Continued Geological and Geochemical Evaluation of the Tyler Formation: a Dual Petroleum System

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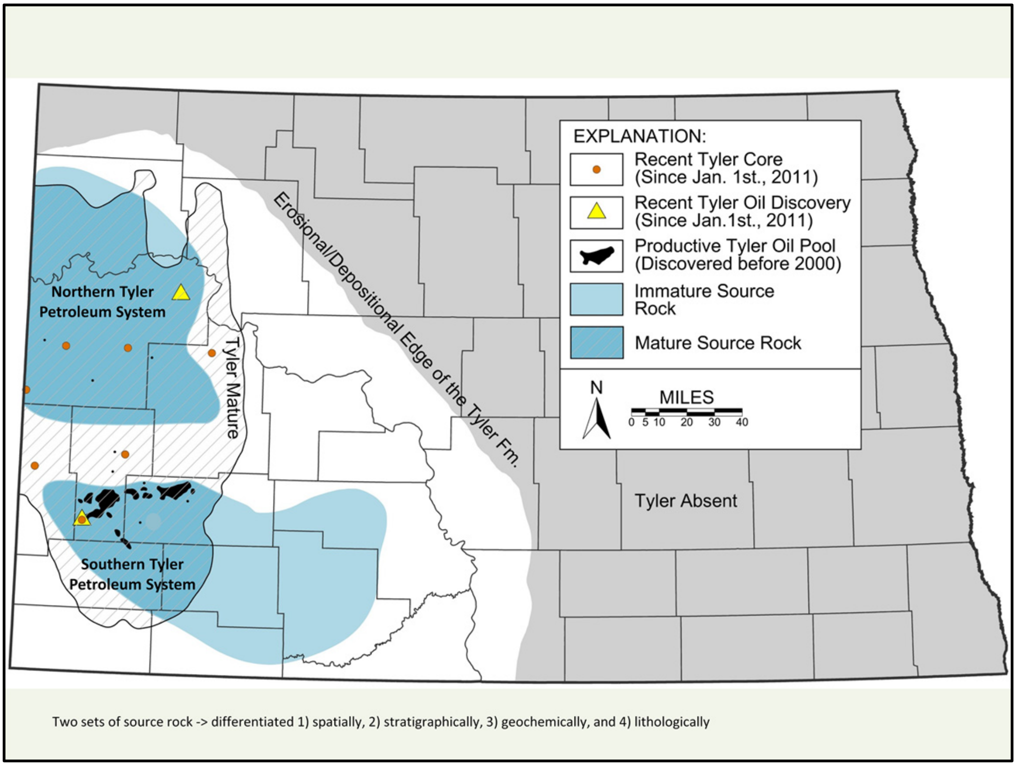
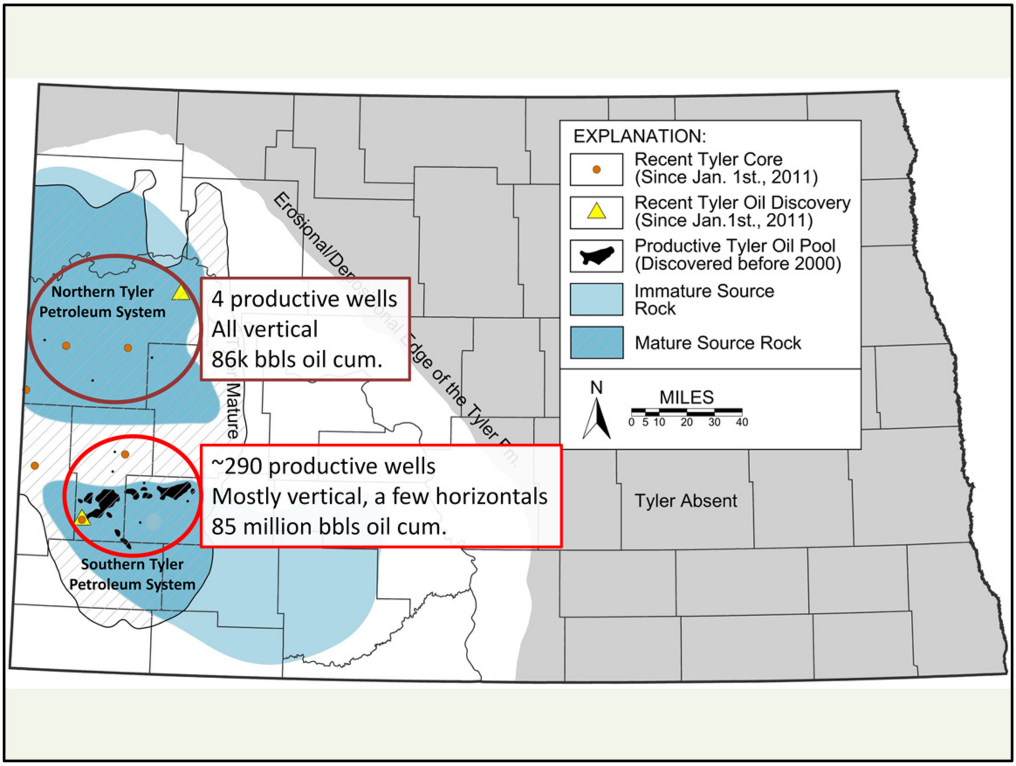
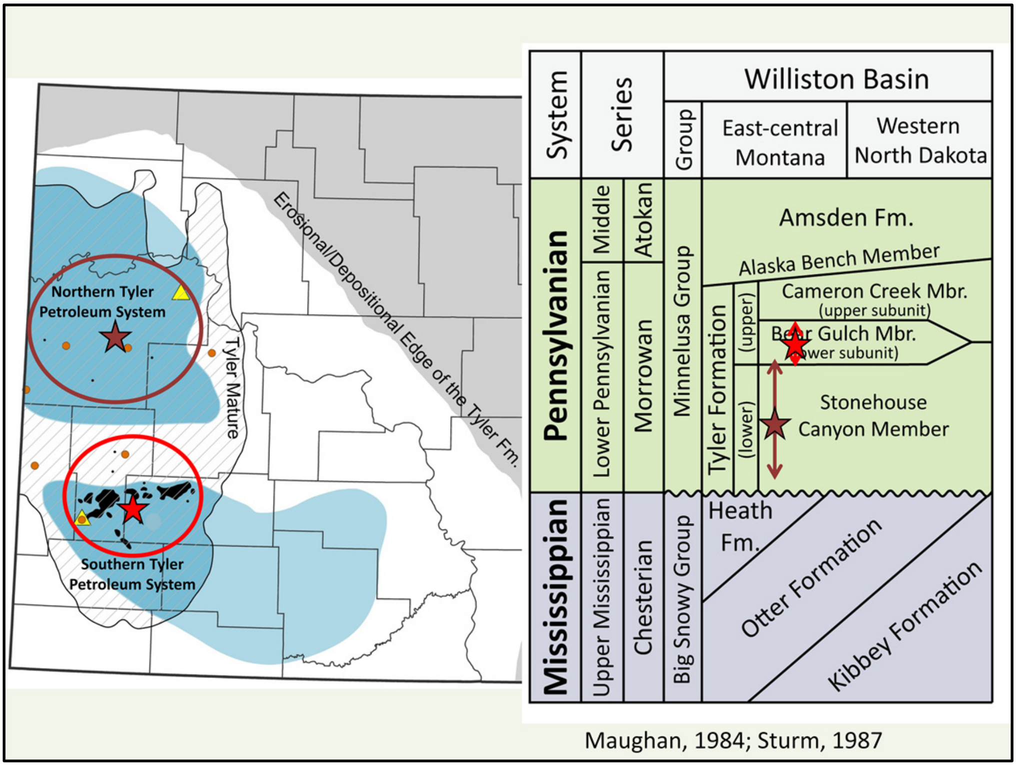


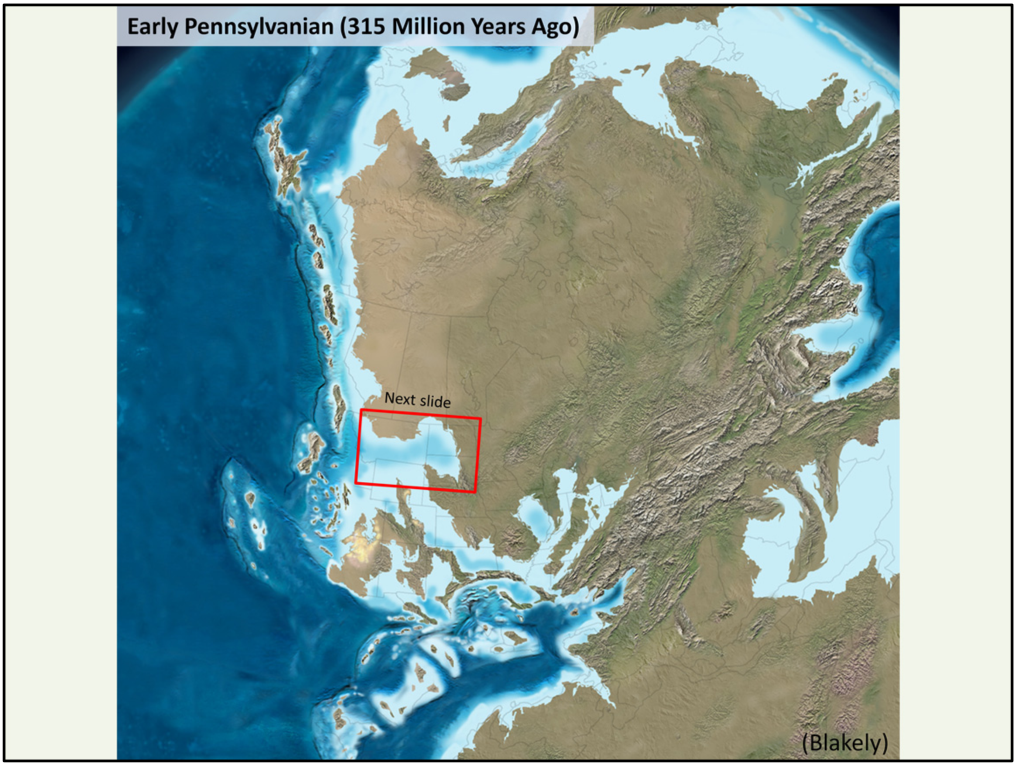
