

Petroleum Occurrences in Cretaceous-Age Reservoirs, Northern Bighorn Basin, Montana and Wyoming*

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Abstract

Oil and natural gas have been produced from Cretaceous-age sandstone and conglomerate reservoirs in more than a dozen fields in the northern Bighorn Basin. Depths of production range from 1000 feet to 14,500 feet. Lower Cretaceous reservoirs have cumulative oil and gas production of 6 MMBO and 56 BCFG. Upper Cretaceous reservoirs have produced 20 MMBO and 110 BCFG. All of the fields are on structural closures. Production is primarily from three stratigraphic intervals. They are in (A) the Pryor Conglomerate interval of the Cloverly Formation, (B) the Greybull Sandstone interval of the Fall River Formation, and (C) the Frontier Sandstone. The Pryor and Greybull reservoirs are Lower Cretaceous age whereas the Frontier is Upper Cretaceous. The Pryor is comprised primarily of fluvial deposits. Reservoir sandstones in the lower portion of the Greybull are of fluvial origin, whereas those in the upper portion are thought to be estuarine to shallow marine. The Frontier sandstones are marine deposits. Oils produced from the Lower Cretaceous intervals are in two distinct geochemical groups. On shallow structures along the flanks of the Pryor and Beartooth Mountains the oils are 10 to 22° API gravity and are biodegraded. Geochemical analysis of the low-gravity oils indicates they came from a marine carbonate source likely contained in the Permian-age Phosphoria Formation. The oil traps containing this biodegraded low-gravity oil may have had more than three billion barrels of original oil in-place. The Mosser Dome field area in Yellowstone County, Montana, houses a giant stratigraphic trap in the Greybull Sandstone once containing as much as 2 billion barrels of Phosphoria-sourced original oil in-place. Deeper in the basin the oils from Cretaceous rocks are 44–60° API gravity condensates. Gas chromatograph analyses of these oils suggest two separate oil families. The higher gravity condensates from the Lower Cretaceous-age Pryor and Greybull are similar to each other and likely had the same source. They are quite different from the distinctive 44° API gravity oil produced from the Upper Cretaceous Frontier Formation. Source-rock analyses of eighty-three Lower Cretaceous-age core samples from fifteen wells in southern Montana show TOC values as high as 4.56% with all samples being in the early to middle oil generation window. The samples from the basal portion of the Thermopolis Formation had the highest TOC values. The Thermopolis is more than 350 feet thick. Significant hydrocarbon shows were seen on mud logs and drill stem tests from this black shale interval in Carbon County, Montana. It is the most likely source for the condensates produced from the Pryor and Greybull reservoirs. The oil produced from the Frontier Sandstone is assumed to have been sourced in the underlying Mowry Formation.

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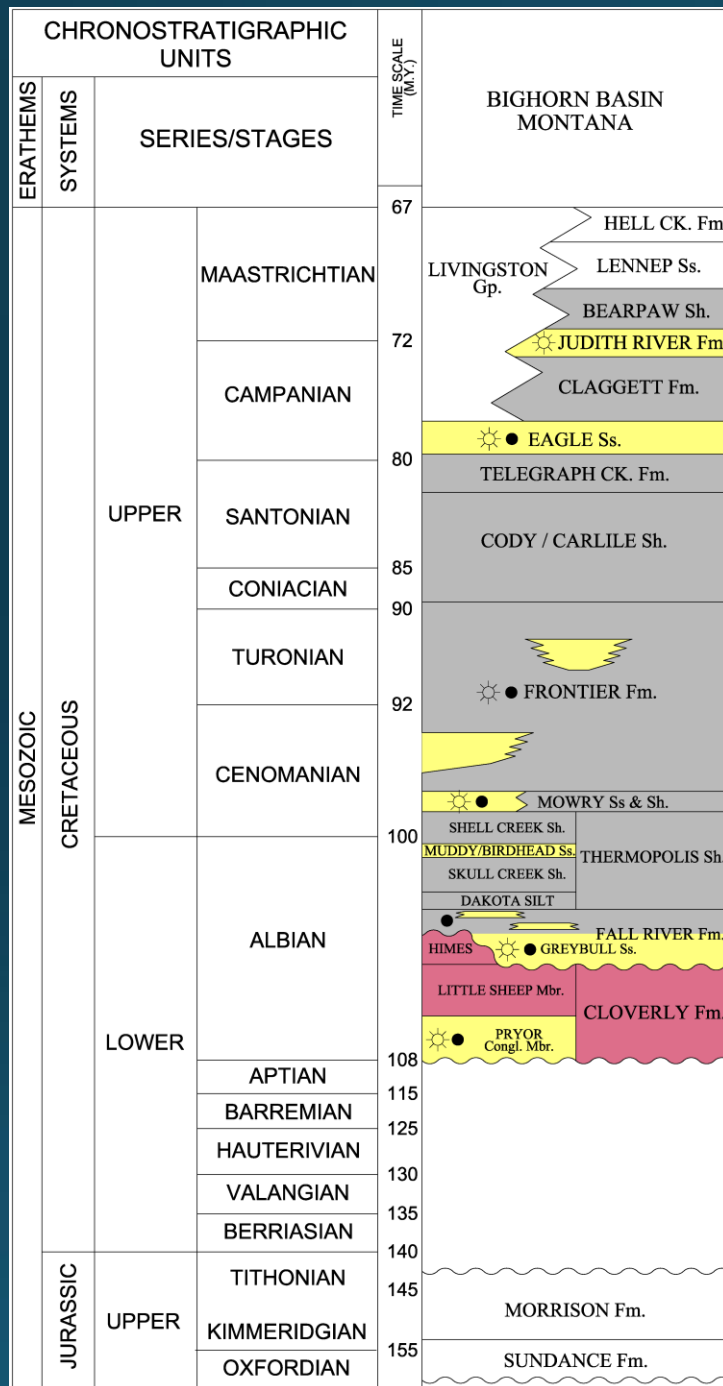
Fall River Exploration LLC,
Tulsa, Oklahoma

Key Points

- Two dozen oil and gas fields in the northern Bighorn Basin have produced oil or gas from Cretaceous-age reservoirs
- Production depths range from 1000 to 14,500 feet
- Cumulative production of 26 MMBO and 170+ BCFG from Cretaceous strata
- All production to date has been located on structural closures
- The Pryor Conglomerate, Greybull sandstone, and Frontier/Mowry sandstones are the primary Cretaceous-age oil and gas reservoir units
- Three geochemically distinctive oil groups have been produced with two groups sourced from Cretaceous shale and one sourced from the Permian Phosphoria Fm.
- Source-rock analyses of core samples from Lower Cretaceous shales demonstrate good source potential for high-gravity oil and natural gas
- Three billion barrels of Paleozoic-sourced oil may have been trapped in Lower Cretaceous reservoirs along the northern Beartooth Mt. front in Stillwater County and in the Mosser Dome area of Yellowstone and Carbon Counties, Montana
- Significant gas shows have been recovered from the Thermopolis Shale in the deeper portions of the basin in the study area

