POTENTIAL OIL-PRONE AREAS IN THE CANE CREEK SHALE PLAY, PARADOX BASIN, UTAH, U.S.A., IDENTIFIED BY EPIFLUORESCENCE TECHNIQUES

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Eby Petrography & Consulting, Inc.

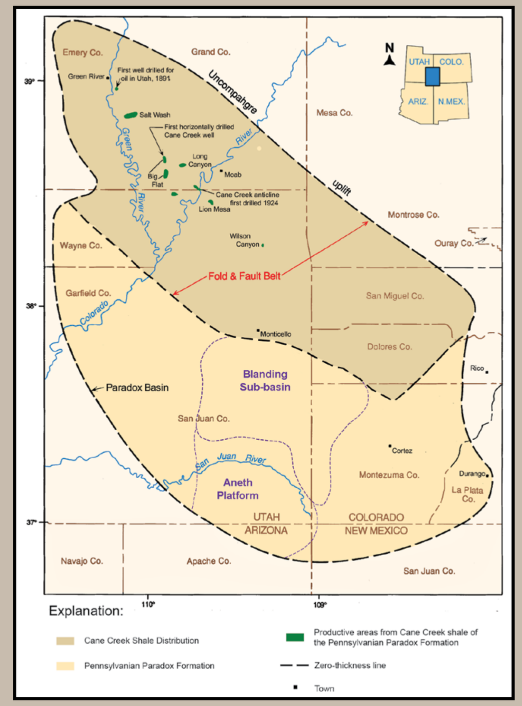
UTAH DNR GEOLOGICAL SURVEY

SUMMARY

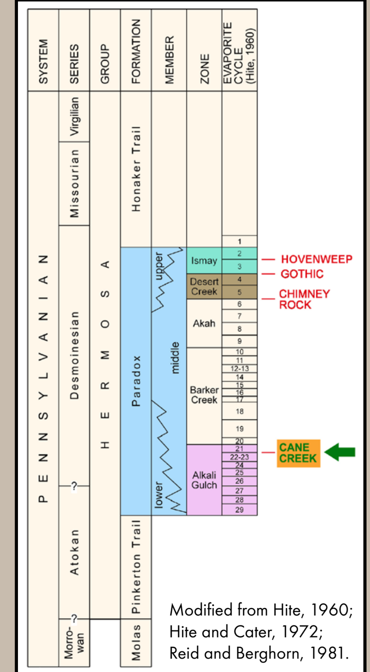
Potential oil-prone areas in the Cane Creek shale zone, Pennsylvanian Paradox Formation, were identified in the Paradox Basin, southeastern Utah, based on hydrocarbon shows recognized using low-cost epifluorescence (EF) microscope techniques on cuttings, core chips, and thin sections. The Cane Creek has produced over 5 MMBO and 4 BCFG from naturally fractured and overpressured dolomitic sandstones/siltstones and dolomites interbedded with anhydrite and organic-rich marine shales. Since the 1990s, horizontal drilling and hydraulic fracturing have 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 three cores (a producer and two 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 zone throughout the region. The wells include seven producers, one with cumulative production of >1 MMBO from the Cane Creek since its completion in 1962. The dolomites in these cuttings display intercrystalline porosity, microporosity, and microbial constructional pores. A qualitative visual EF rating was applied to the group of samples from each depth interval in each well. The highest average and maximum EF ratings from each well were plotted and mapped.

As expected, productive wells (fields) are distinguished by their generally higher EF ratings. 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 zone 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.

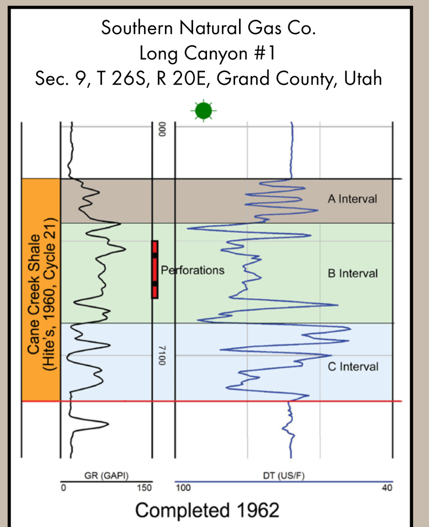


Location of fields that produce from the Pennsylvanian Cane Creek shale zone within the Paradox Basin of Utah.



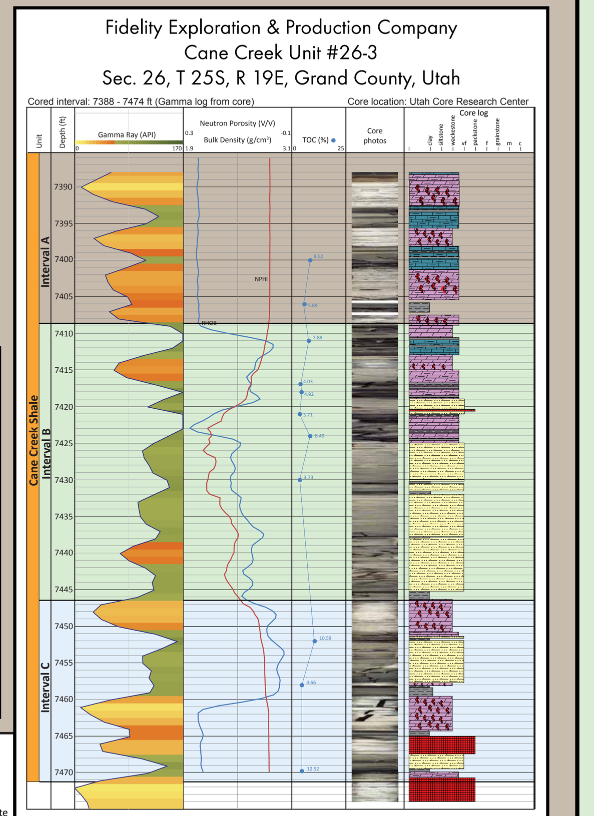
Modified from Hite, 1960; Hite and Cater, 1972; Reid and Berghorn, 1981.

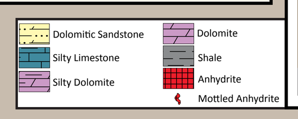
Stratigraphic column of a portion of the Pennsylvanian section determind from subsurface well data in the Paradox fold and fault belt in Utah. Note the position of the **Cane Creek shale zone**, which occurs below the other important resource play shales in the Paradox Basin (the Hovenweep, Gothic, and Chimney Rock).



Typical gamma ray-sonic log of the Cane Creek shale zone,Long Canyon field, Grand County, Utah. Note the division of the Cane Creek shale into "A," "B," and "C" intervals.

Cumulative Production from a vertical interval in this well (to Jan., 1, 2015; Utah Division of Oil, Gas, and Mining, 2014) = 1,125,463 BO, 1.16 BCFG, 571,991 BW.





Gamma ray-neutron porosity-bulk density log profiles as well as TOC and lithology data from a recent Cane Creek shale core in Big Flat field, Grand County, Utah. Note the characteristics of the "A," "B," and "C" intervals.

Cumulative Production from a horizontal interval in this well (to Jan., 1, 2015; Utah Division of Oil, Gas, and Mining, 2014) = 270,762 BO, 0.16 BCFG, 881 BW.

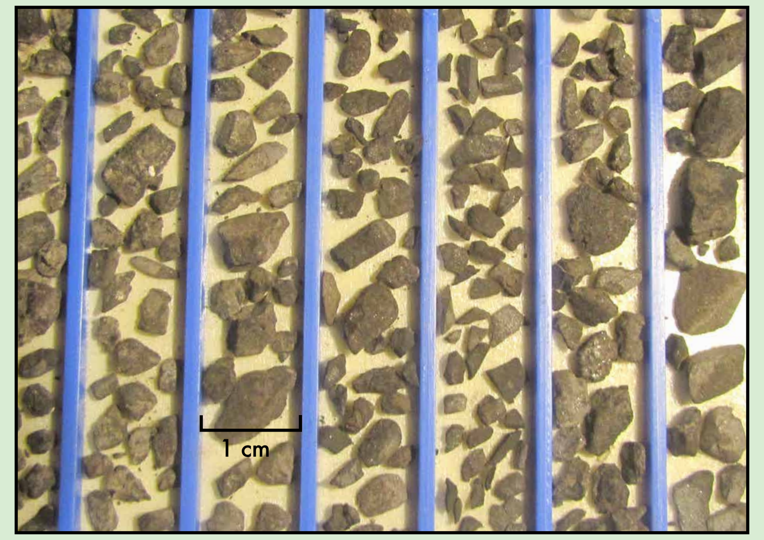
METHODS

Epifluorescence (EF) microscopy has been used extensively within industry and research for enhancing petrographic observations, including the recognition of depositional and diagenetic fabrics within recrystallized limestone and massive dolomite. The study of pore structures, microfractures, and microporosity within both carbonates and sandstones has been greatly facilitated by impregnating these voids with epoxy spiked with fluorescing dyes. EF petrography for this project used incident (reflected) blue-light fluorescence microscopy. Fluorescence data and observations collected for this study utilized a Jena (now part of Carl Zeiss) research-grade combination polarizing-reflected light microscope equipped with a high-pressure mercury vapor lamp for EF excitation, a Zeiss IIIRS EF nosepiece, and a film imaging system. Magnification ranges for examination and image-documentation were between about 130 and 320x. Blue light (about 420-490 nm exciter filter/520 nm barrier filter) was used to excite the cuttings, core-chips, and thin sections. We have found broad-band, blue-light EF to be the most helpful in observational work on dolomites, although some workers report applications using UV light (330-380 nm exciter filter/420 nm barrier filter) or narrow-band, blue-violet light (400-440 nm exciter filter/480 nm barrier filter). Finally, the greater depth of investigation into a sample by the reflected fluorescence technique than by transmitted polarized light 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.

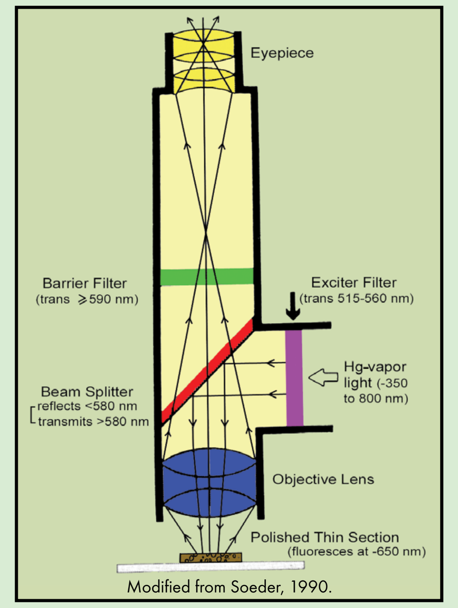
Wells penetrating the Cane Creek shale zone in the Utah part of the Paradox fold and fault belt were plotted and all Cane Creek well cuttings and core chips available from the collection at the Utah Core Research Center were compiled. Cuttings were examined under a binocular microscope and representative samples of dolomites and sandstones were selected from various units over the Cane Creek section: generally four to ten samples per depth interval from each well. The cuttings or core chips were placed on Petrologs™, a small plastic, self-adhesive compartmentalized cuttings storage unit, for EF examination. (All Petrologs™ containing Cane Creek cuttings, core chips, and thin sections from the project are stored at the Utah Core Research Center and are available to the public.) Thus, sample preparation is inexpensive and rapid.