The Tyler Formation contains two separate petroleum systems where two sets of unique source rock can be differentiated spatially, stratigraphically, geochemically, and lithologically. These two source rock sets and their respective stratigraphic sequences are the focus of this presentation.



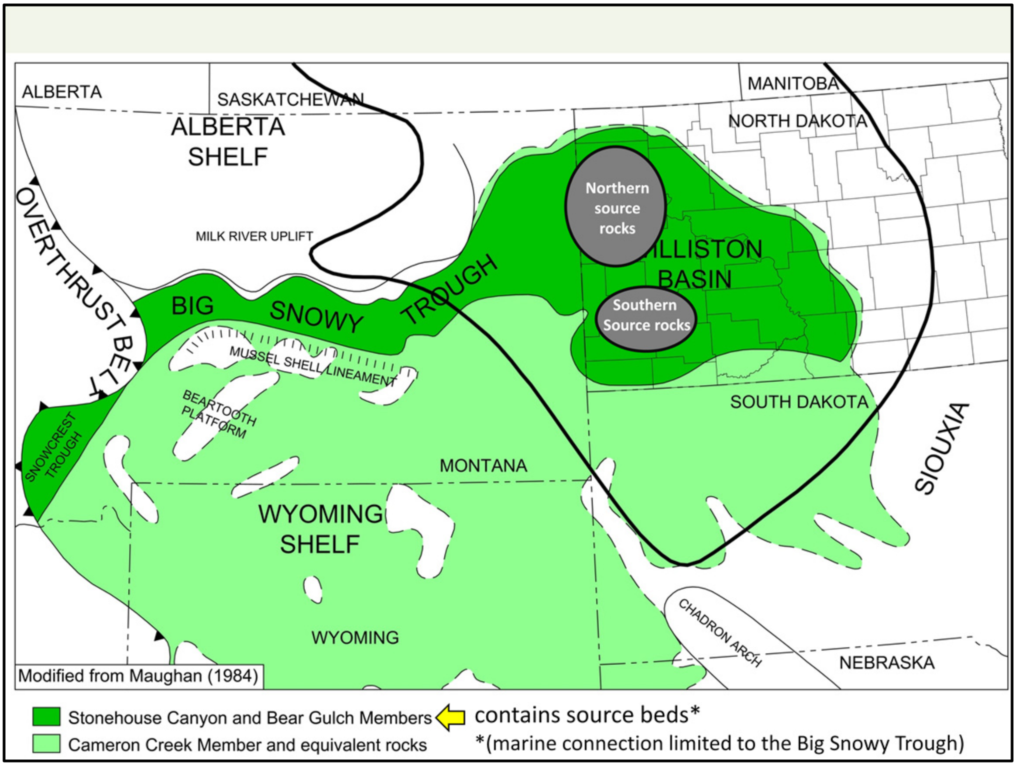
The northern petroleum system appears to lack significant quantities of conventional reservoir, which is why there have only been four productive wells in the system to date. The southern petroleum system contains oil productive bar-type and channel sandstone reservoirs that have been successfully explored and developed over the past 50+ years.