Cretaceous Stratigraphic Column

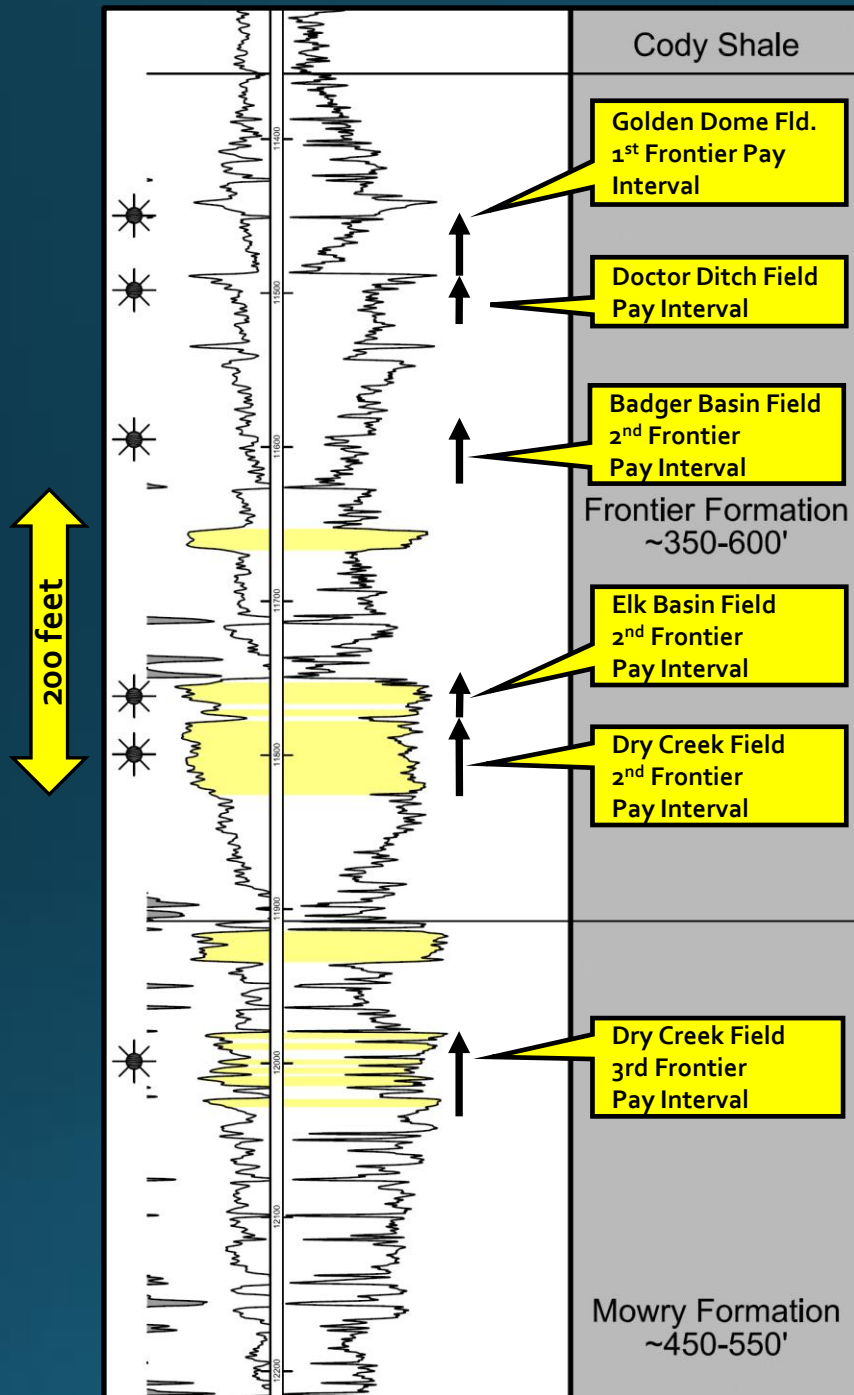
Bighorn Basin, Montana



Marine

Non-Marine

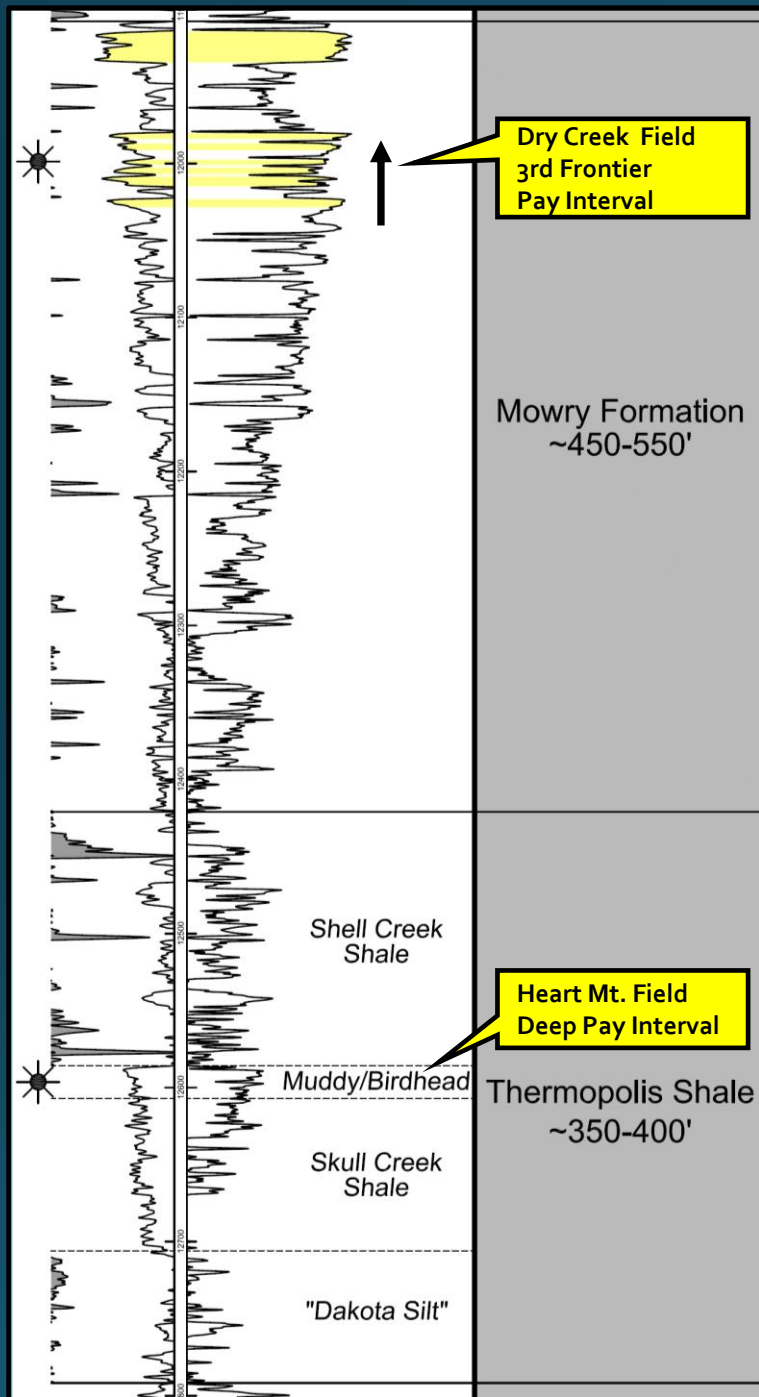
Type Log Frontier Fm. Bighorn Basin, MT



- The Frontier Fm. in the northern Bighorn Basin is comprised of a series of coarsening-upward regressive sequences capped by flooding surfaces
- Sandstones and conglomeratic sandstones in the Frontier were deposited in marine to brackish-water environments and commonly contain fossils and trace fossils
- The sandstone units generally coarsen upward from very fine-grained to medium-grained sandstone often capped with chert and/or andesite pebbles/cobbles
- There are multiple oil- and gas-bearing sandstone reservoirs developed in the Frontier and are generally discontinuous between producing fields

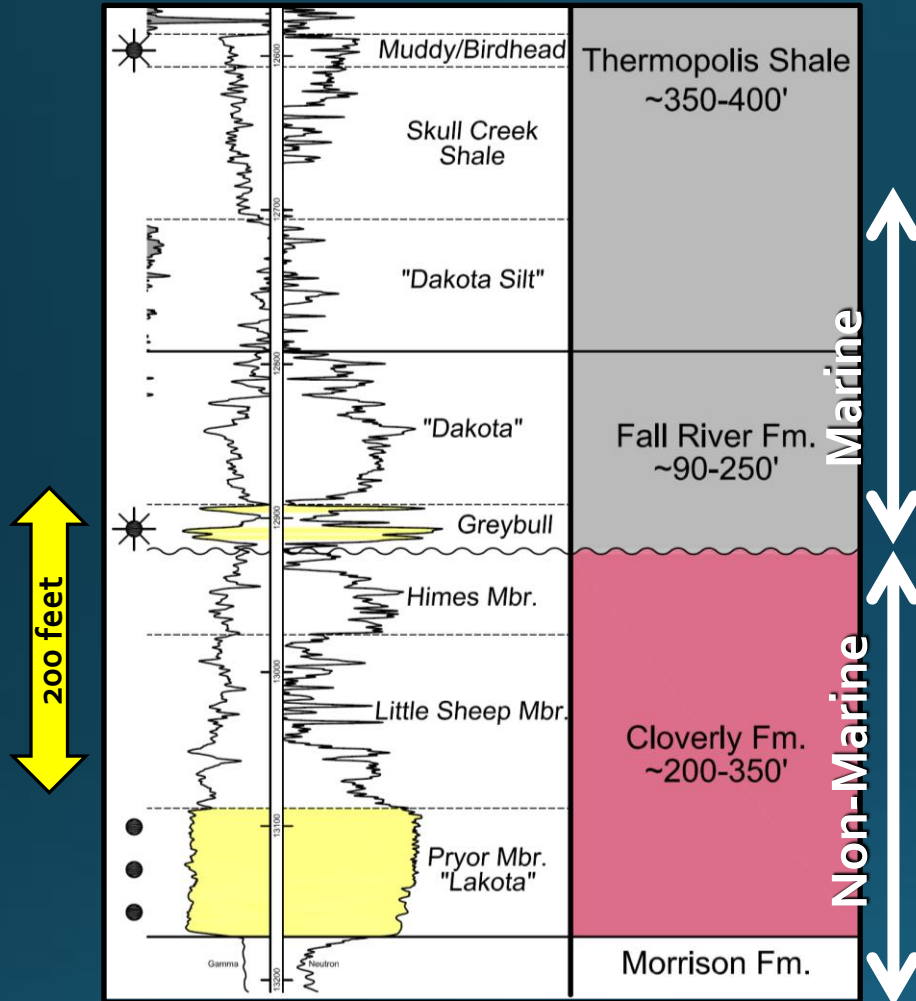
Type Log Mowry and Thermopolis Fms. Bighorn Basin, MT