EF petrography makes it possible to clearly identify hydrocarbon shows in Cane Creek cuttings selected for study. Since the image brightness is directly proportional to magnification, the best images are obtained at relatively high magnifications (such as 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 (when available) from each depth interval in each well. Using the qualitative visual rating scale, a variety of EF readings from each well were plotted and mapped.

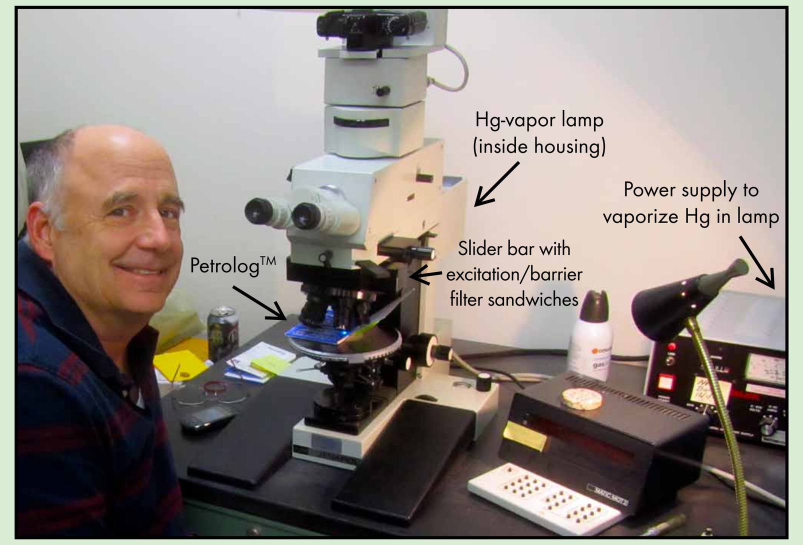
GENERALIZED MICROSCOPE OPTICAL CONFIGURATION FOR OBSERVING FLUORESCENCE UNDER INCIDENT LIGHT



Example of hand-picked Cane Creek shale cuttings samples selected from various depths from 7770 to 7870 ft, Belco Petroleum State #1 well (NENE sec. 32, T 29S, R 24E, Grand County, Utah), placed on Petrologs™ for epifluorescence examination.



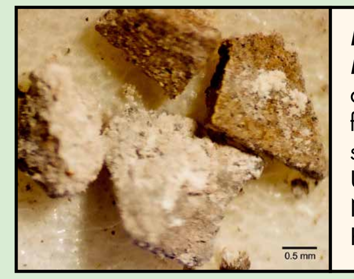
Generalized optical configuration of a microscope for observing fluorescence under incident light.



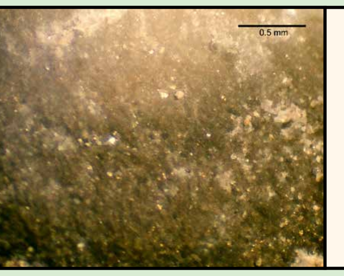
Microscope equipment used for this study.

PRINCIPAL ROCK TYPES FOR EPIFLUORESCENCE WORK IN CANE CREEK "SHALE" CUTTINGS OBSERVED WITH A BINOCULAR MICROSCOPE

Dolomitic Sandstone cutting composed of quartz grains surrounded by dolomitic mud and/or cement from the 5960-70 ft sample in the Mineral Canyon #1-14 well (Map #12; SWSE sec. 14, T. 26S, R. 19E, Grand County).

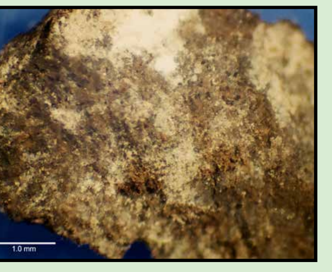


Microcrystalline Dolomite Mudstone cutting displaying microporosity from the 6290-6300 ft sample in the Horsehead Unit #1 well (Map #21; NWSW sec. 18, T. 29S, R. 21E, San Juan County).

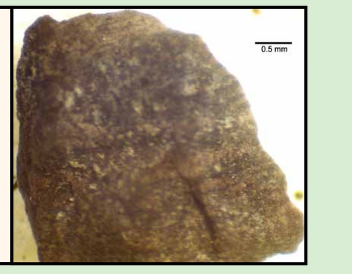


Dolomitized Peloidal Grainstone with minor amounts of quartz sand grains from the 6350-60 ft sample in the Horsehead Unit #1 well (Map #21; NWSW sec. 18, T. 29S, R. 21E, San Juan County).

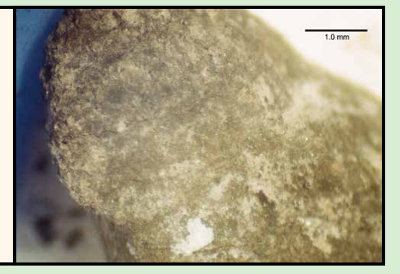
Dolomitized Peloidal/ Coated Grain Grainstone/ Packstone displaying good visible porosity from the 6360-70 ft sample in the Horsehead Unit #1 well (Map #21; NWSW sec. 18, T. 29S, R. 21E, San Juan County).



Dolomitized Microbial Laminite ("Stromatolitic Bindstone") displaying alternating light and dark crinkly laminations from the 5940-50 ft sample in the West Bridger Jack Unit #3 well (Map #15; SESW sec. 3, T. 27S, R. 21E, San Juan County).



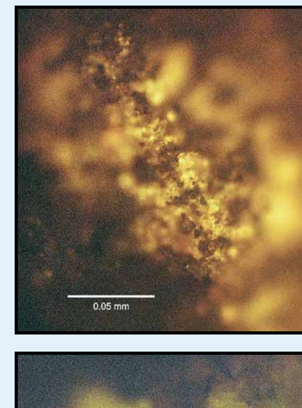
Dolomitized Oncolitic/ Pisolitic Rudstone from the 5960-70 ft sample in the West Bridger Jack Unit #3 well (Map #15; SESW sec. 3, T. 27S, R. 21E, San Juan County).



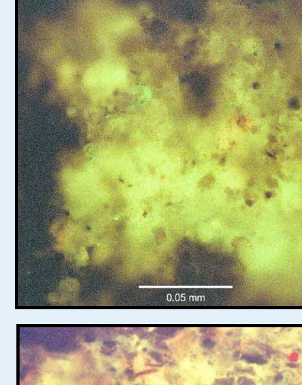
MICROGRAPHS SHOWING EXAMPLES OF VISUALLY RATED EPIFLUORESCENCE IN CANE CREEK "SHALE" PLAY

Almost no fluorescence (rated at 0.7) in a silty to dolomitic shale from the 6290-6300 ft sample in the Horsehead Unit #1 well (Map #21; NWSW sec. 18, T. 29S, R. 21E, San Juan County).

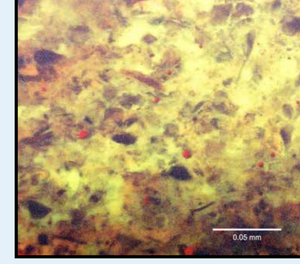
Weak and spotty fluorescence (rated at 1.5) in a microcrystalline and microporous dolomitic mudstone from the 7380-90 ft sample in the Mineral Canyon #1-14 well (Map #12; SWSE sec. 14, T. 26S, R. 19E, Grand County).



Moderately bright fluorescence (rated at 2.5) in a microcrystalline dolomite with possible organic or microbial structures from the 4785-90 ft sample in the Lockhart Federal #1 well (Map #19; SWSW sec. 22, T. 28S, R. 20E, San Juan County).

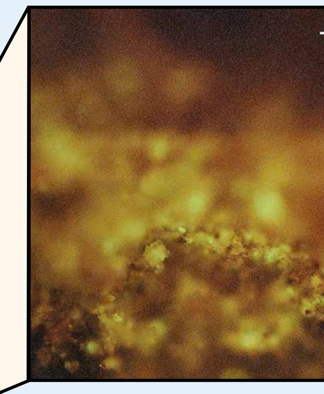


Very bright and continuous fluorescence (rated at 3.6) in a very silty microcrystalline dolomite mudstone imaged in a polished uncovered thin section from conventional core at 7430.9 ft from the Cane Creek Unit #26-3 well (Map #10; NESW sec. 26, T. 25S, R. 19E, Grand County). The reddish spots are iron-rich, and probably micro-pyrite.

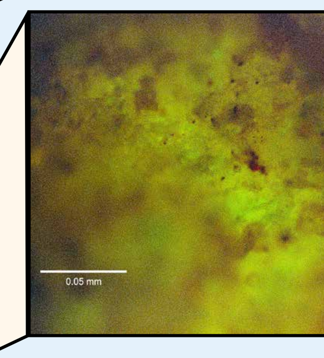


Key to Epifluorescence Qualitative Visual Rating Scale

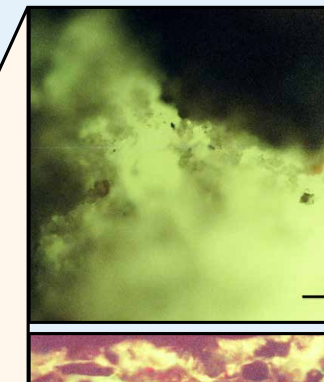
Rating	Generalized Interpretation
0 – 1.0	No Fluorescence: Not capable of oil production. May be wet, if not a gas-bearing interval.
1.0 – 1.5	Very Weak Fluorescence: An "oil" show. Indicative of minor oil in the system, but not capable of production. Some dull or weak fluorescence may exist in a wet zone (especially if there is "speckled" fluorescence) or in a mixed oil/water zone.
1.5 – 2.0	Weak/Spotty Fluorescence: A good "oil" show. Indicative of oil in the system, but probably not capable of production.
2.0 – 2.5	Moderate Fluorescence: A good indication of oil within this interval. Probably capable of some oil production if there is adequate porosity and permeability/fracturing.
2.5 – 3.0	Moderately Bright Fluorescence: A good to very good indication of movable oil within this interval. May be capable of some oil production if there is adequate porosity and permeability/fracturing.
3.0 – 3.5	Bright Fluorescence: A very good to excellent indication of oil within this interval. Should be capable of oil production if there is adequate porosity and permeability.
3.5 – 4.0	Very Bright, Intense Fluorescence: Also an excellent to the best indication of oil within this interval. However, some very bright fluorescence may indicate very tight oil-bearing rocks or mature oil-generating source rocks.



Very weak fluorescence (rated at 1.3) in a microcrystalline dolomitic mudstone from the 6290-6300 ft sample from the Horsehead Unit #1 well (Map #21; NWSW sec. 18, T. 29S, R. 21E, San Juan County). Note the crinkly lamina that could be microbial in origin.