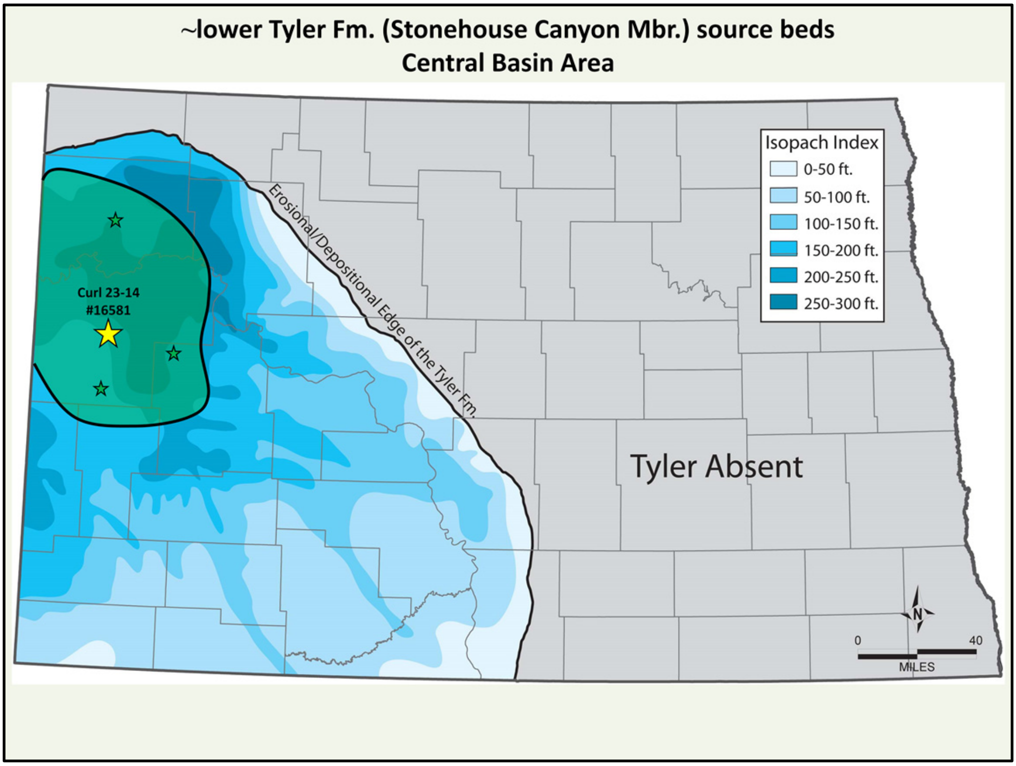
The Tyler Formation within southwestern North Dakota has previously been split informally by Sturm (1987) into upper and lower units, which may correlate with the Cameron Creek, Bear Gulch, and Stonehouse Canyon Members proposed by Maughan (1984) as displayed above. As reviewed in this presentation, the Northern Tyler Petroleum System appears to contain source rock within the middle to lower portion of the Tyler section whereas the Southern Tyler Petroleum System primarily contains source rock in the upper portion of the section.



