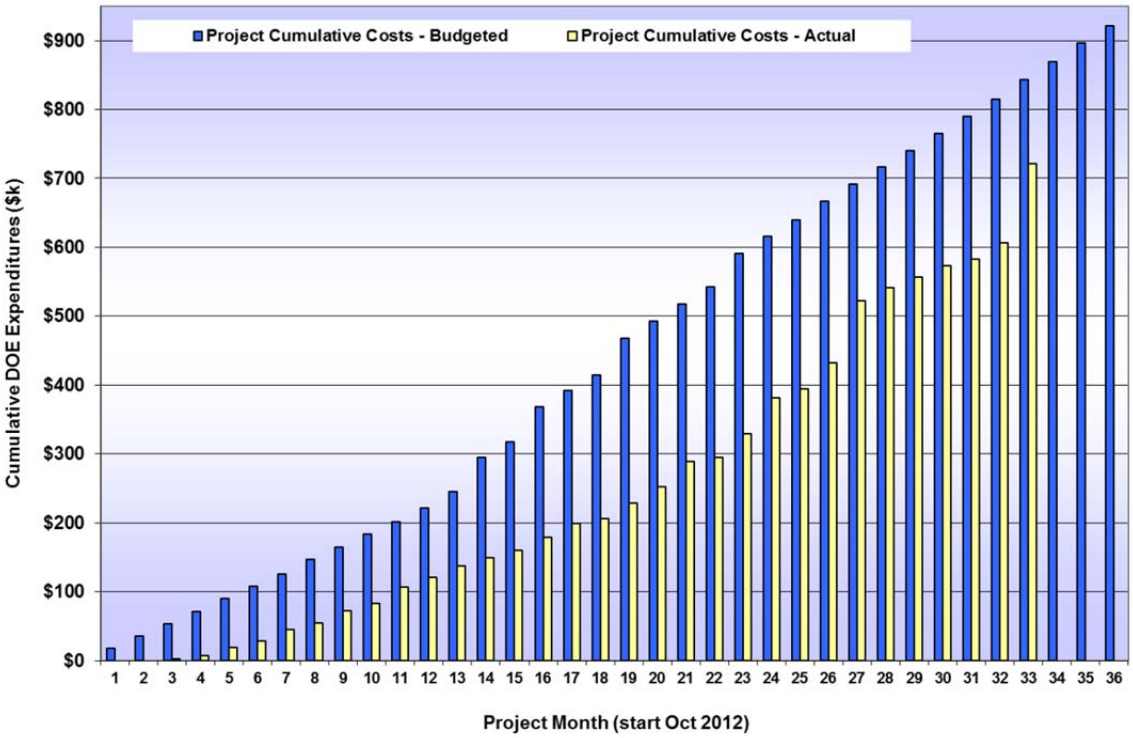

Figure 4. *Project cumulative costs.*

MILESTONE STATUS

Table 2. *Milestone log for Budget Period 3.*

	Title	Related task or subtask	Completion Date	Update/comments
Milestone 32	Quarterly updates of website	Subtask 2.1	Quarterly	Ongoing
Milestone 33	Quarterly reports	Subtask 2.2	Quarterly	Ongoing
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	2 presentations at 2015 AAPG
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

- Presented two posters at AAPG annual meeting in May/June 2015.
- UGS funded and published a report on the “shale oil” resource play potential of the Green River Formation (OFR 639), authored by Steven Schamel, GeoX Consulting.

PROBLEMS OR DELAYS

Several subcontracts (EGI, TerraTek, Eby Petrography & Consulting, and University of Alberta) were significantly delayed due to new, unanticipated, and exceedingly cumbersome State of Utah contract procedures; therefore the PI requested and DOE approved a one-year no-cost extension, pushing the project end date to September 30, 2016. Sufficient project funds are available for the extension as the project is currently only at 85.5% of 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 – January to March 2015
  - Completed late April and is available on the project website.
- Two poster presentations – 2015 AAPG Annual Meeting, Denver, CO, May 31-June 3, 2015

    - A core poster titled *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* was presented in the "Core – The Ultimate Source of Underground Truth" session on Monday, June 1, 2015.
    - A poster titled *Potential Oil-Prone Areas in the Cane Creek Shale Play, Paradox Basin, Utah, U.S.A., Identified by Epifluorescence Techniques* was presented in the "Tight Oil Plays" session on Monday, June 1, 2015.
    - Both presentations are available on the UGS project website.
- Article for the AAPG-EMD (Energy and Minerals Division) Shale Gas and Liquids Committee 2015 Annual Report
    - Project team member Tom Chidsey wrote an article summarizing the geology and current drilling and research activities of the Uteland Butte and Cane Creek tight oil plays.
    - The article is available on the UGS project website.
- New UGS Open-File Report on the "shale oil" play potential of the Green River Formation
    - *Shale Oil Resource Play Potential of the Green River Formation, Uinta Basin, Utah* – Open-File Report 639, published May 2015.
    - Written by Steve Schamel, GeoX Consulting, Inc. – Funded and reviewed by UGS.
    - The report is available on the UGS project website.
- Core workshop and field trip – Green River Formation, Uinta Basin, Utah
    - The PI led a core workshop and field trip for several oil and gas industry geologists in April 2015, highlighting the petroleum geology of the Green River Formation in the Uinta Basin, Utah, including the unconventional Uteland Butte member.
- *Survey Notes* article on the Cane Creek shale.
    - Project team member, Craig Morgan, wrote an article on the Cane Creek tight oil play for the May 2015 issue of *Survey Notes*, the UGS newsletter.
    - The article is available on the UGS project website.

National Energy Technology Laboratory

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

One West Third Street, Suite 1400
Tulsa, OK 74103-3519

1450 Queen Avenue SW
Albany, OR 97321-2198

2175 University Ave. South
Suite 201
Fairbanks, AK 99709

Visit the NETL website at:
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1-800-553-7681