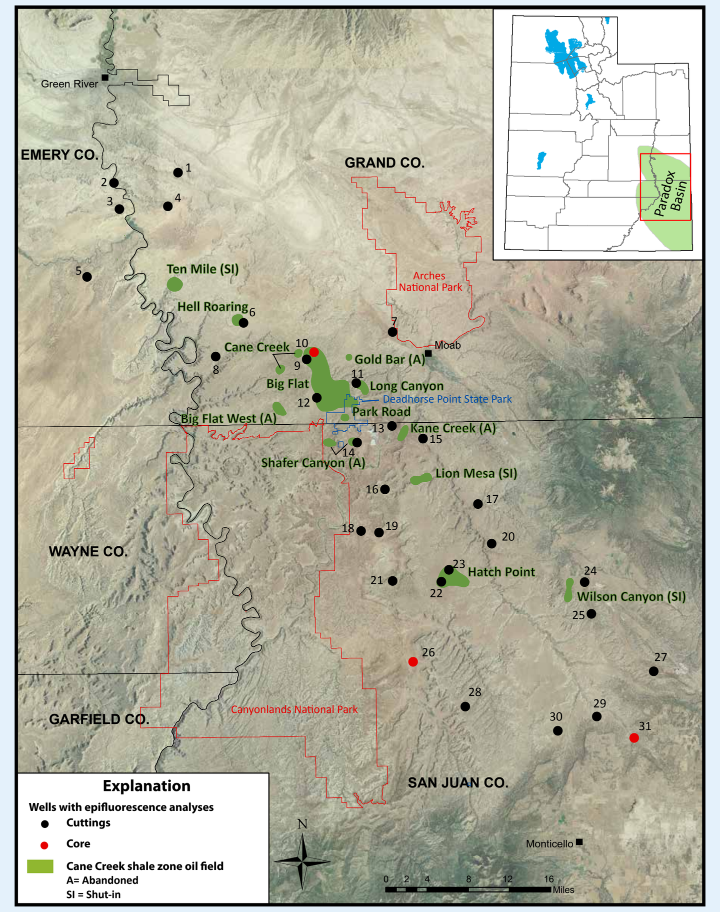
Moderate and continuous fluorescence (rated at 2.4) in rhombic clusters of crystalline dolomite in a peloidal(?) grainstone from the 7260-70 ft sample in the Hatch Point #1 well (Map #23; NESE sec. 14, T. 29S, R. 21E, San Juan County).



Moderately bright fluorescence (rated at 3.0) in a microcrystalline dolomite with possible organic or crinkly microbial structures from the 7560-70 ft sample in the Kane Springs Federal #25-19-34-1 well (Map #9; NWSE sec. 34, T. 25S, R. 19E, Grand County).

Moderately bright fluorescence (rated at 3.0) in a silty and dolomitic peloidal grainstone/packstone imaged in a polished uncovered thin section from conventional core at 7439 ft from the Cane Creek Unit #26-3 well (Map #10; NESW sec. 26, T. 25S, R. 19E, Grand County). Note the connected bands of bright yellow oil fluorescence. The rare reddish spots are iron-rich, and probably micro-pyrite.

WELLS CONTAINING CUTTINGS OR CORE CHIPS IN THE CANE CREEK SHALE ZONE EVALUATED USING EPIFLUORESCENCE TECHNIQUES



Map #	Well Name	Location			Well Type	N	Cane Creek Highest Maximum Value	Cane Creek Average Highest Value	Cane Creek Highest Average Value	Cane Creek Average of Highest Averages	A Interval Highest Maximum Value	A Interval Average Highest Value	A Interval Highest Average Value	A Interval Average of Highest Averages	B Interval Highest Maximum Value	B Interval Average Highest Value	B Interval Highest Average Value	B Interval Average of Highest Averages	C Interval Highest Maximum Value	C Interval Average Highest Value	C Interval Highest Average Value	C Interval Average of Highest Averages
1	Salt Wash Unit 22-34	22S	17E	34	Dry hole	80	1.4	1.1	0.7	0.6	1.4	1.4	0.7	0.7	1.4	1.2	0.6	0.6	1.4	1.1	0.7	0.7
2	Jakey's Ridge 12-3	23S	16E	3	Dry hole	97	2.4	1.9	1.6	1.1	1.8	1.6	1.1	1.1	2.4	2.1	1.6	1.3	2.2	1.8	1	0.8
3	Jakey's Ridge 34-15	23S	16E	15	Dry hole	100	2.2	1.6	1.6	0.9	0.8	0.6	0.4	0.3	2.2	2.2	1.4	1.1	ND	ND	ND	ND
4	Salt Wash 1-16	23S	17E	16	Dry hole	71	3	2.7	2.4	2.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5	Gruvers Mesa 1	24S	16E	19	Dry hole	100	2.1	2	1.8	1.5	2.1	2.1	1.7	1.7	2.1	2	1.8	1.6	2.1	2	1.4	1.3
6	Kane Springs Fed 10-1	25S	18E	10	Producing oil well	49	3	2.8	2.3	2.2	3	3	2.3	2.3	2.8	2.6	2.3	2.1	ND	ND	ND	ND
7	Utah 2	25S	21E	18	Dry hole	108	2.5	2	2	1.5	2.1	1.6	1.4	1.1	2.4	2.2	1.9	1.7	2.5	2.4	1.9	2
8	Fed Bowknot 1	25S	18E	30	Dry hole	71	2.6	2.3	2.1	1.9	ND	ND	ND	ND	2.5	2.3	2	1.9	2.6	2.5	2.1	2.1
9	Kane Springs Fed 25-19-34-1	25S	19E	34	Producing oil well	149	3.4	2.8	3.1	2.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10	Cane Creek Unit 26-3	25S	19E	26	Producing oil well	197	3.2	2.3	2.6	1.9	2.3	2	2.1	1.7	3.2	2.5	2.6	2.5	2.8	2.2	2.3	1.9
11	Long Canyon 1	26S	20E	9	Producing oil well	39	3	2.2	2	1.2	2.7	2.1	1.2	0.8	2.8	2	1.8	1.1	3	2.6	2	1.5
12	Mineral Canyon U 1-14	26S	19E	14	PA oil well	65	2.1	1.5	1.7	1.1	1.6	1.3	1.4	1	2.1	1.6	1.7	1.3	1.9	1.6	1.4	1.1
13	Federal 1-X	26S	20E	36	Dry hole	43	2.8	2.4	2.2	1.8	2.3	2.3	1.7	1.7	2.4	2.4	1.7	1.7	2.8	2.4	2.2	1.9
14	Featherstone-Federal 9-1	27S	20E	9	Dry hole	100	2.9	2.4	2.1	1.6	2.3	2.1	1.2	1.2	2.9	2.4	2.1	1.7	2.9	2.5	1.8	1.7
15	West Bridger Jack U 3	27S	21E	3	Dry hole	68	1.2	1	0.9	0.6	ND	ND	ND	ND	1.2	1	0.9	0.7	1.2	1	0.7	0.6
16	Cane Creek State 1-36	27S	20E	36	Dry hole	90	3.1	2.5	2.7	1.9	3.1	3	2.5	2.4	3	2.5	2.7	2.1	2.6	2.3	1.7	1.6
17	Red Rock Unit 1	28S	22E	9	Dry hole	104	2.5	1.8	1.3	1	1.1	1.1	0.7	0.7	2.2	2	1.2	1	2.5	1.8	1.3	1
18	Lockhart-Fed 1	28S	20E	22	Dry hole	94	3	2.2	2.2	1.7	1.6	1.6	1.5	1.3	2.8	2.2	2	1.6	3	2.4	2.2	1.9
19	USA Lockhart 1	28S	20E	23	Dry hole	46	1.3	1.1	1.1	0.8	ND	ND	ND	ND	1	1	0.7	0.7	1.3	1.2	1.1	1
20	Government B-1	28S	22E	34	Dry hole	156	3.2	2.3	1.8	1.5	3.2	2.5	1.7	1.4	3	2.3	1.8	1.4	2.9	2.2	1.8	1.6
21	Horsehead Unit 1	29S	21E	18	Dry hole	100	3	2.1	2.2	1.7	1.7	1.6	1.5	1.4	3	2.4	2.2	1.8	2.3	2.2	2	1.8
22	Hatch Point 1	29S	21E	14	Producing oil well	38	2.4	2.1	1.9	1.3	ND	ND	ND	ND	2.2	1.9	1.6	1.2	2.4	2.3	1.9	1.5
23	Threemile 12-7	29S	21E	12	Producing oil well	38	2.5	2.1	1.9	1.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
24	La Sal USA 1	29S	24E	19	Dry hole	106	2	1.7	1.2	0.8	1.7	1.6	0.7	0.7	1.5	1.4	0.8	0.6	2	1.8	1.2	0.9
25	Lisbon D232	29.5S	24E	32	Dry hole	60	0.7	0.5	0.5	0.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26	Gibson Dome	30S	21E	21	Dry hole	89	2.4	2.2	2.1	1.8	2.2	2.1	1.9	1.8	2.4	2.4	2.1	2.1	2.2	2.2	1.8	1.7
27	Little Valley 2	30S	25E	29	Dry hole	35	1.2	0.8	0.6	0.4	0.6	0.6	0.4	0.4	1.2	1	0.6	0.5	ND	ND	ND	ND
28	Hart Point Fed 1	31S	22E	8	Dry hole	77	2.5	2.2	2.1	1.6	2.1	2.1	1.4	1.4	2.5	2.3	2.1	1.7	2.3	2.2	1.6	1.5
29	Winchester 21-1H	31S	24E	21	Dry hole	90	2	1.6	1.3	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	Church Rock Unit 1	31S	23E	26	Dry hole	48	1.8	1.3	1	0.7	ND	ND	ND	ND	1.8	1.4	0.8	0.7	1.5	1.2	1.1	0.7
31	Cisco State 36-13	31S	24E	36	Dry hole	133	2.8	2	2.3	1.7	2.3	1.5	2	1.2	2.8	2.3	2.3	1.9	2	1.5	1.9	1.2