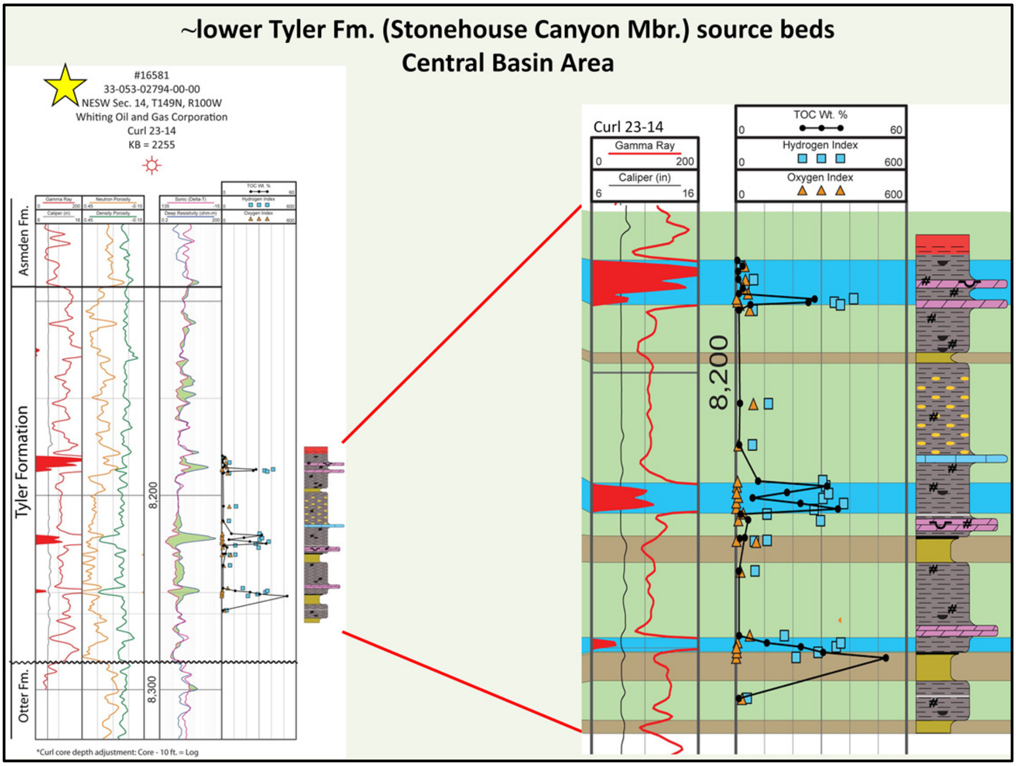
The displayed paleogeographic map depicts the Tyler Formation's regional depositional setting. The Tyler Formation was deposited during the Early Pennsylvanian, a time period that experienced substantial glaciation. Numerous glacial ice buildups and melts caused drastic sea level fluctuations that in turn formed cyclic depositional sequences within Pennsylvanian aged units, such as the Tyler Formation within the Williston Basin.



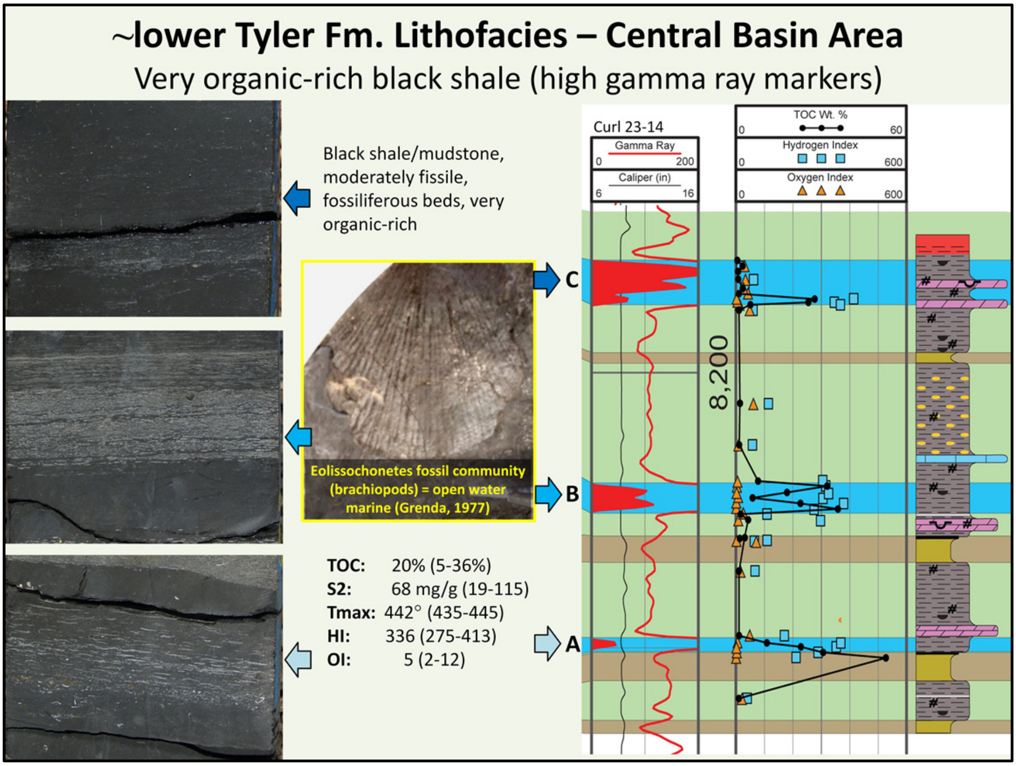
Based on the current extent of the Stonehouse Canyon and Bear Gulch members as interpreted by Maughan (1984), the Williston Basin's westward connection to the open ocean was limited to the Big Snowy Trough. This spatially limited connection to the open ocean may have lead to periodic restricted, anoxic water conditions that allowed for the accumulation and preservation of substantial amounts of organic carbon which formed the present day active source beds within both of the Tyler petroleum systems.