200 feet



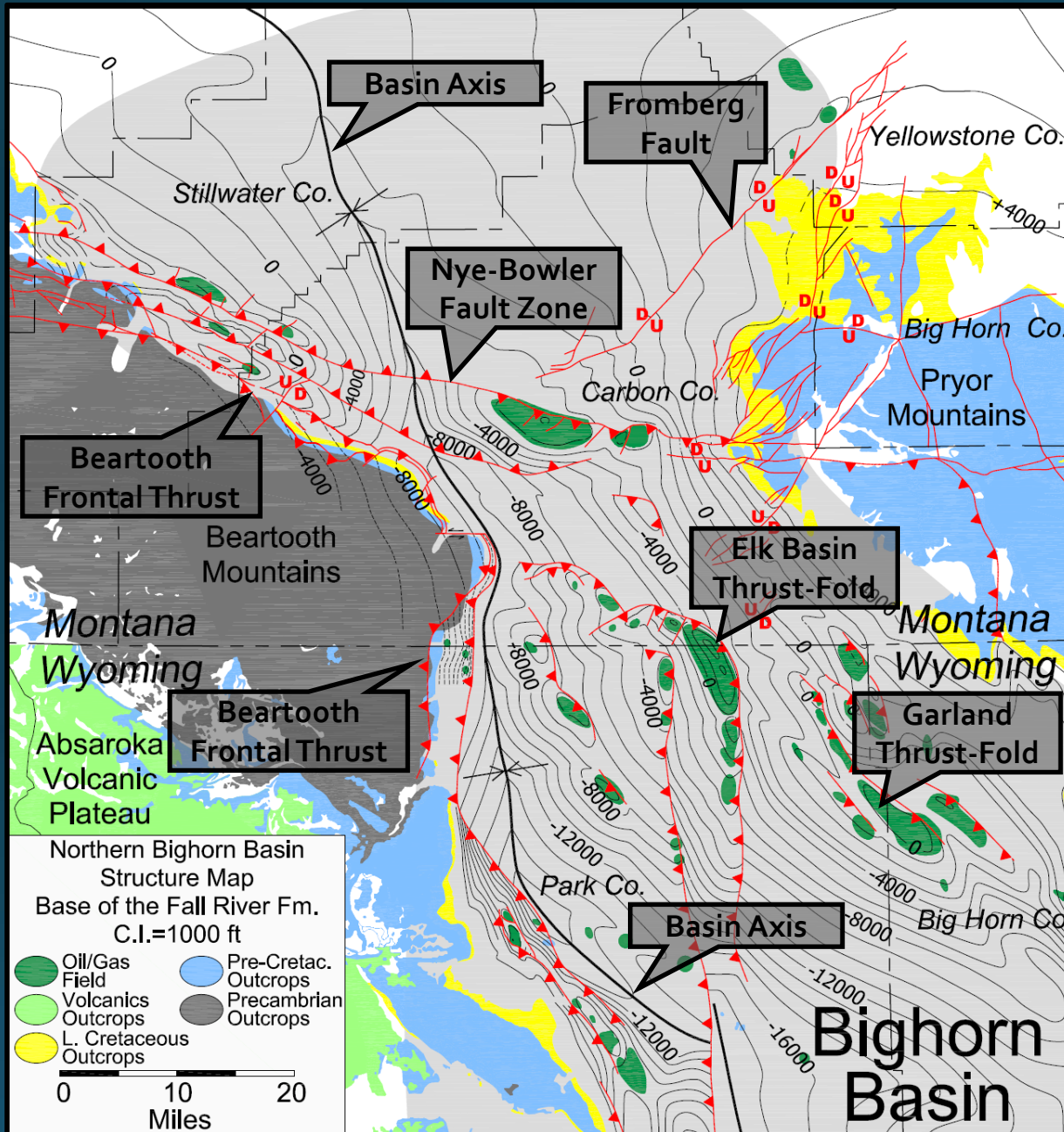
- The Thermopolis is subdivided into four subunits in ascending order: (A) the Dakota silt, (B) the Skull Creek shale, (C) the Muddy/Birdhead Ss., and (D) the Shell Creek shale
- Each of these units is, in turn, comprised of numerous coarsening-upward cycles of black shale and siltstone
- The Mowry Formation is comprised of black siliceous shale, bentonite beds, and thin siliceous cherty sandstones in the upper portion
- The Mowry is also comprised of numerous coarsening-upward cycles
- The sandstones in the Mowry are commonly assigned to the overlying Frontier Fm.

Type Log Fall River and Cloverly Fms. Bighorn Basin, MT



- The Cloverly Fm. is a non-marine unit comprised of three members
- The basal member is the Pryor Conglomerate, a chert-rich conglomeratic sandstone deposited in a fluvial environment
- The Pryor is hydrocarbon-bearing on structural closures related to the Nye-Bowler fault zone
- The Fall River Fm. unconformably overlies the Cloverly Fm.
- Sandstones and black/grey shales in the Fall River were deposited in fluvial to marine deposits that mark the initial Cretaceous marine transgression
- High-gravity oil and natural gas are present in the Greybull Sandstone units on most structural closures in the area

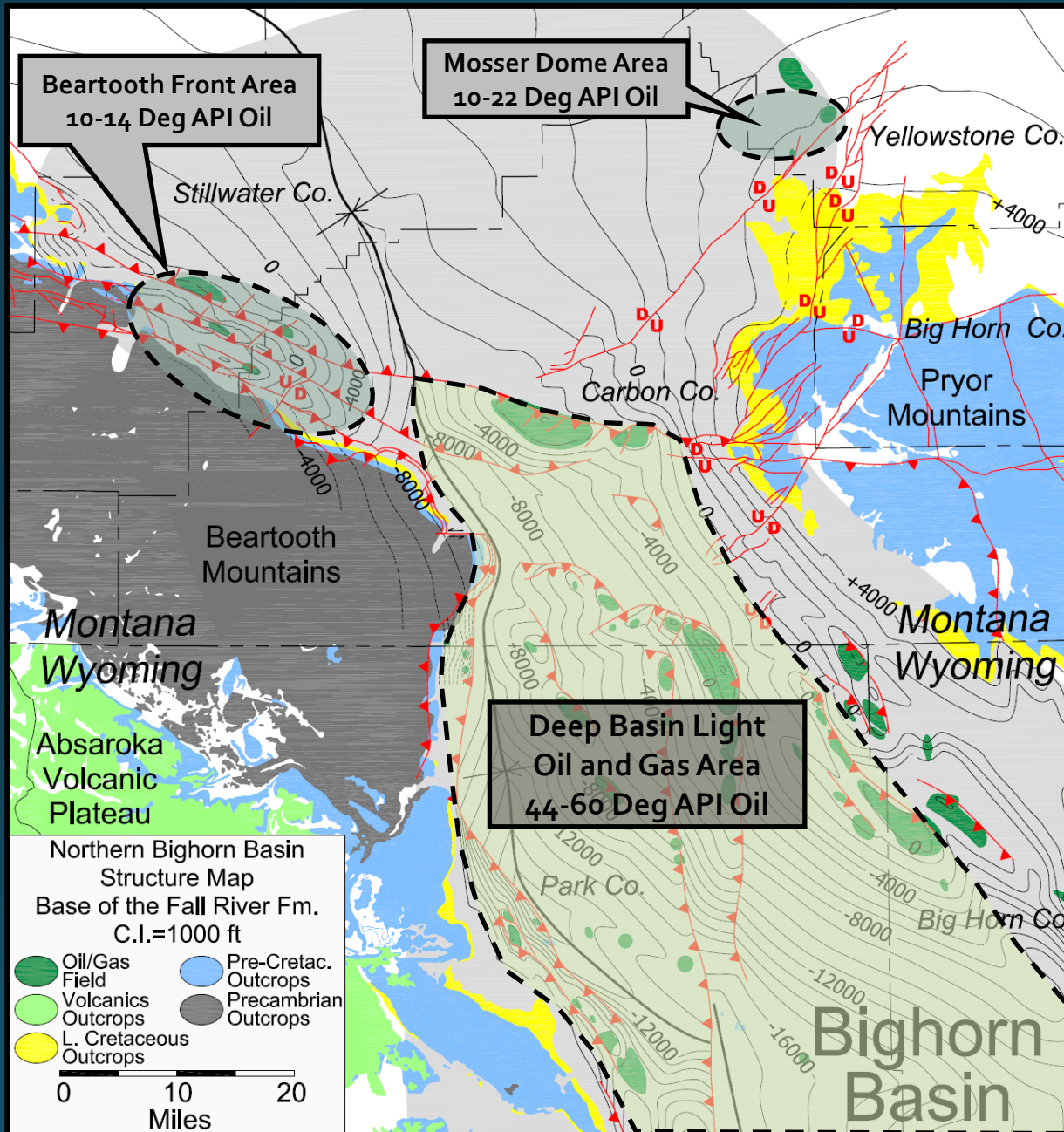
Structure Map: Base of the Fall River Fm. (L. Cretaceous) C.I.=1000 Feet