N = number of samples
NA = not available
ND = no data

Yellow columns contain data mapped in Panels II and III

CANE CREEK SHALE ZONE

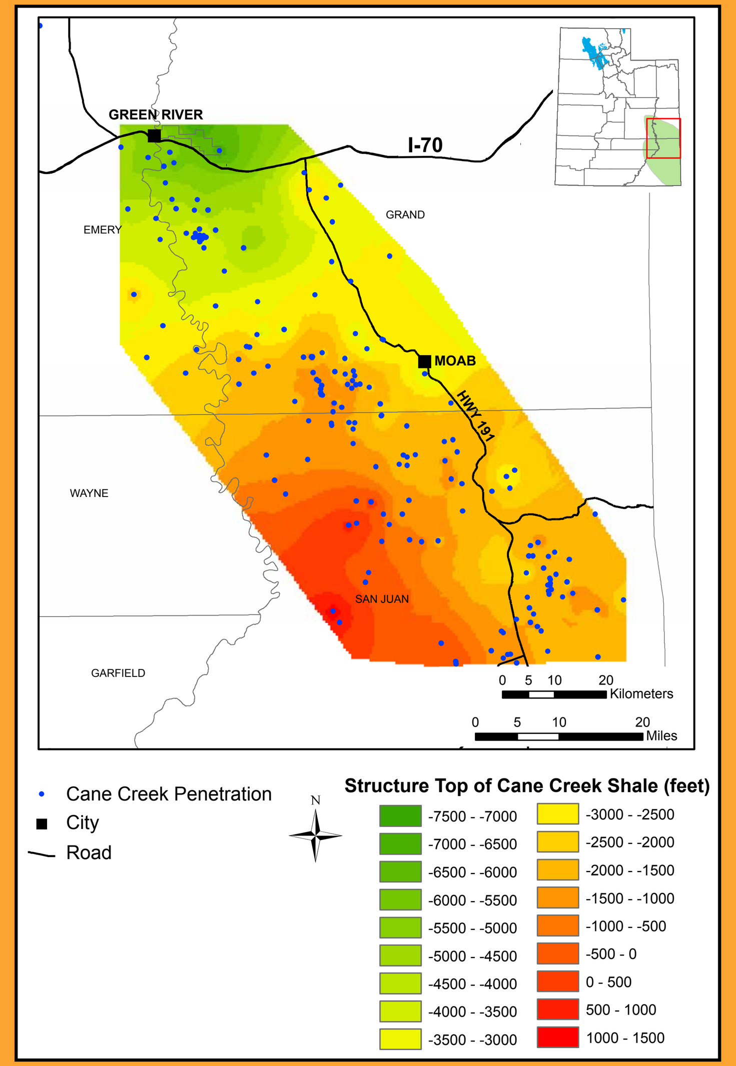
Cane Creek Structure

- Deeper in northern part of study area
- Shallow near western edge/shelf of basin
- Majority of production from Big Flat area

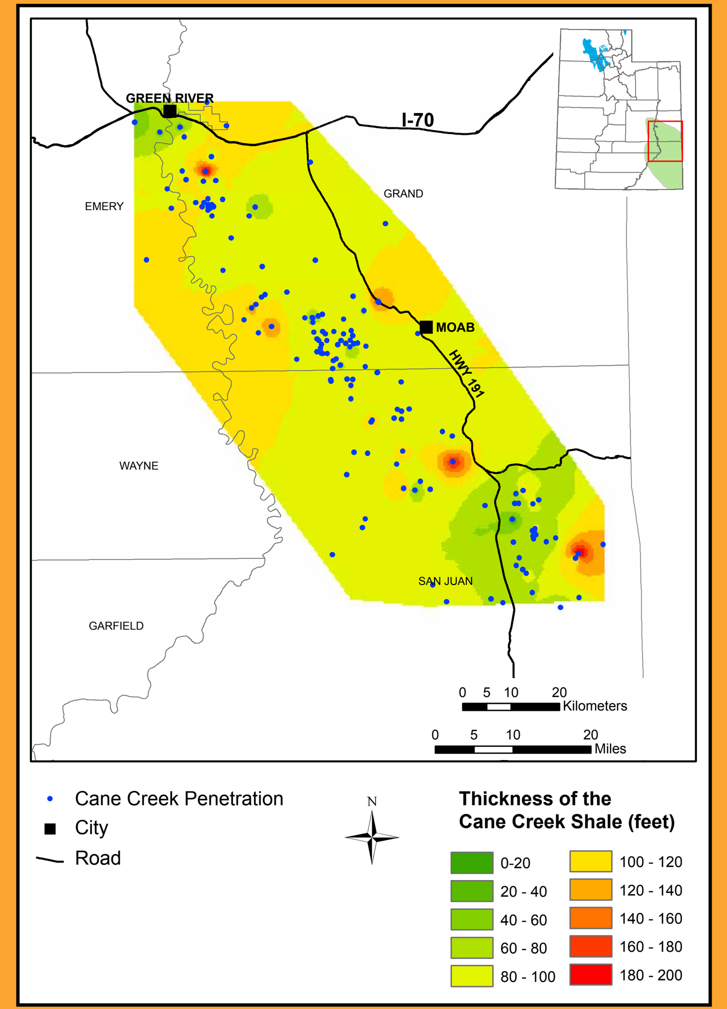
Cane Creek Thickness

- Thickness range = 20 to 200 ft
- Average thickness = 100 ft
- Thickest spots possibly due to faulting in fold/fault belt of basin
- NW-SE trending "fairway"