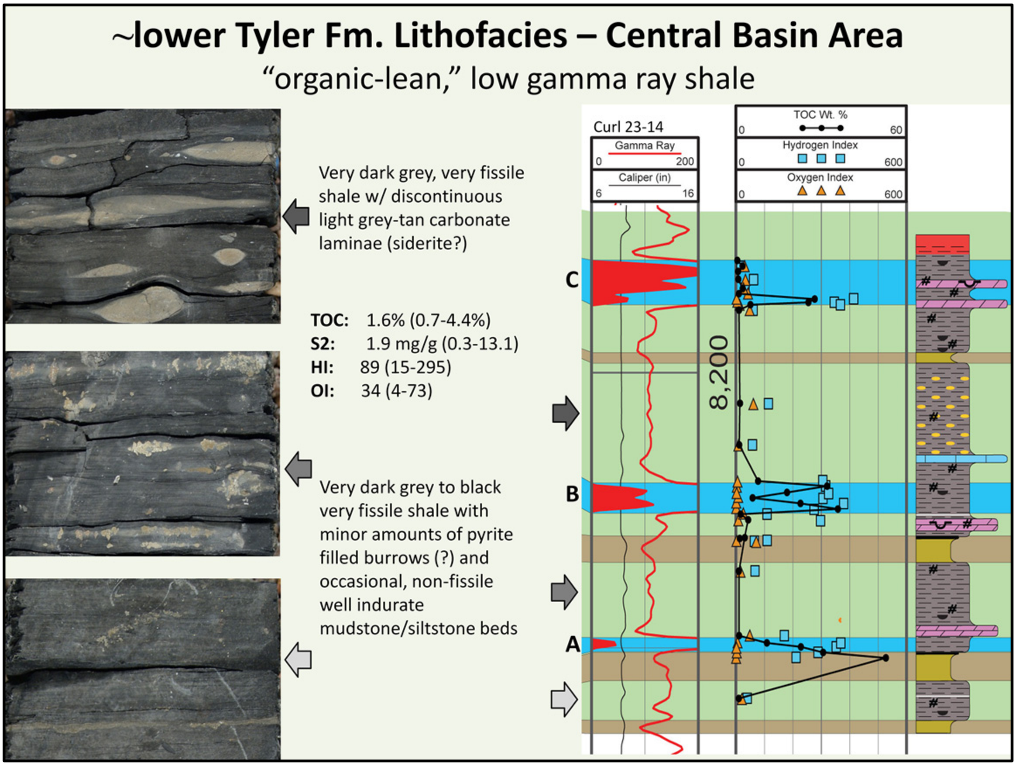
The Tyler core from Whiting's Curl 23-14 (yellow star) is currently the longest, most complete core of the Tyler Formation in the central, deeper portions of the Williston Basin (the green shaded area represents the approximate extent of the primary source beds in the Tyler's northern petroleum system).