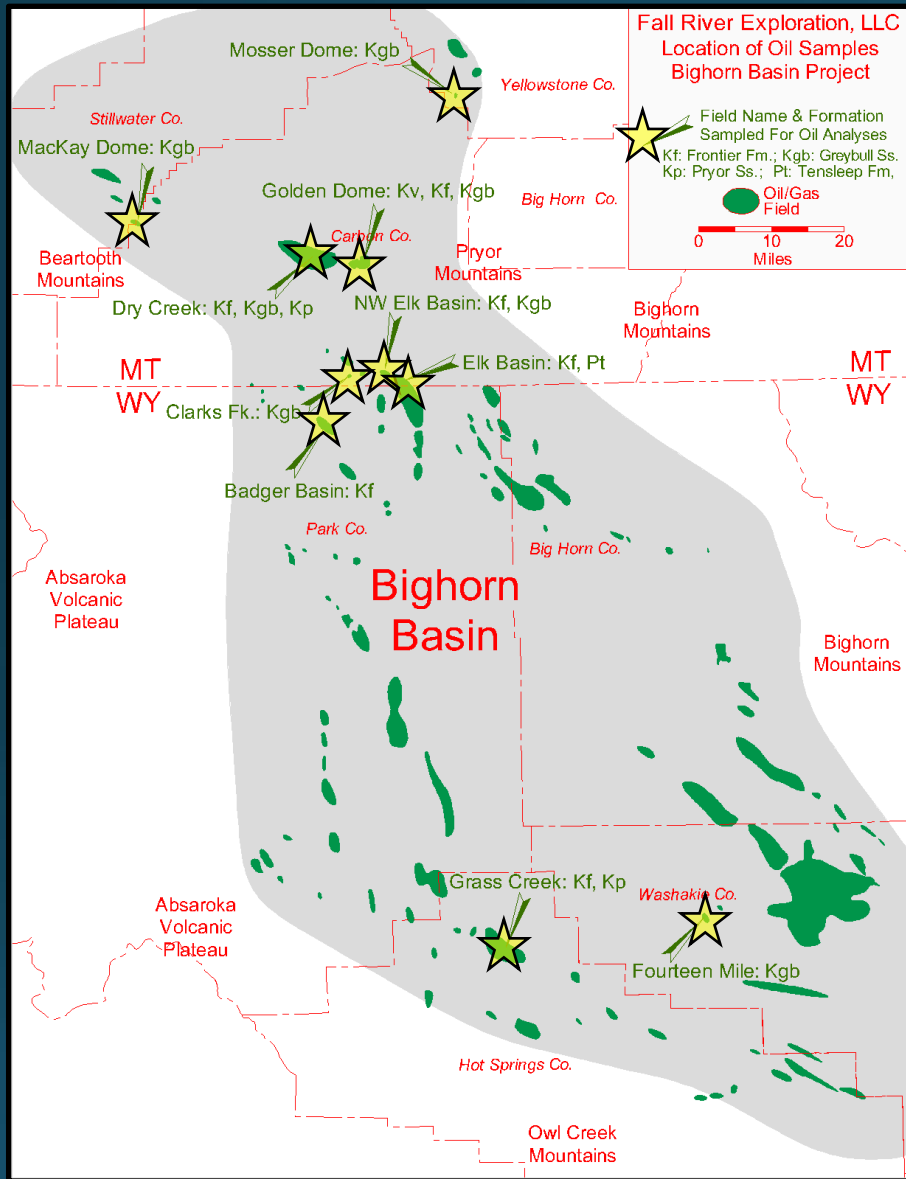
- Basin is strongly asymmetric
- West side of basin overthrust by Beartooth Mts.
- Smaller E-NE directed thrust-fold complexes at Elk Basin and Garland on east limb of basin
- Nye-Bowler fault zone at north end of basin is a complex structural feature with a variety of structural components
- Fromberg fault is dominant feature on relatively undeformed north end of basin

Oil Group Areas in Cretaceous Reservoirs

The Beartooth Front and Mosser Dome areas may have contained as much as 3 billion barrels of original oil in place in Lower Cretaceous Greybull and Pryor intervals. The now heavily degraded oil is typed as sourced from pre-Late Cretaceous marine carbonates, likely the Phosphoria Fm. In the Deep Basin Light Oil area, the Greybull and Pryor produce 50-60 Deg condensate while the Upper Cretaceous Frontier Ss. produces a 44 API degree oil. These light oils are geochemically distinct from each other, based upon gas chromatograph analysis, gravities, and color.