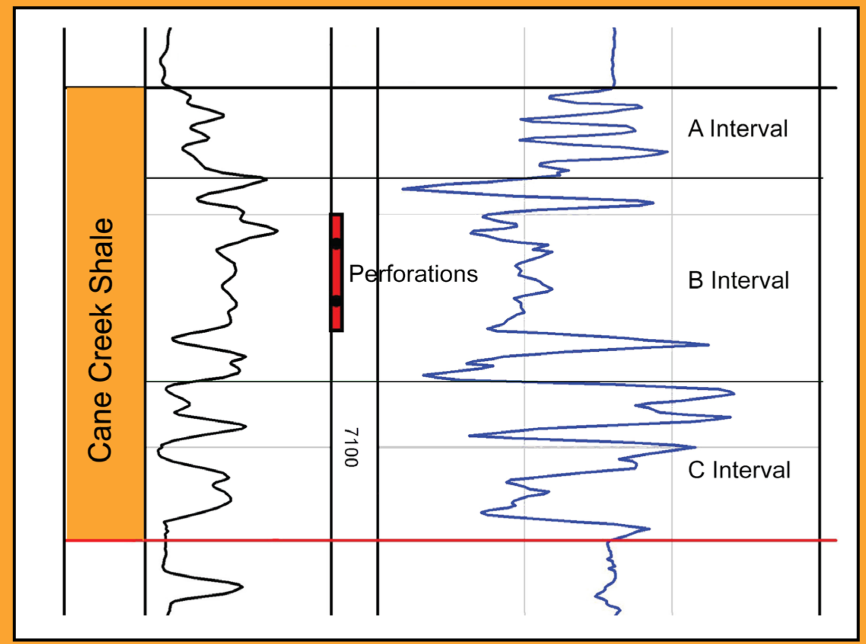
STRUCTURE TOP OF THE CANE CREEK SHALE ZONE



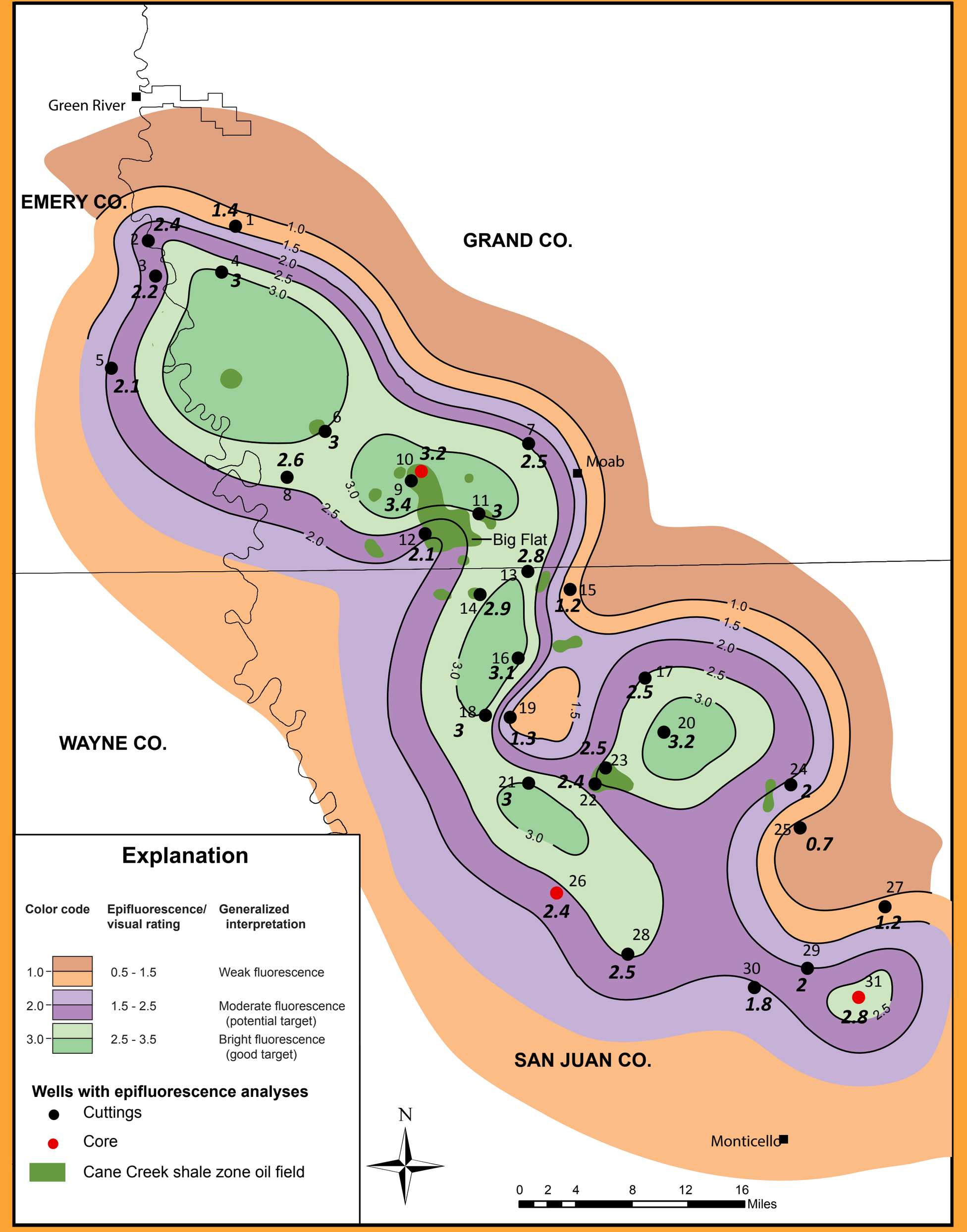
THICKNESS OF THE CANE CREEK SHALE ZONE



TYPICAL GAMMA RAY-SONIC LOGS OF CANE CREEK SHALE ZONE

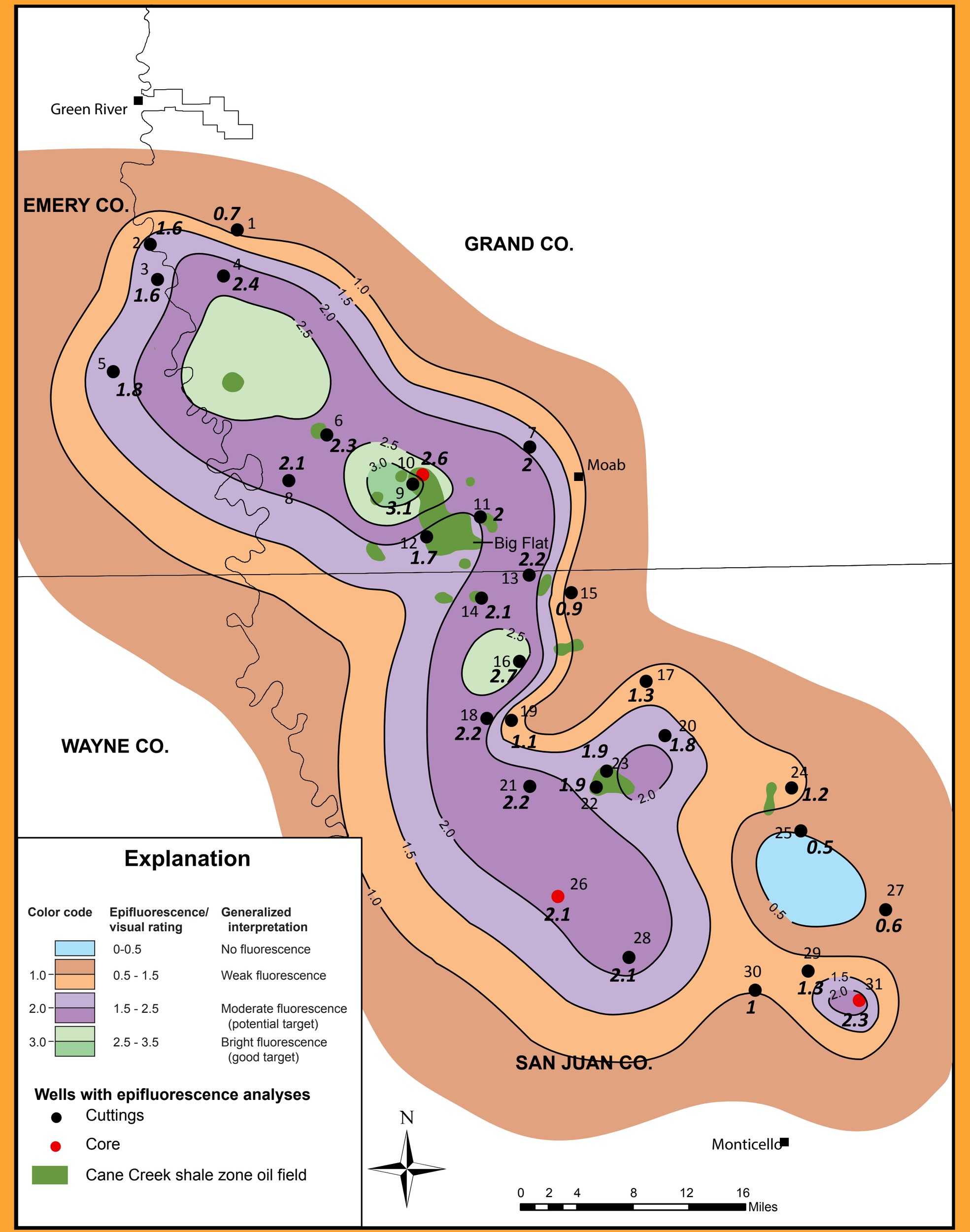


MAP OF THE HIGHEST MAXIMUM EPIFLUORESCENCE BASED ON VISUAL RATING OF CANE CREEK WELL CUTTINGS AND CORE CHIPS



- In this map, and those that follow, 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 thus have a much higher risk for finding new oil reserves in the Cane Creek shale zone.

MAP OF THE HIGHEST AVERAGE EPIFLUORESCENCE BASED ON VISUAL RATING OF CANE CREEK WELL CUTTINGS AND CORE CHIPS



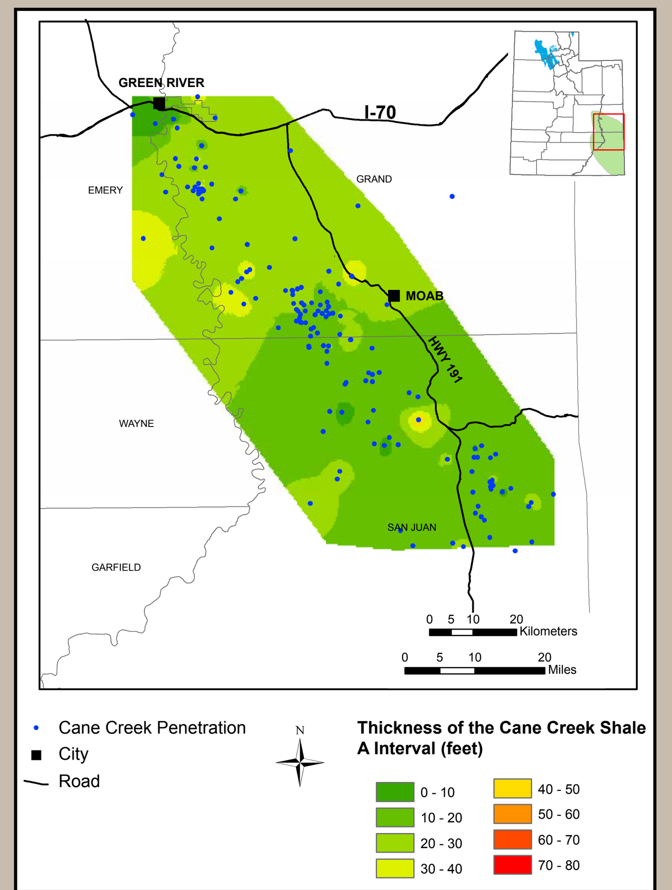
- Again, there is a pronounced curvilinear fairway of anomalous fluorescence ratings that follows the same northwest to southeast trend seen in the "highest maximum" map.
- The anomalous trend displays lower average ratings (displayed in both green and purple) than "highest maximum" ratings shown in the previous map.
- 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 as large and continuous as those suggested by the previous "highest maximum" map.
- Some of the smaller fields containing productive Cane Creek wells display highest average ratings that are less than the area around and possibly to the northwest of Big Flat field.

CANE CREEK SHALE INTERVAL A

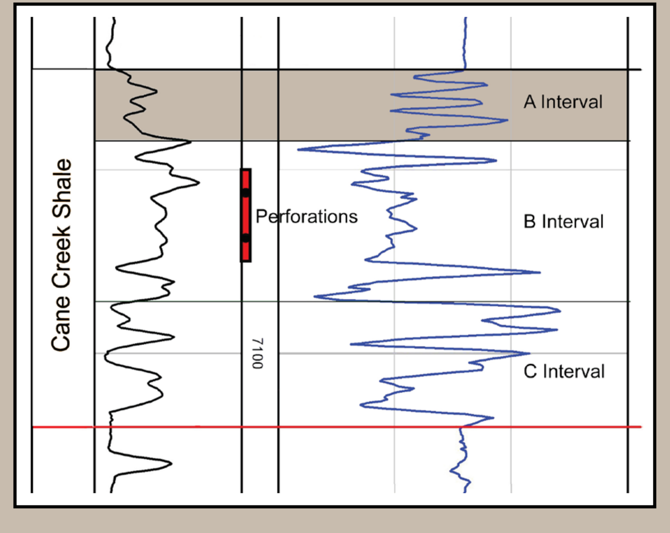
General Characteristics

- Upper seal
- Silty dolomite with thin organic-rich shale and abundant anhydrite
- Generally thicker to north
- Thickness range = 10 to 84 ft
- Average thickness = 31 ft