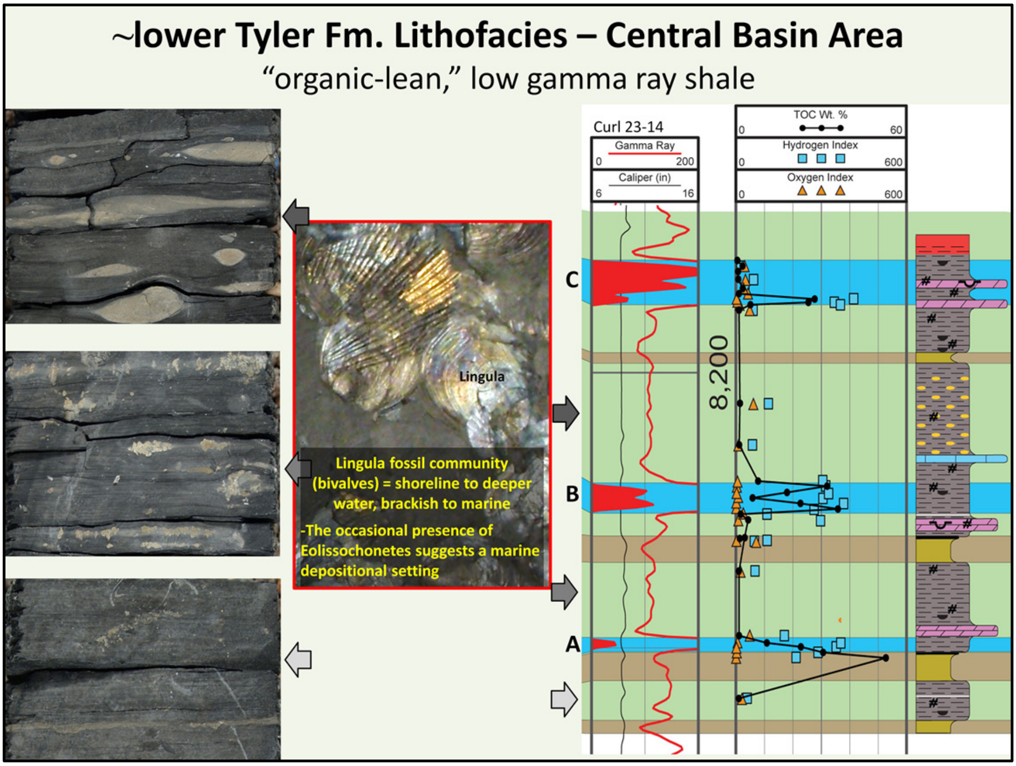
Most of the Curl's Tyler section consists of dark grey to black shale with several interbedded greenish mudstone and some thin, finely crystalline dolomite beds. As you can see from the plotted geochemical data, TOC values (black dots on a 0-60 wt. % scale) are extremely high from the shale intervals that yield high gamma ray signatures. These high gamma ray shales yield TOC values of 5-35 wt. % as well as S2 values and hydrogen-oxygen index ratio's that classify as excellent quality, oil-prone source rock.



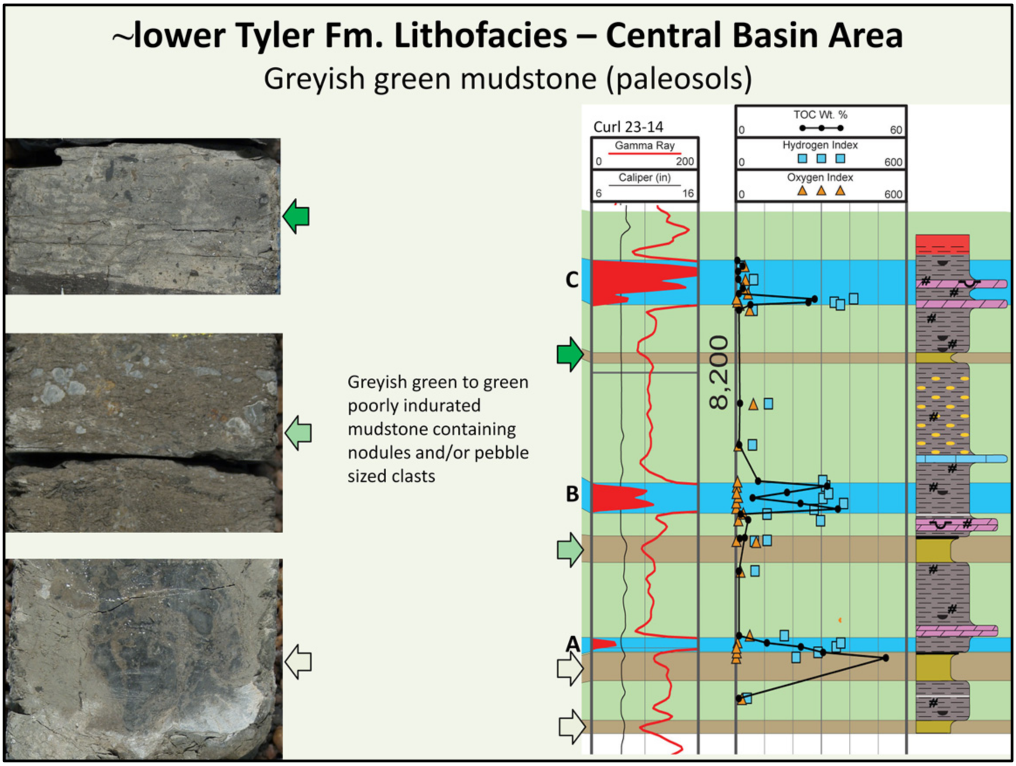
In core, these very organic-rich, high-gamma ray intervals consist of black shale that is moderately fissile with some lighter colored fossiliferous beds. Observed brachiopod fossils appear to be Eolissochonetes, a fossil species that Grenda (1977) interpreted to indicate an open water marine setting. Given the extremely high TOC content, these shale intervals were likely deposited within an oxygen depleted, restricted marine water setting.