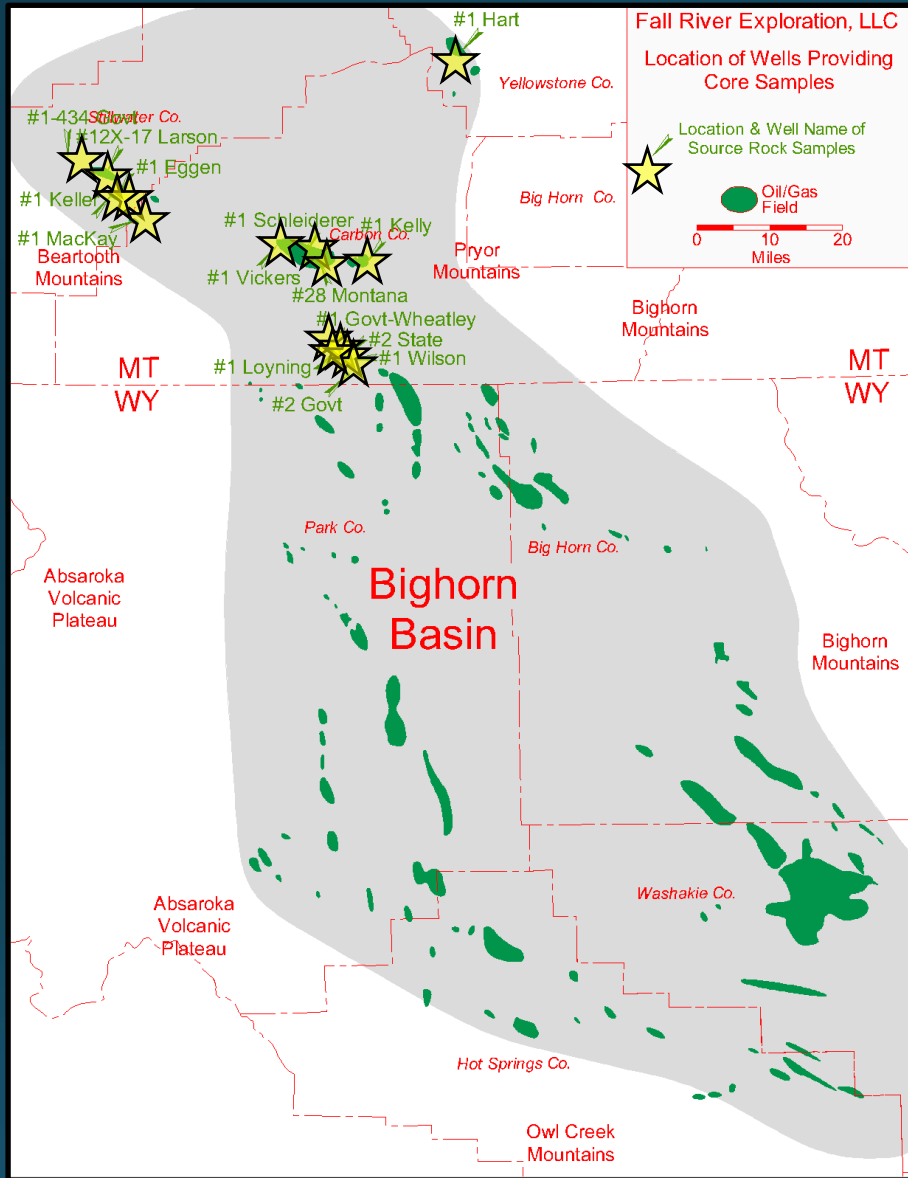


Oil Geochemistry in Bighorn Basin Cretaceous Reservoirs



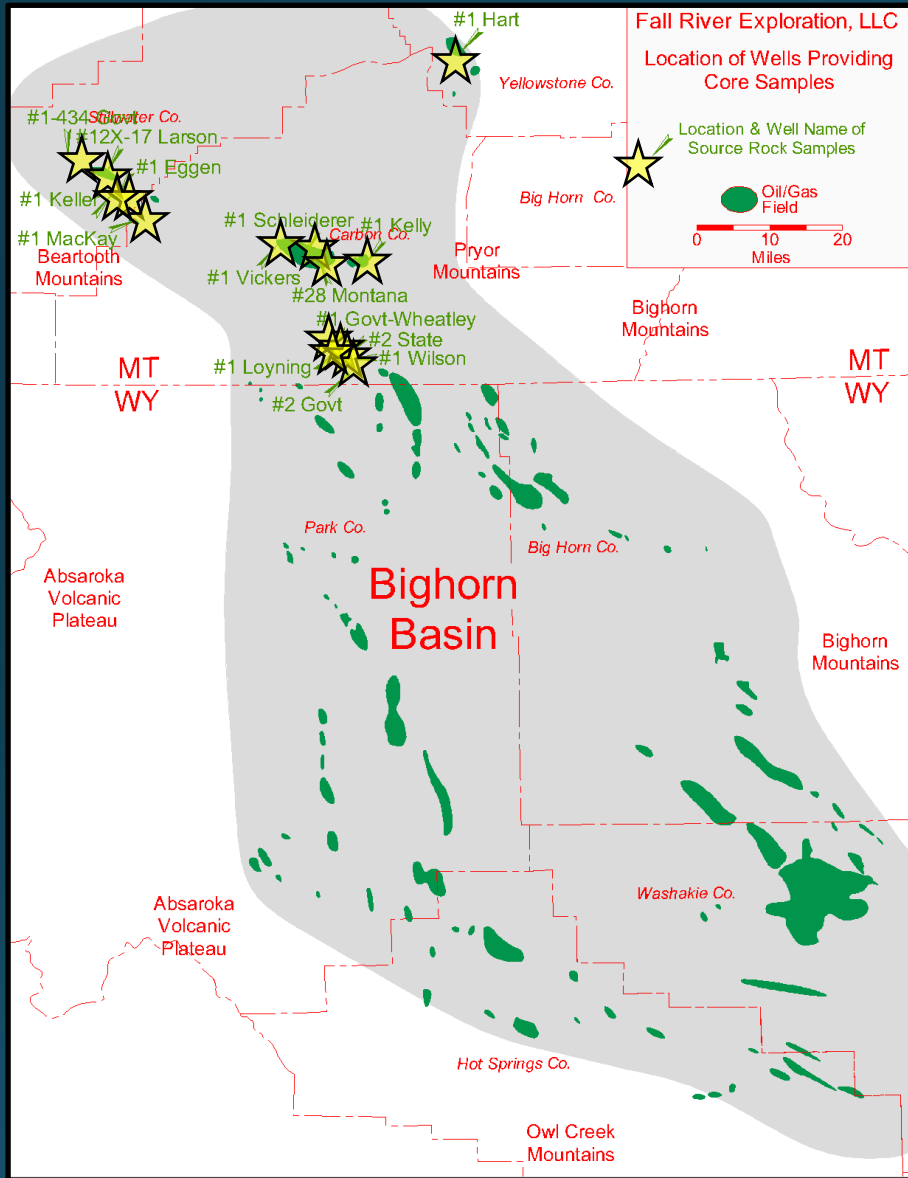
- Sixteen (16) oil samples taken across basin from Virgelle (U. Cret.), Frontier (U. Cret.) Greybull (L. Cret.) Pryor (L. Cret.), Tensleep (Pslv) producing wells
- Gas chromatography (GC) analysis performed
- Three (3) oil groups present, based on GC fingerprinting and API grouping
- Three groups are (A) Frontier-Virgelle oils; (B) Greybull-Pryor oils; (C) Tensleep-Phosphoria oils.
- The Cretaceous light oils were generated from shales while the Tensleep-Phosphoria oils were generated from marine carbonates (diagnostic biomarkers and high sulfur content)
- Two oils from southern portion of basin had lowest generation/expulsion temperatures (114-116 deg C) while the light Cretaceous oils from Carbon Co., MT had generation/expulsion temperatures of 125-130 deg C.

Source Rock Data in Thermopolis and Fall River Fms.



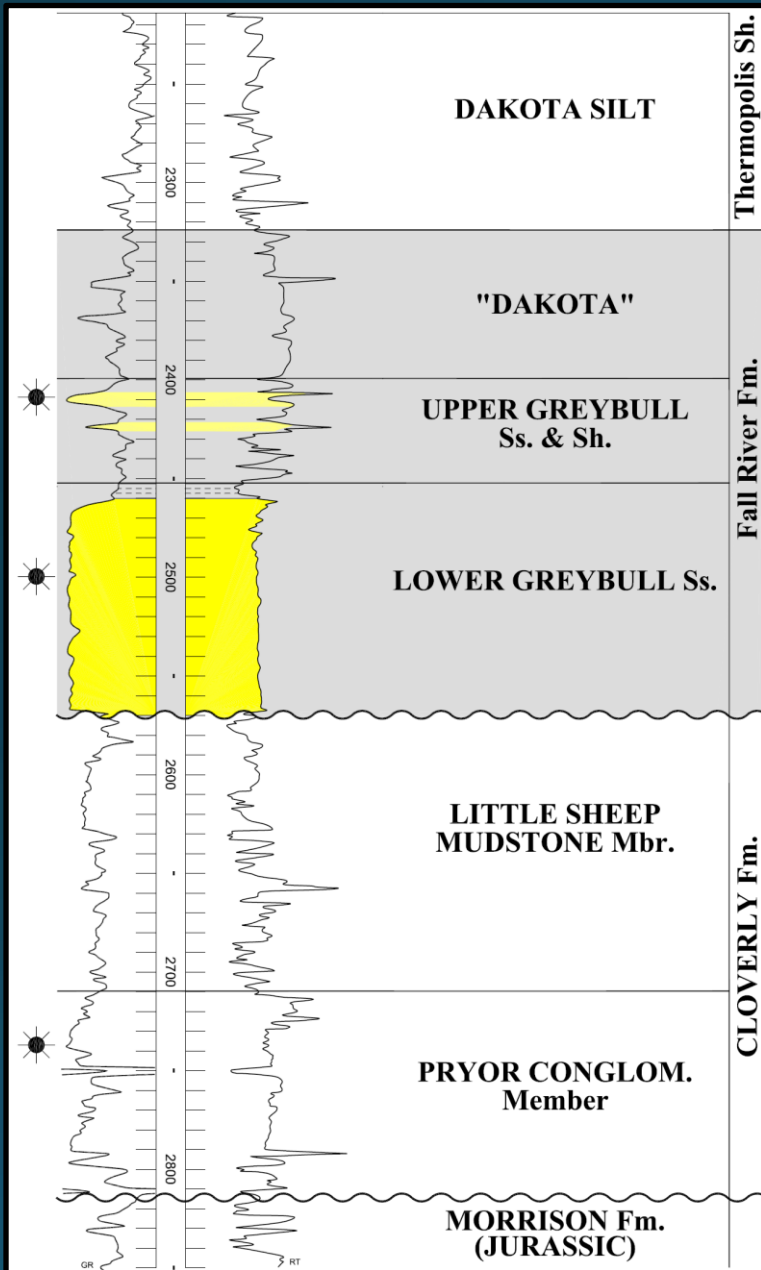
- Eighty-four (84) core chips from fifteen (wells) analyzed for TOC and Rock-Eval data
- Sample depths from 994-9826 feet
- Sample intervals in Skull Creek Mbr of the Thermopolis Shale and the Fall River Fm.
- Of 84 samples, 44 had total organic carbon values $> 1.0\%$ with the highest value at 4.6%; average TOC of the 44 samples is 1.7%
- The remaining 40 samples have TOC values of 0.5 to 1.0%; several have significant reduction of TOC values due to thermal maturation
- The bulk of the samples are in the early to middle oil generation window

Source Rock Data in Thermopolis and Fall River Fms.



- There is mixed oil and gas source potential in these Lower Cretaceous rocks
- Samples have an average hydrogen index of 149 with a high value of 321
- This kerogen type would likely generate a high-quality light oil, such as that seen in the Greybull Ss. and Pryor Conglomerate in the deeper Bighorn Basin
- The maturity range for the entire sample set is early mature at a depth of 990' to peak-oil generation at 9800' depth
- Conversion levels of kerogen to oil assessed between the least and most mature samples is estimated @ 50%
- There is good correlation between burial depth and thermal maturity

Source Rock Data in Thermopolis and Fall River Fms.