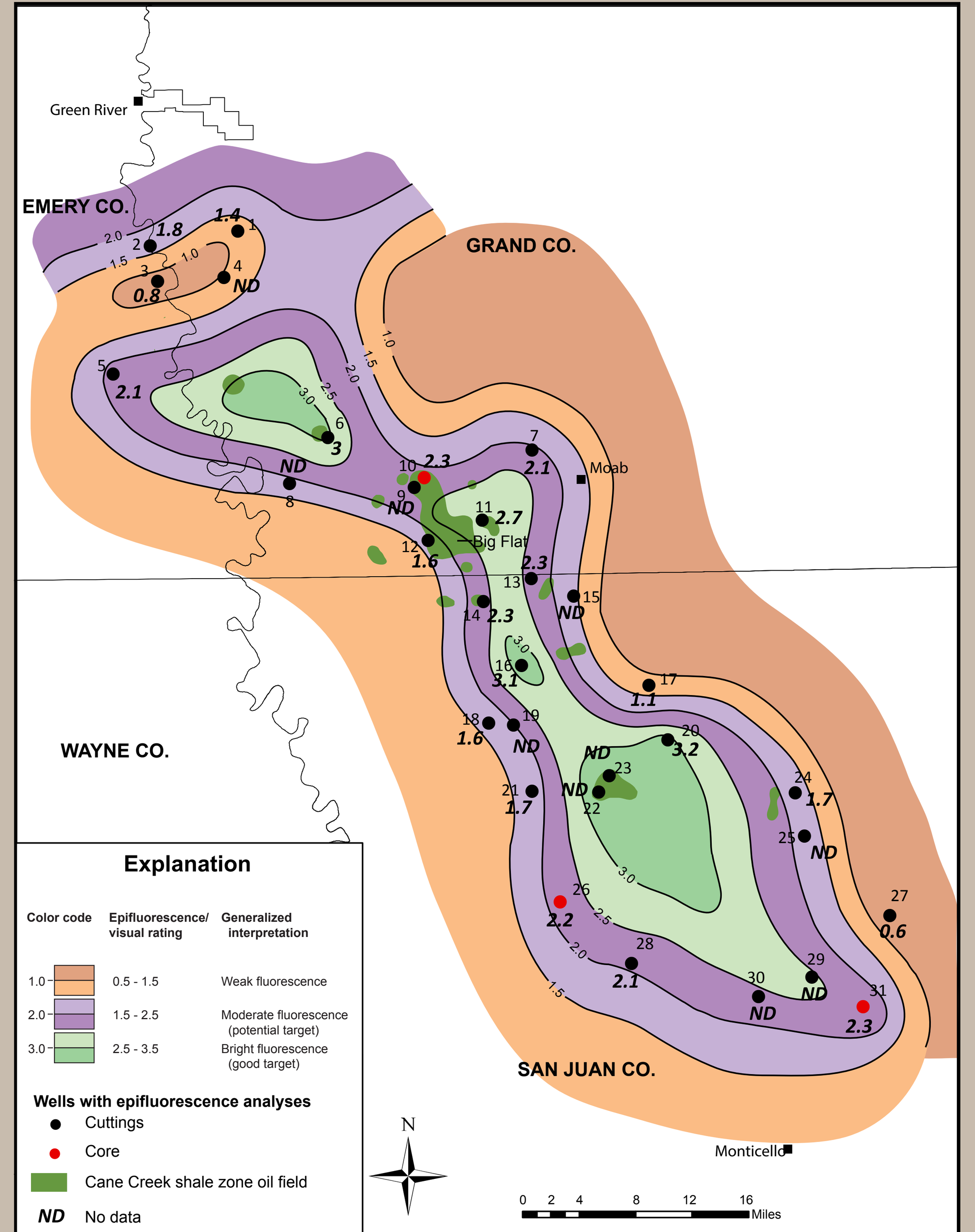
THICKNESS OF THE CANE CREEK SHALE ZONE, INTERVAL A



TYPICAL GAMMA RAY-SONIC LOGS OF CANE CREEK SHALE ZONE

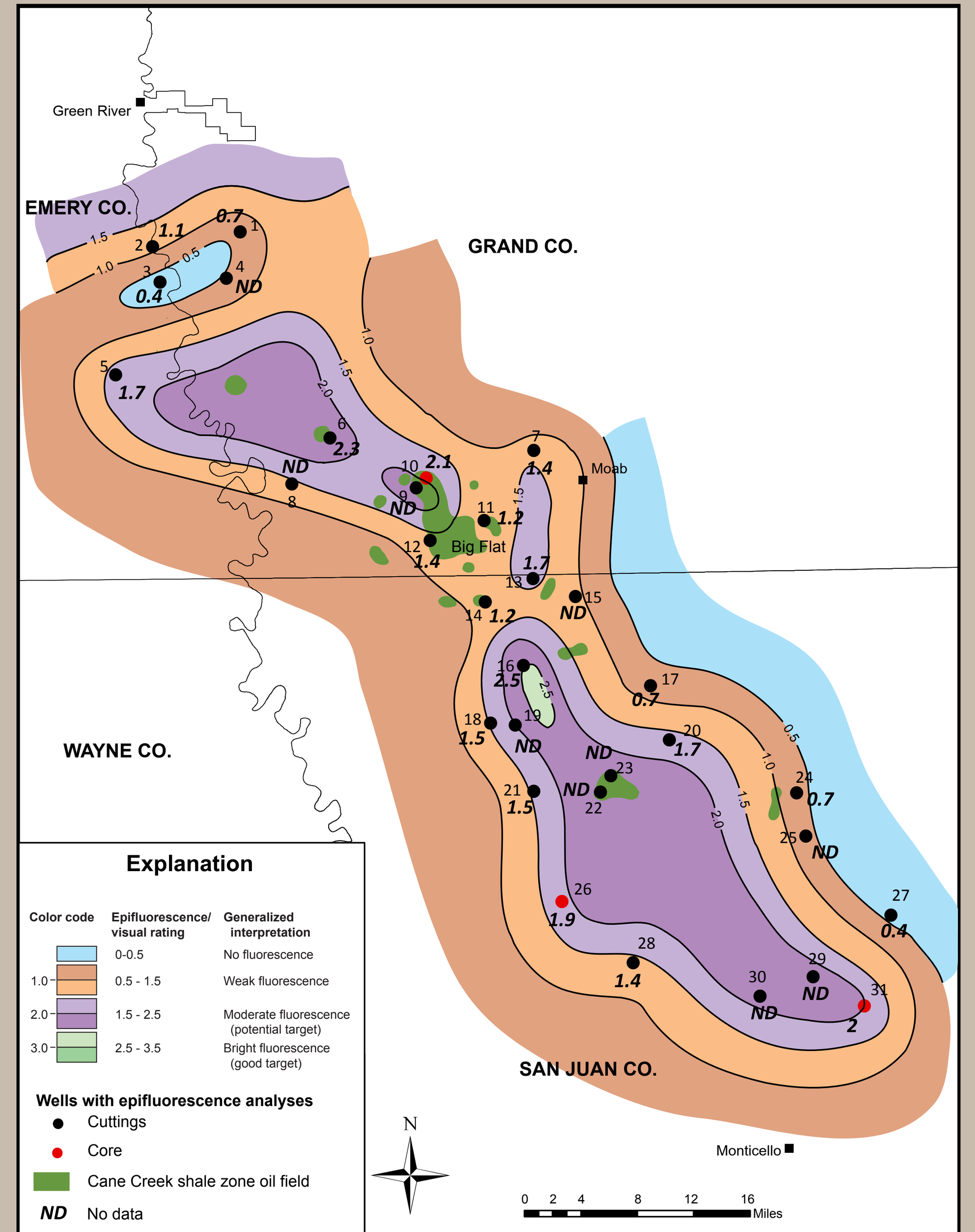


MAP OF THE HIGHEST MAXIMUM EPIFLUORESCENCE BASED ON VISUAL RATING OF CANE CREEK WELL CUTTINGS AND CORE CHIPS, INTERVAL A



- A constricted fairway of very highest maximum (in green) ratings for "Interval A," the highest stratigraphic portion of the Cane Creek shale zone, follows the same general trend as the total Cane Creek shale thickness highest maximum ratings.
- Very prospective "A Interval" sections appear to exist in large lobes to the northwest and southeast of Big Flat field.
- The northern and western portions of Big Flat field seem to have lower highest maximum ratings than the southeastern and eastern productive areas.
- High risk areas that have low ratings (in orange) within "Interval A" occur at the northwest end of the highest maximum fairway as well as to the northeast and southwest of the overall favorable ratings fairway.

MAP OF THE HIGHEST AVERAGE EPIFLUORESCENCE BASED ON VISUAL RATING OF CANE CREEK WELL CUTTINGS AND CORE CHIPS, INTERVAL A



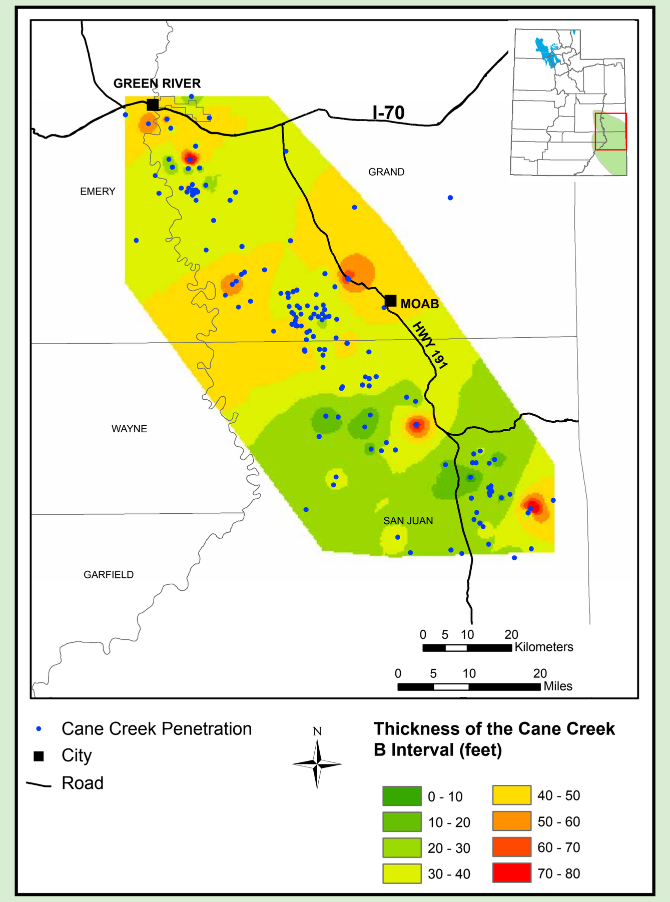
- The anomalous trend on this map displays lower average ratings (shown in both green and dark purple) than "highest maximum" ratings for "Interval A" shown in the previous map.
- Fragmented or isolated pods of highest average ratings (shown in green and dark purple) suggest that "Interval A" does not have uniform prospectivity or productivity along the favorable Cane Creek shale fairway.
- The southern portions of Big Flat field do not rate very well for the "Interval A" using the highest average ratings, suggesting that "Interval A" may not be highly productive through the entire area of the field.
- Very prospective "Interval A" sections appear to exist in discrete lobes to the northwest and southeast of Big Flat field as determined by the highest average ratings (in green and dark purple).
- High risk areas that have low ratings (in orange and blue) within "Interval A" occur at the northwest end of the highest average fairway as well as to the northeast and southwest of the overall favorable ratings fairway.

CANE CREEK SHALE INTERVAL B

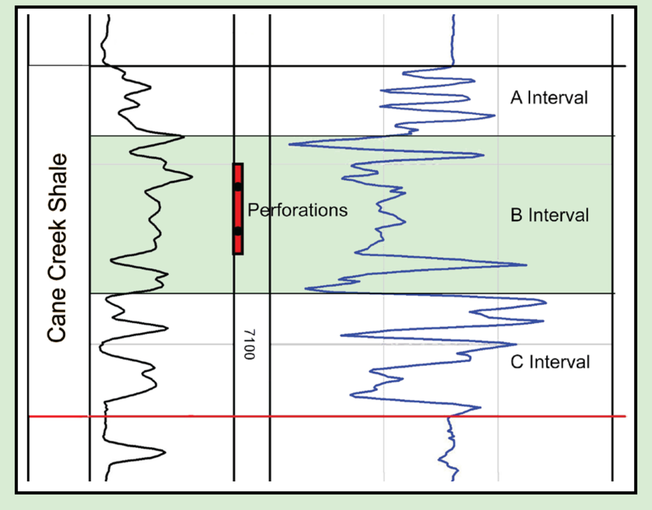
General Characteristics

- Primary Cane Creek reservoir
- Silty dolomite with thin organic-rich shale and minor mottled anhydrite
- Thickness range = 4 to 72 ft
- Average thickness = 26 ft
- Thicker E-W band near middle of play area
- Low variance in thickness
- Natural fractures trend NE-SW