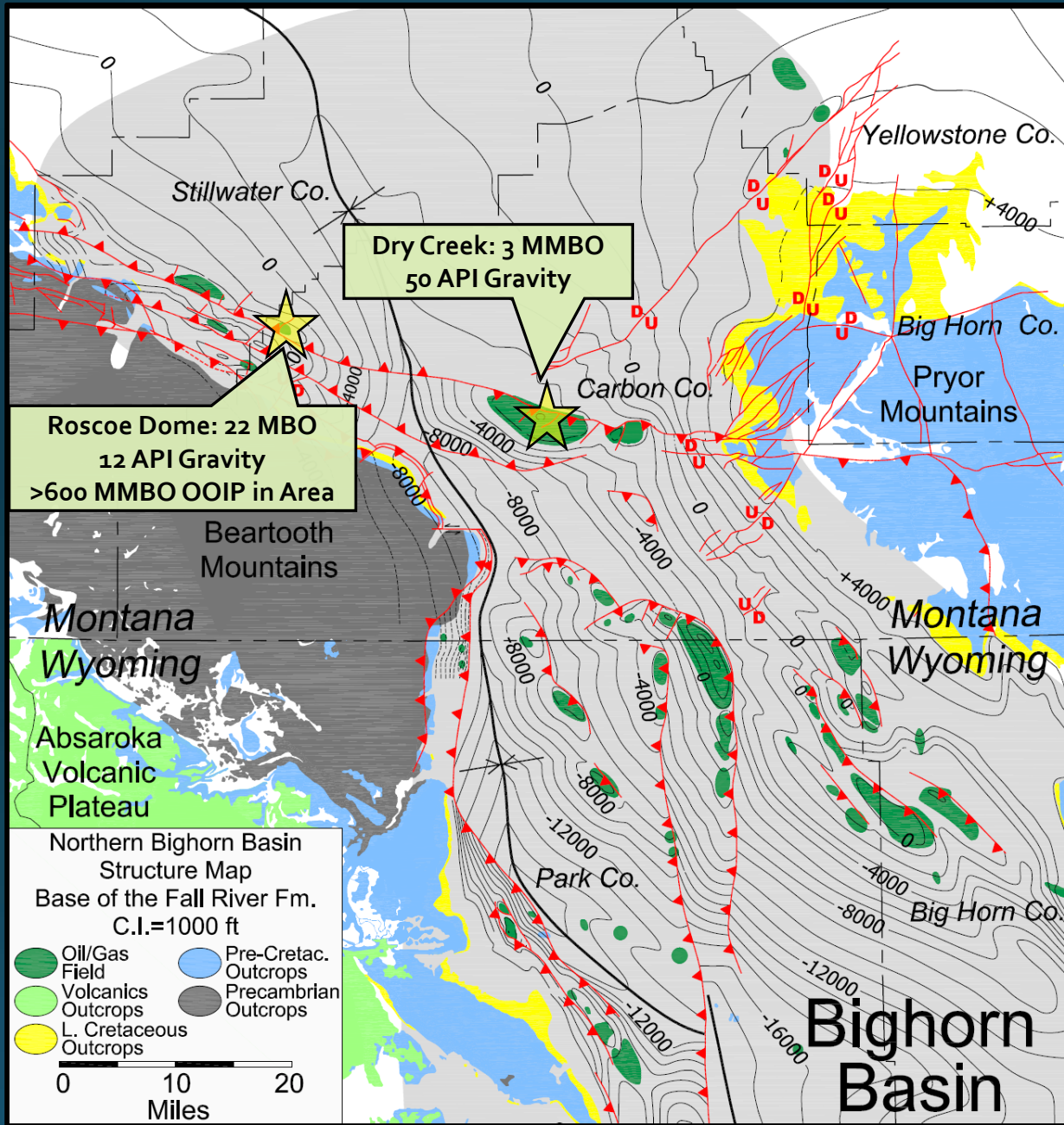


- Twelve (12) shale samples from four (4) wells
- Avg. TOC 1.93%
- Four (4) samples have TOC > 2.3%

- Twenty-six (26) shale samples from seven (7) wells
- Avg. TOC 1.1%
- Four (4) samples have TOC > 1.8%

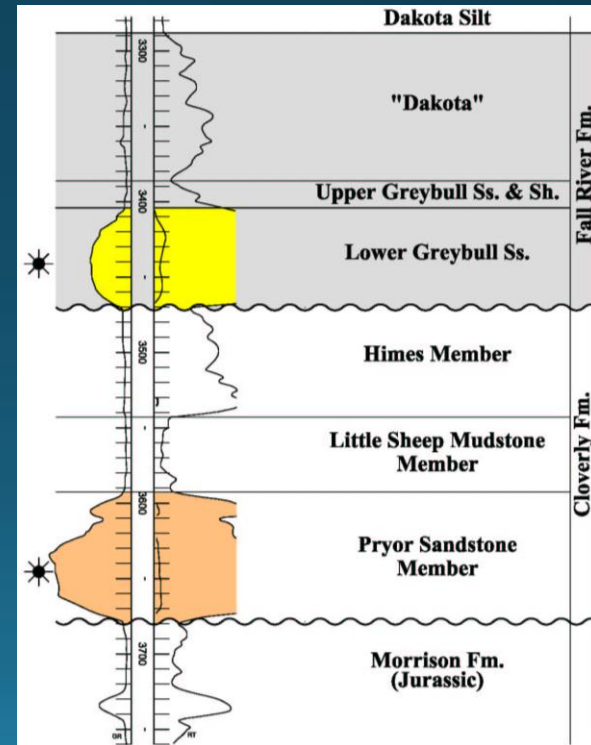
- Thirty-one (31) shale samples from eleven (11) wells
- Avg. TOC 1.9%
- Two (2) samples have TOC > 3.3%

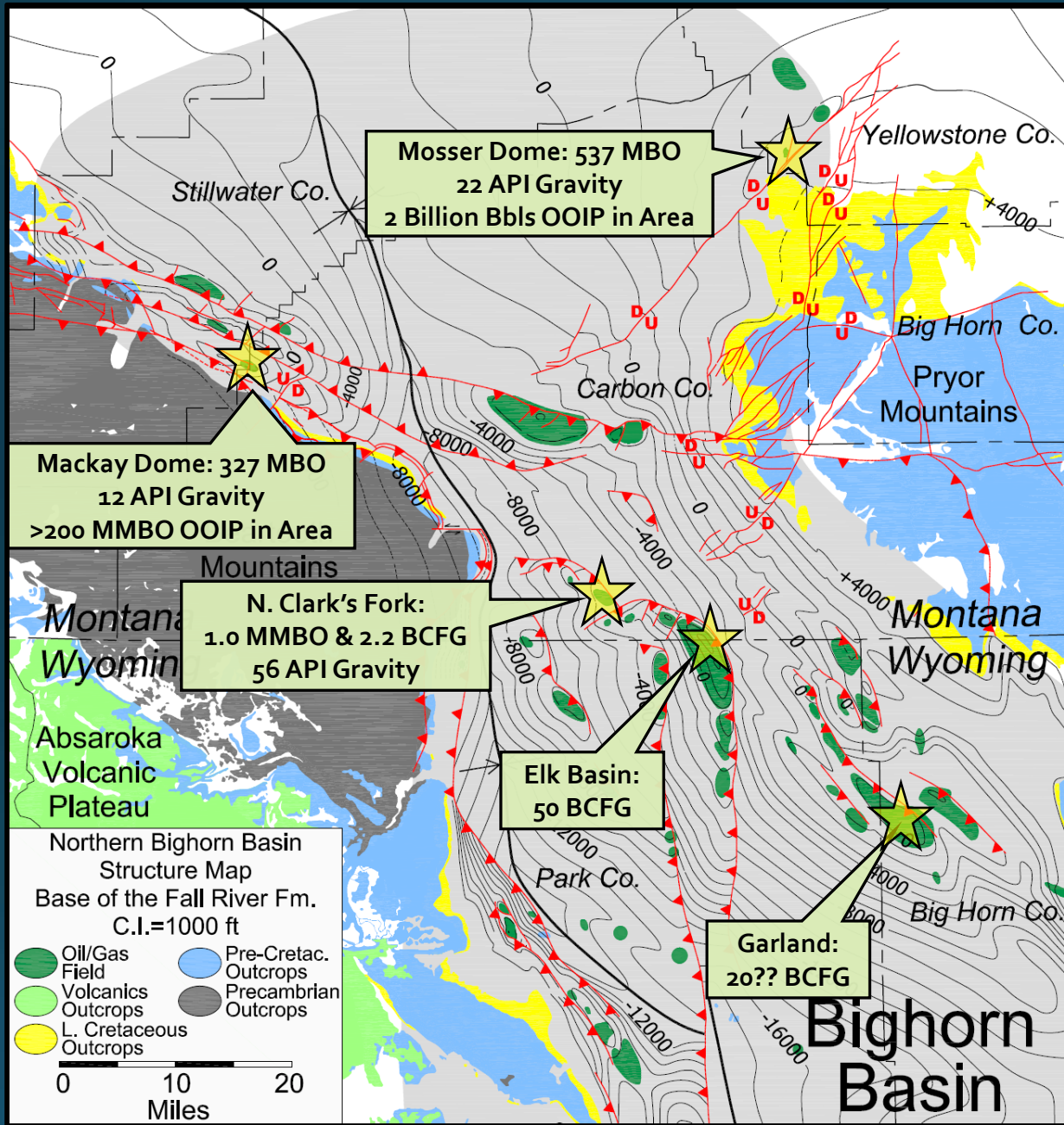
- Ten (10) shale samples from four (4) wells
- Avg. TOC 0.4%
- Two (2) samples have average TOC of 0.9% at an average depth of 8920 feet in the peak-oil generation window