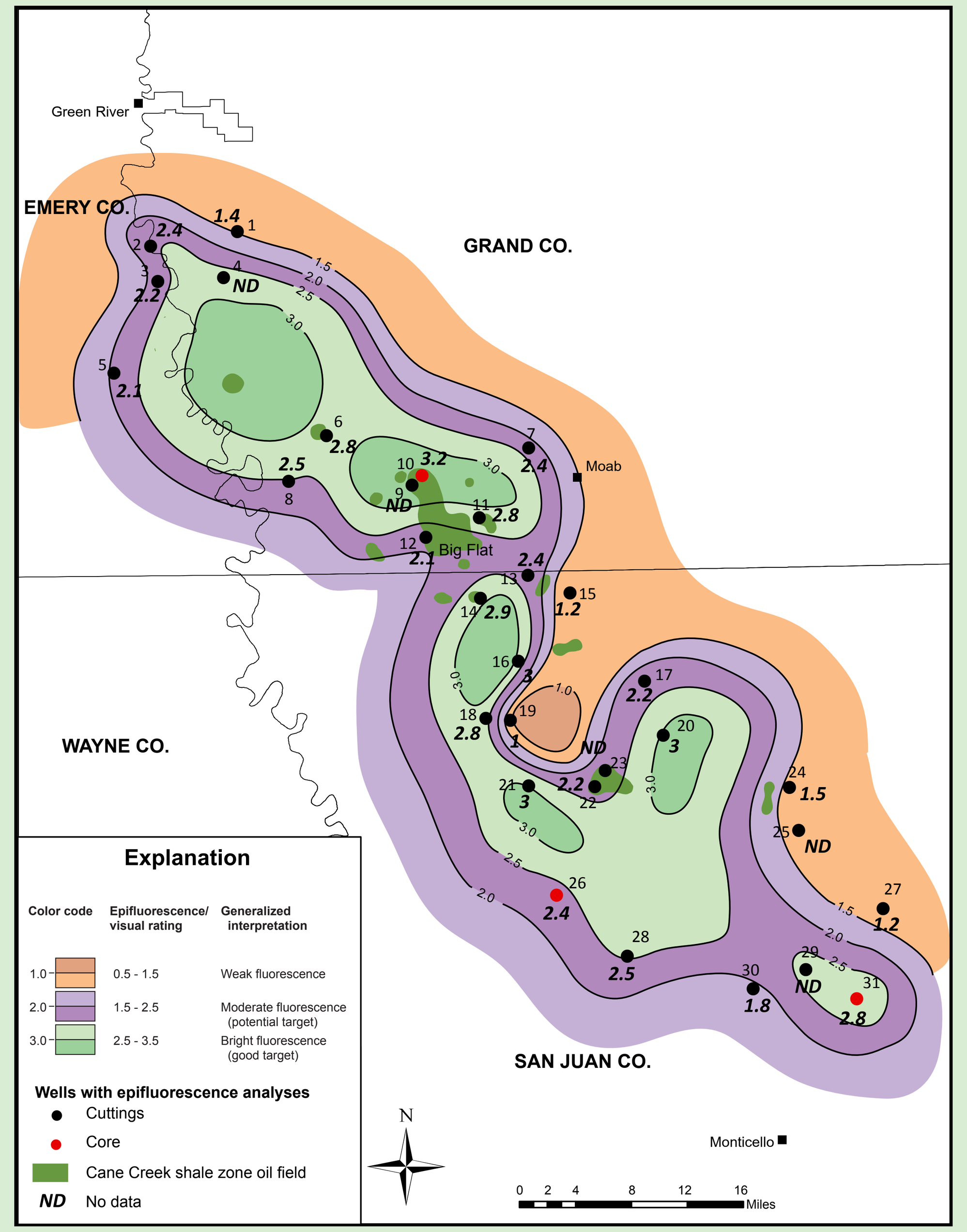
THICKNESS OF THE CANE CREEK SHALE ZONE, INTERVAL B



TYPICAL GAMMA RAY-SONIC LOGS OF CANE CREEK SHALE ZONE

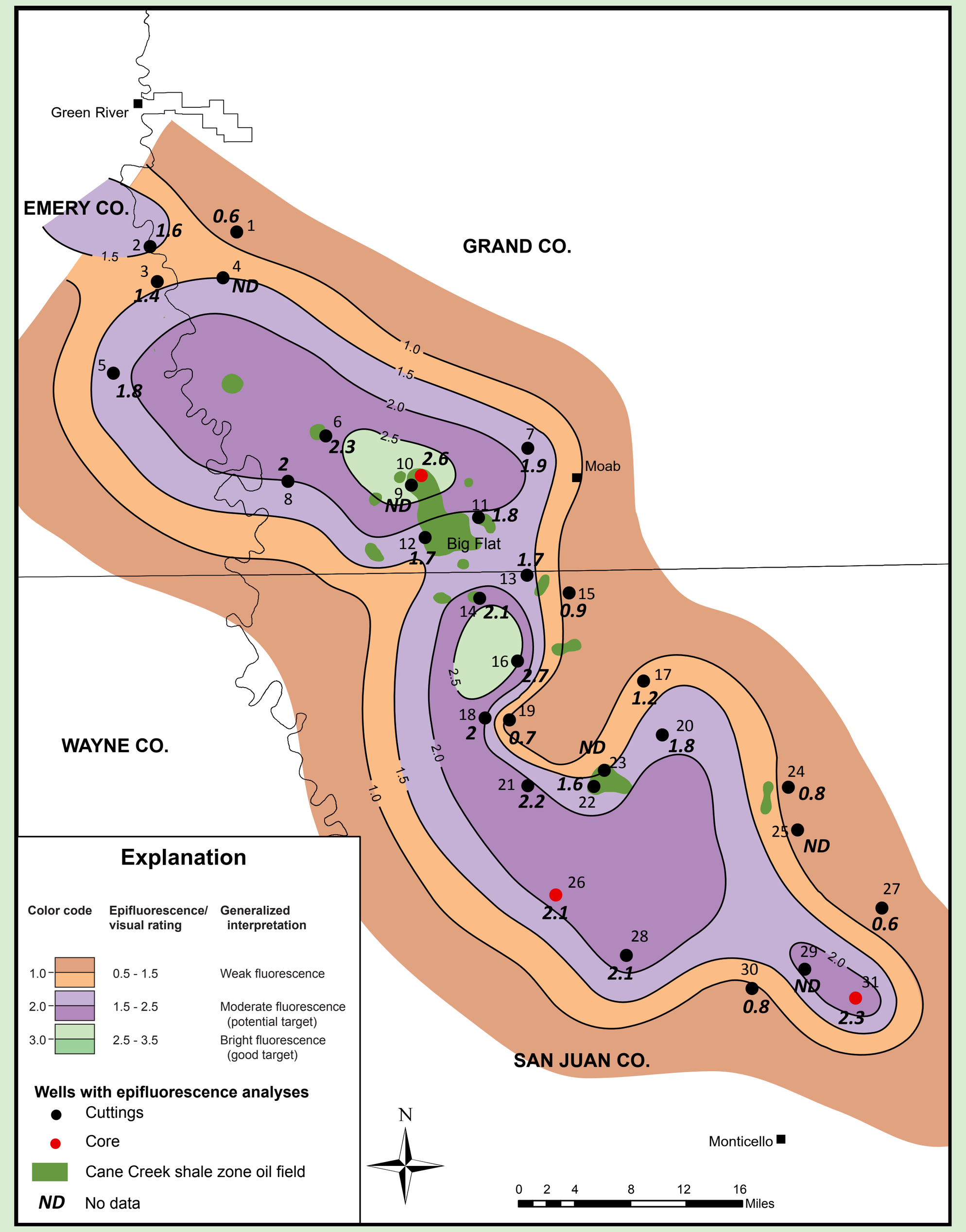


MAP OF THE HIGHEST MAXIMUM EPIFLUORESCENCE BASED ON VISUAL RATING OF CANE CREEK WELL CUTTINGS AND CORE CHIPS, INTERVAL B



- A well-defined fairway of very highest maximum (in green and dark purple) ratings for "Interval B," the middle stratigraphic portion of the Cane Creek shale zone, follows the same general trend as the total Cane Creek shale thickness highest maximum ratings.
- All of the Cane Creek shale oil fields to date have "Interval B" highest maximum ratings that are rated very high (in green and purple). "Interval B" appears to be the best and most widespread Cane Creek shale interval for oil production and prospectivity.
- Very prospective "Interval B" sections appear to exist in lobes to the northwest and southeast of Big Flat field.
- High-risk areas that have low ratings (in orange) within "Interval B" only occur to the northeast and southwest of the overall favorable ratings fairway.

MAP OF THE HIGHEST AVERAGE EPIFLUORESCENCE BASED ON VISUAL RATING OF CANE CREEK WELL CUTTINGS AND CORE CHIPS, INTERVAL B



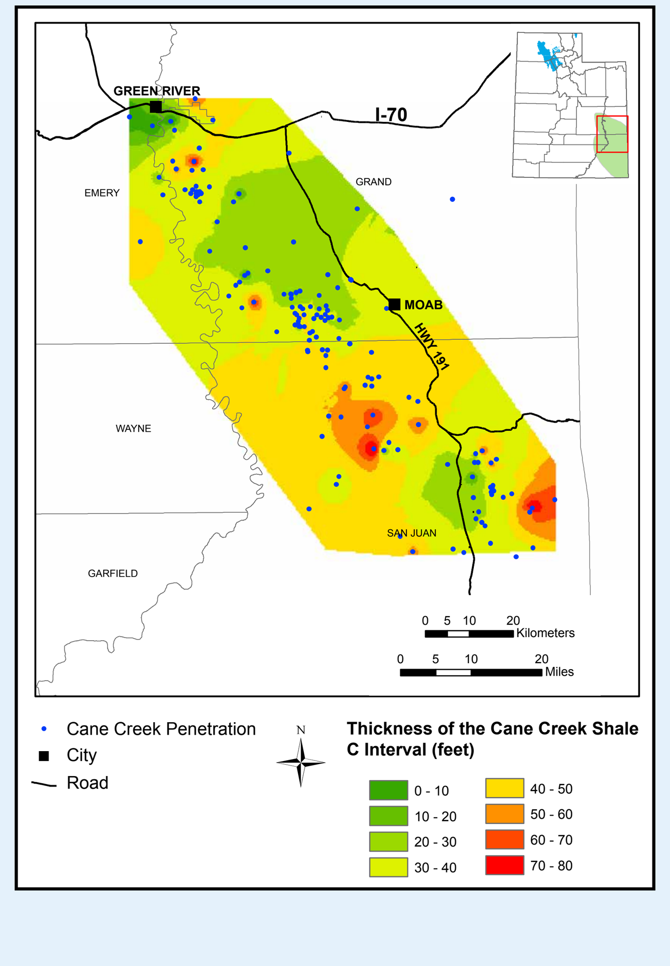
- The anomalous trend displays lower average ratings (shown in both green and purple) than highest maximum ratings for "Interval B" shown in the previous map.
- Discontinuous or patchy areas of highest average ratings (shown in green and dark purple) suggest that "Interval B" may not have uniform prospectivity or productivity along the favorable Cane Creek shale fairway.
- There are relatively large undrilled areas in which "Interval B" appears to be prospective for oil accumulations.

CANE CREEK SHALE INTERVAL C

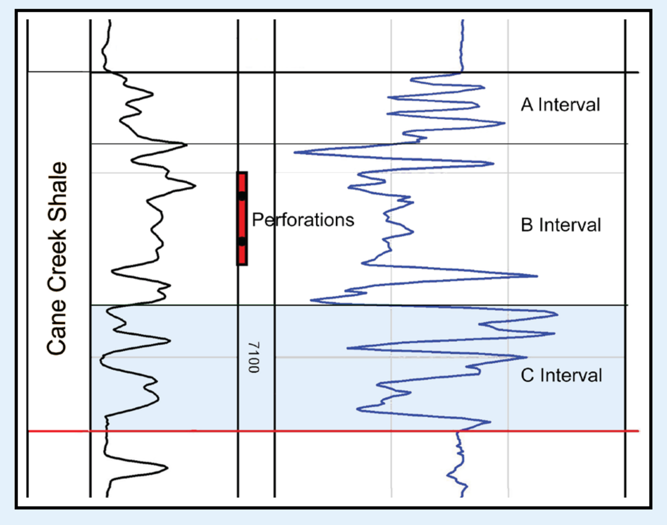
General Characteristics

- Lower seal
- Silty dolomite with abundant anhydrite and minor shale
- Thickness range = 10 to 81 ft
- Average thickness = 36 ft
- Generally thicker in south

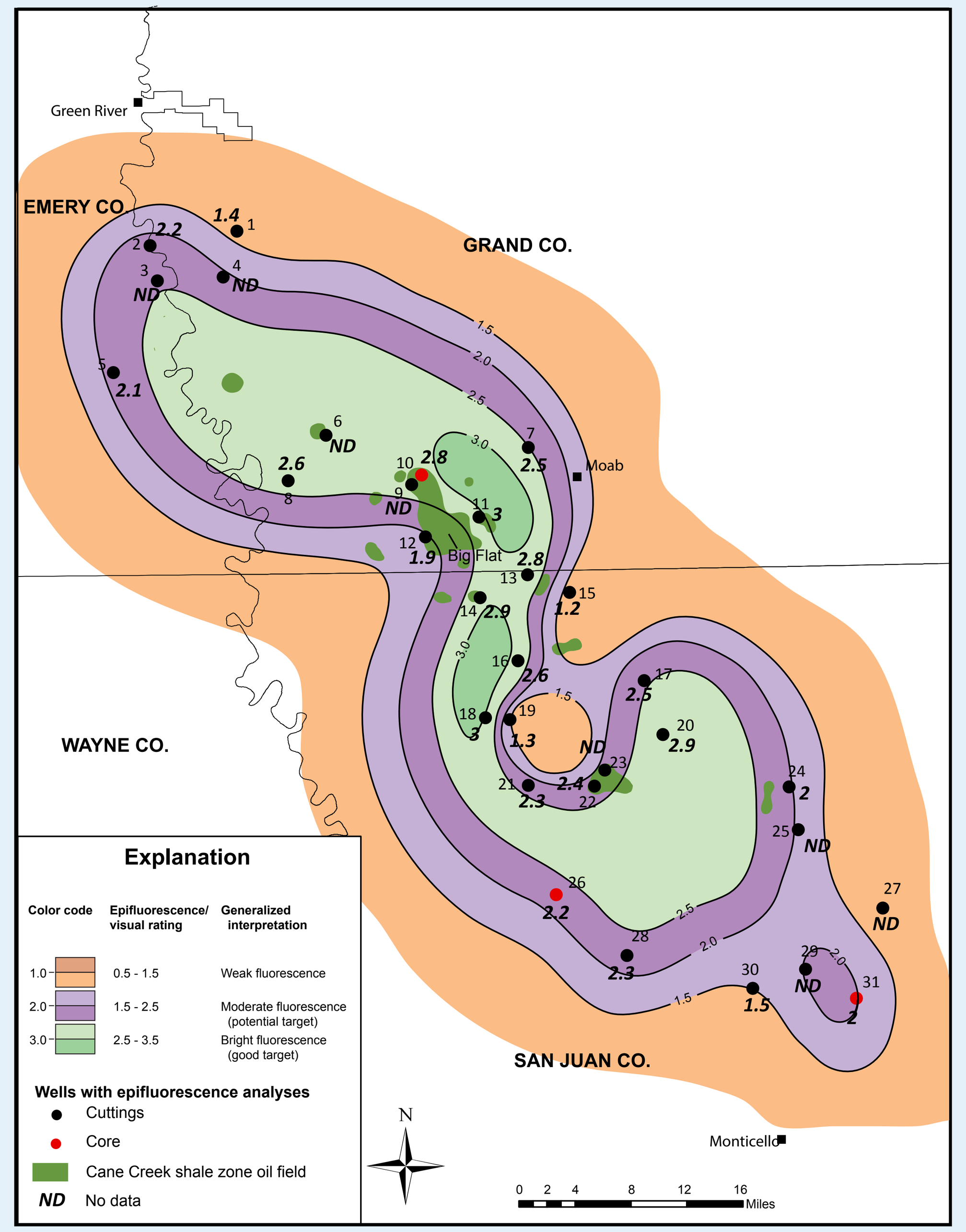
THICKNESS OF THE CANE CREEK SHALE ZONE, INTERVAL C



TYPICAL GAMMA RAY-SONIC LOGS OF CANE CREEK SHALE ZONE

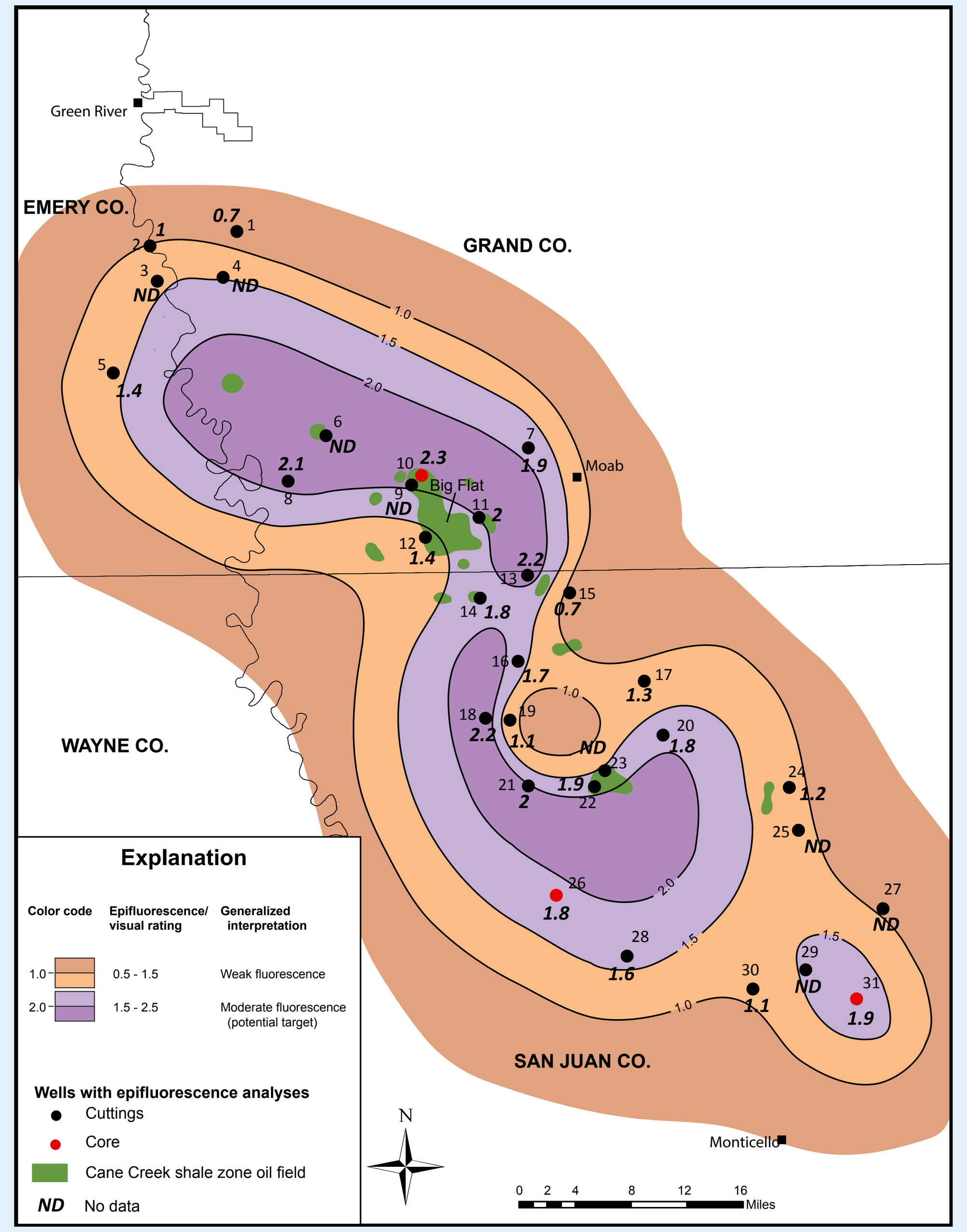


MAP OF THE HIGHEST MAXIMUM EPIFLUORESCENCE BASED ON VISUAL RATING OF CANE CREEK WELL CUTTINGS AND CORE CHIPS, INTERVAL C



- A well-defined fairway of very highest maximum ratings (in green and dark purple) for "Interval C," the lowest stratigraphic portion of the Cane Creek shale zone, is smaller in area than the fairways defined on the other rating maps.
- The most prospective areas for "Interval C" may occur in a continuous, curvilinear fairway to the northwest, south, and southeast of Big Flat field.
- Some of the wells are labeled "ND" (No Data) because "Interval C" is either absent or very thin in those wells.
- High-risk areas that have low ratings (in orange) within "Interval C" only occur to the northeast and southwest of the overall favorable ratings fairway.

MAP OF THE HIGHEST AVERAGE EPIFLUORESCENCE BASED ON VISUAL RATING OF CANE CREEK WELL CUTTINGS AND CORE CHIPS, INTERVAL C



- The anomalous trend displays lower average ratings (shown only in purple) than highest maximum ratings for "Interval C" shown in the previous map.
- A favorable Cane Creek shale fairway for "Interval C" based upon highest average ratings is somewhat narrowed and smaller than the fairway defined on the previous map using highest maximum ratings.
- There are relatively large areas that may have high exploration risk associated with them (the orange map areas) for oil accumulations within "Interval C" based upon highest average ratings.

CONCLUSIONS AND RECOMMENDATIONS

1. The Cane Creek shale play in the Pennsylvanian Paradox Formation, Paradox fold and fault belt of the Paradox Basin, southeastern Utah, contains potential oil-prone areas identified from hydrocarbon shows recognized using low-cost EF microscope techniques on cuttings, core chips, and thin sections. The Cane Creek has produced over 5 MMBO and 4 BCFG from naturally fractured and overpressured dolomitic sandstones/siltstones and dolomites interbedded with anhydrite and organic-rich marine shales.
2. The Cane Creek shale is divided into three intervals (in descending order): the A, B, and C. Most oil production is found in porous dolomite beds within the "B Interval;" the "A and C Intervals" provide the reservoir seals and some additional oil storage. Horizontal drilling and hydraulic fracturing targeting the "B Interval" have been used to successfully develop the Cane Creek play since the early 1990s.
3. EF petrography makes it possible to clearly identify hydrocarbon shows in Cane Creek shale cuttings, core chips, and uncovered thin sections selected for study. It is a non-destructive procedure that can be done using a petrographic microscope equipped with reflected light capabilities, mercury-vapor light, and appropriate filtering. Sample preparation is inexpensive and rapid.
4. Cuttings and core chips from 31 productive and dry exploratory wells penetrating the Cane Creek shale zone in the Utah part of the Paradox fold and fault belt were examined under a binocular microscope. Over 2650 samples of porous dolomite, siltstone, and some limestone were selected from various intervals over the Cane Creek section for EF evaluation.
5. EF allows one to observe the presence or absence of oils, especially in the sandstones, dolomites, and microbialites of the Cane Creek "shale." Samples displaying significant fluorescence help define areas where hydrocarbons may have migrated or accumulated. If no fluorescence is observed in porous dolomites, the samples are also good representatives of areas where liquid hydrocarbons are not currently trapped in the subsurface.
6. A qualitative visual "rating" scale (a range and average) based on EF evaluation was applied to the group of hand-picked cuttings (or core chips) from each depth in each well. The highest maximum and highest average EF readings from each well were plotted and mapped for the total Cane Creek shale package as well as for three recognized intervals (A, B, and C) within the Cane Creek.
7. The EF analysis and mapping indicates there is a narrow, distinct curvilinear northwest-southeast-trending fairway and isolated pods that are most perspective for future exploration and development in the Cane Creek shale zone within the Utah portion of the Paradox fold and fault belt. It is likely that this fairway is structurally controlled by folds, faults, and fractures zones.

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