Field Production Map Showing Production From Key Pryor Fields

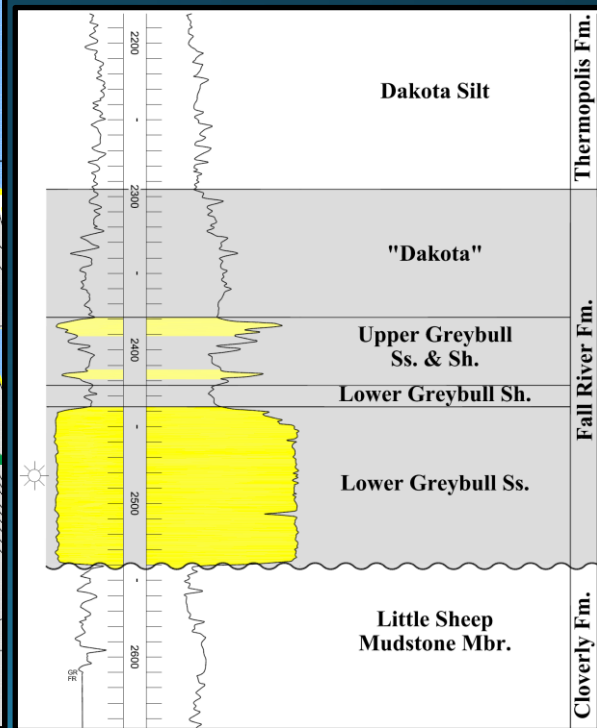
Type Log – Fall River Fm. & Cloverly Fms.
 Sec. 14, T6S R17E
 Stillwater Co., Montana

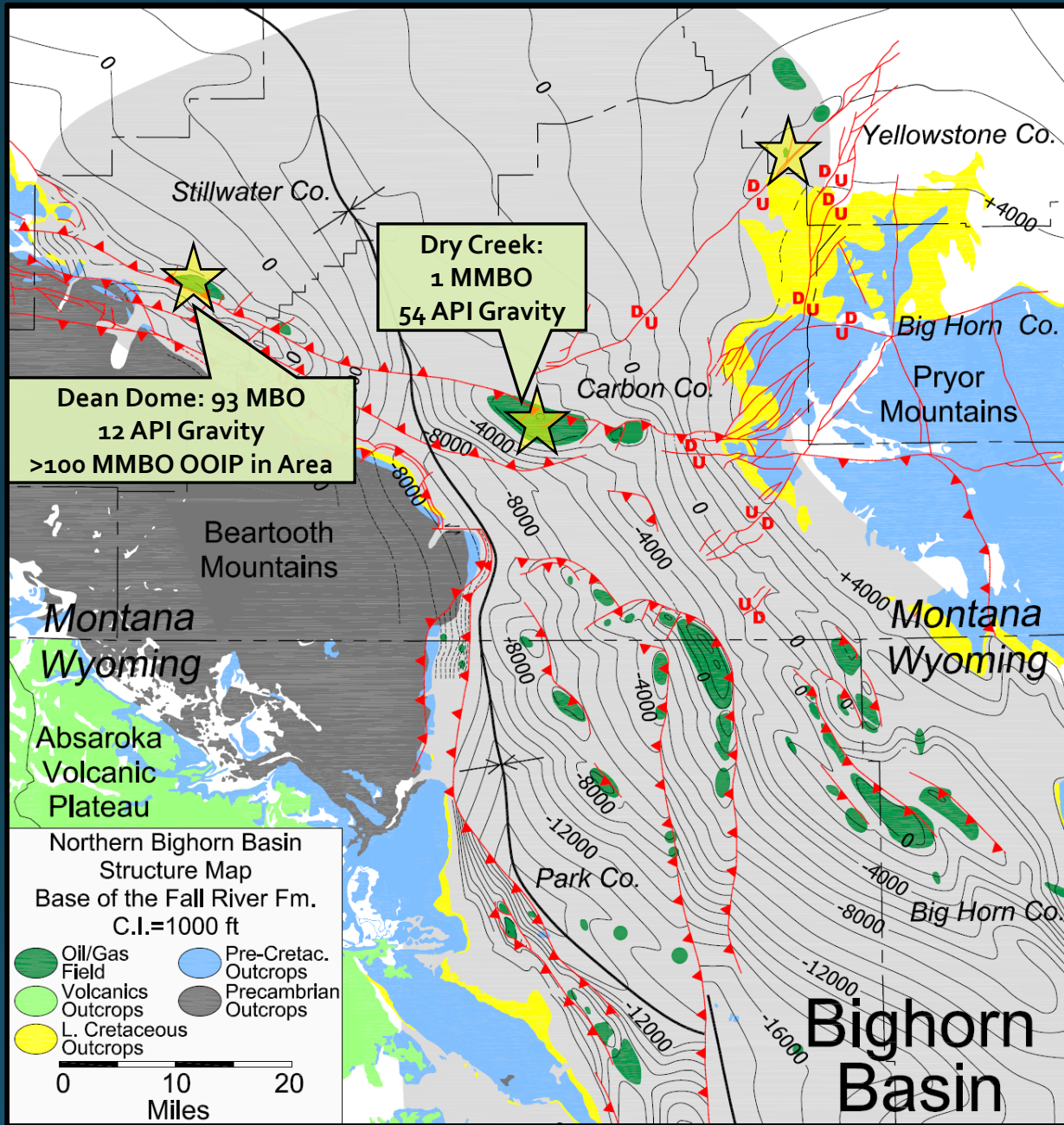




Field Production Map Showing Production From Key Lower Greybull Ss. Fields

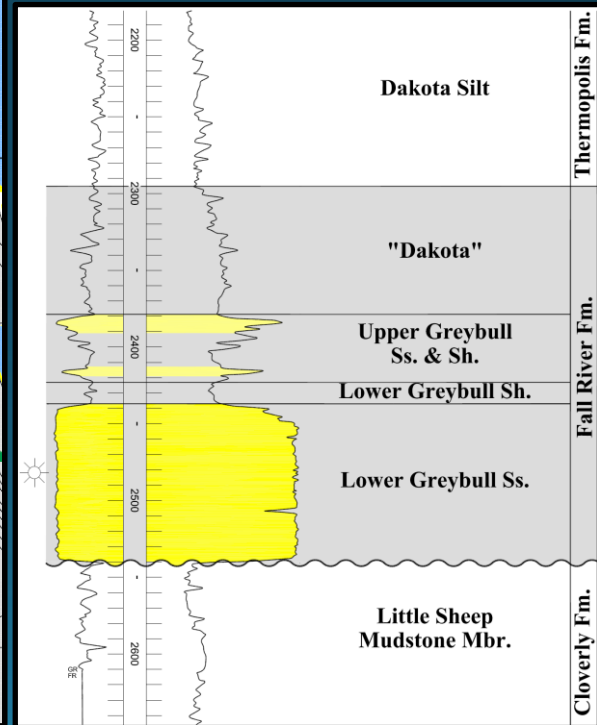
Type Log – Fall River Fm.
Sec. 35, T9S R23E
Carbon Co., Montana

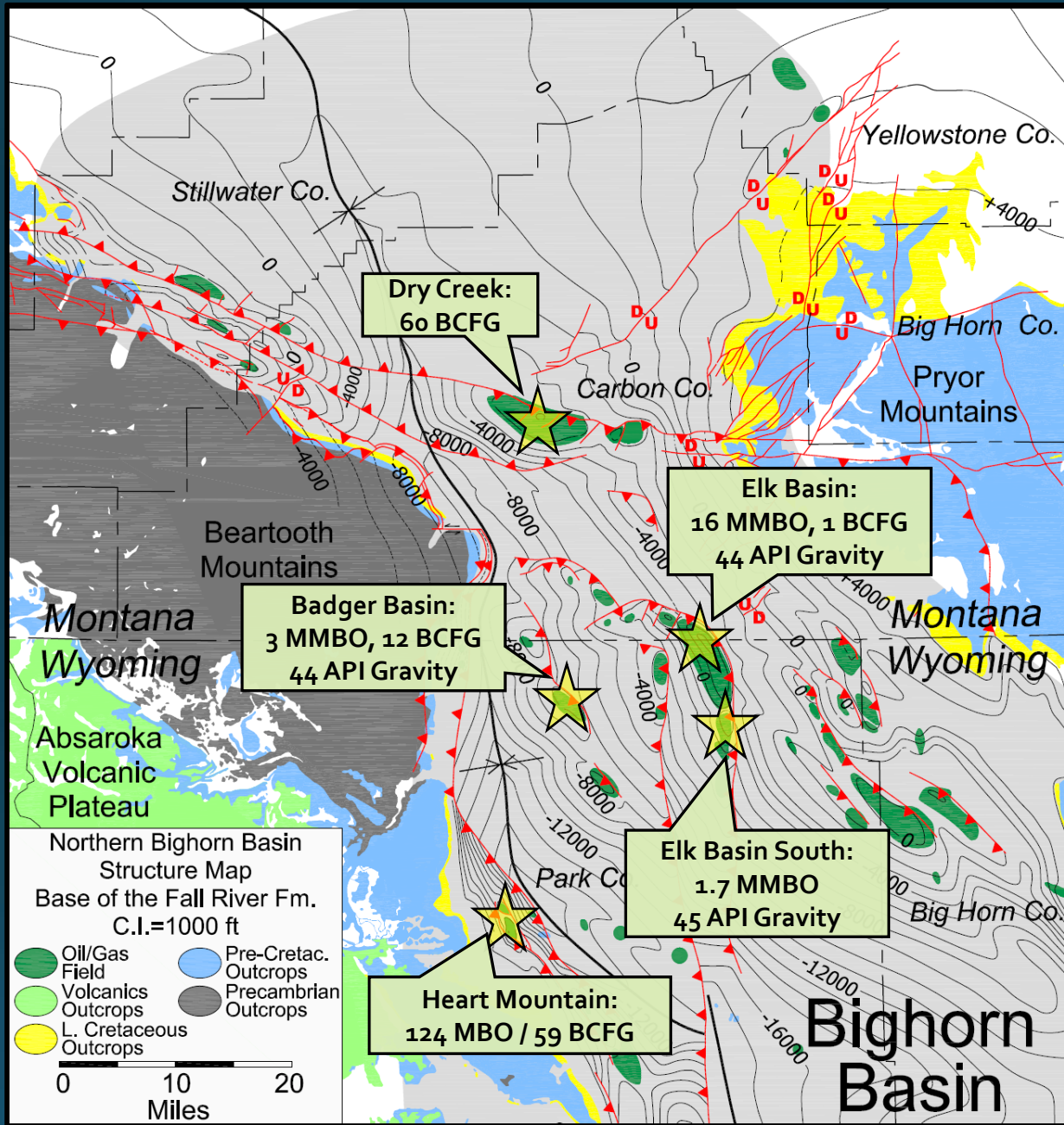




Field Production Map Showing Production From Key Upper Greybull Ss. Fields

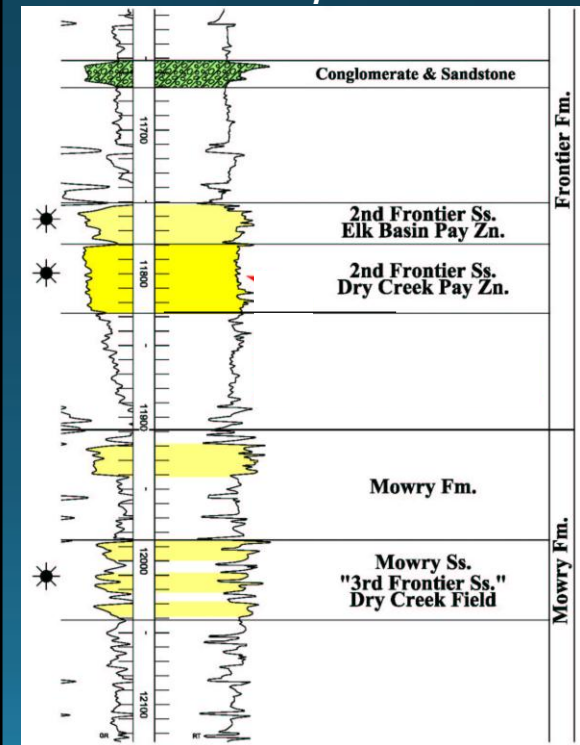
Type Log – Fall River Fm.
Sec. 35, T9S R23E
Carbon Co., Montana



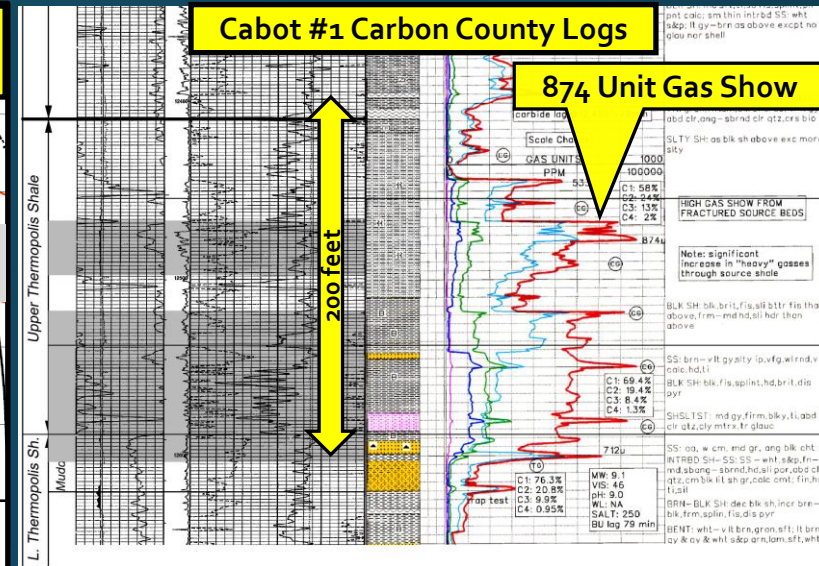
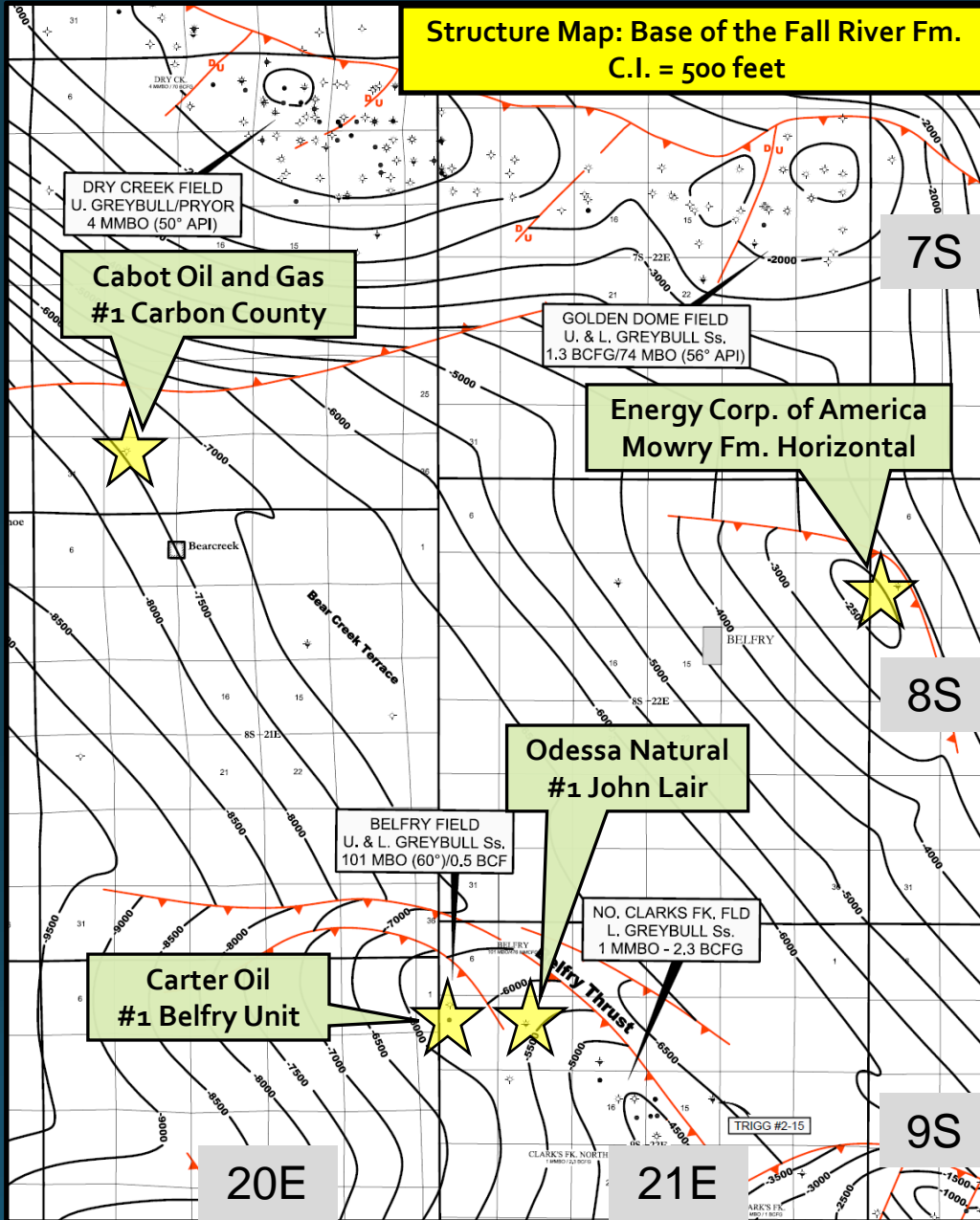


Field Production Map Showing Production From Key Frontier Ss. Fields

Type Log – Frontier Fm.
Sec. 32, T7S R21E
Carbon Co., Montana



Significant Gas Shows from the Thermopolis Shale in Carbon Co., MT



- The #1 Carbon County well in Sec. 32, T7S R20E had a 874-unit gas show on mud log in the Upper Thermopolis Shale
- The #1 Belfry Unit well in Sec. 7, T8S R22E flowed 110 MCFGPD on DST from the Upper Thermopolis Shale, had shut-in pressure of 4780#, pressure gradient of 0.51PSI/ft
- The #1 Lair well flowed 108 MCFGPD from Thermopolis on DST, recovered highly gas- and oil-cut mud in sample chamber
- Energy Corp of America has recently drilled a horizontal well (2014) in the Mowry Fm (Upper Thermopolis?) in Sec. 8, T8s R23E, no information available

Conclusions

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Thanks go to the following individuals for their work, ideas or insights:

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Also, thanks to my family for their support and patience over my career and my many days in the field in the Bighorn Basin.