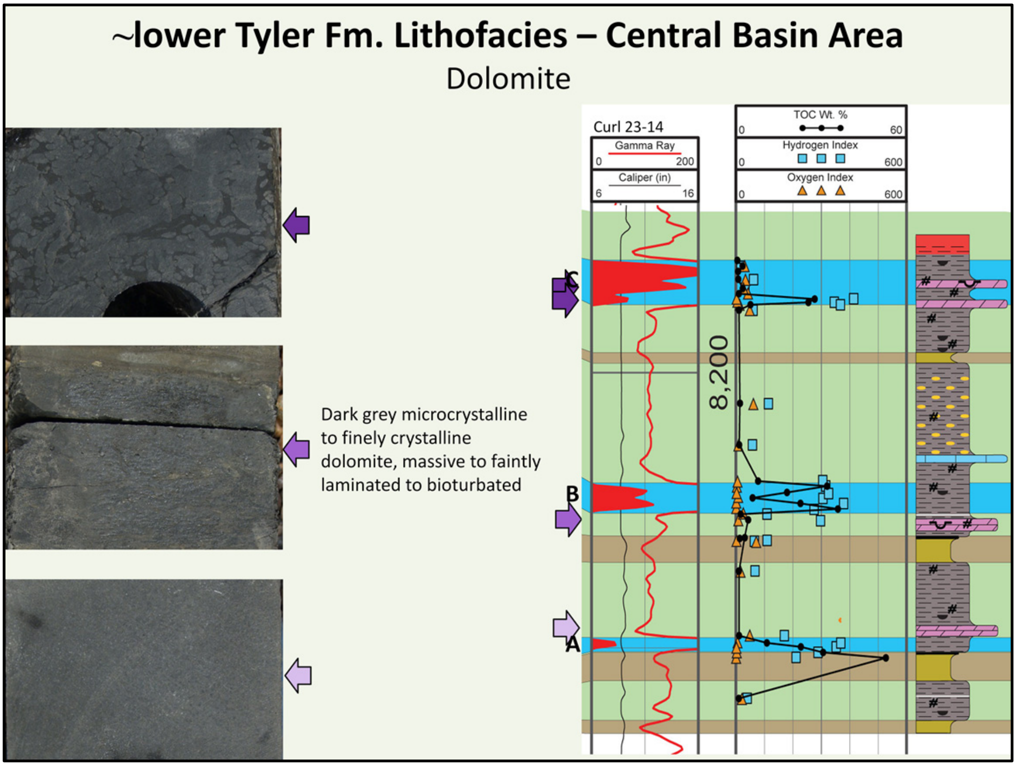
The intervals below and in between the organic-rich, high-gamma ray shale is also made up mostly of very dark grey to black shale which correlates with only a low/moderate gamma ray signature. This moderate gamma ray shale is very fissile, significantly more fissile than the high gamma ray shale, and contains minor amounts of pyrite filled burrows. One section of the lower gamma ray shale consists in part of lenses/discontinuous laminations of siderite (?), an iron-based carbonate mineral. While moderate gamma ray shale intervals are very darkly colored, visually appearing to be potentially great source rock, their TOC content and corresponding S2 and Hydrogen Index values are significantly lower that the high gamma ray shale.



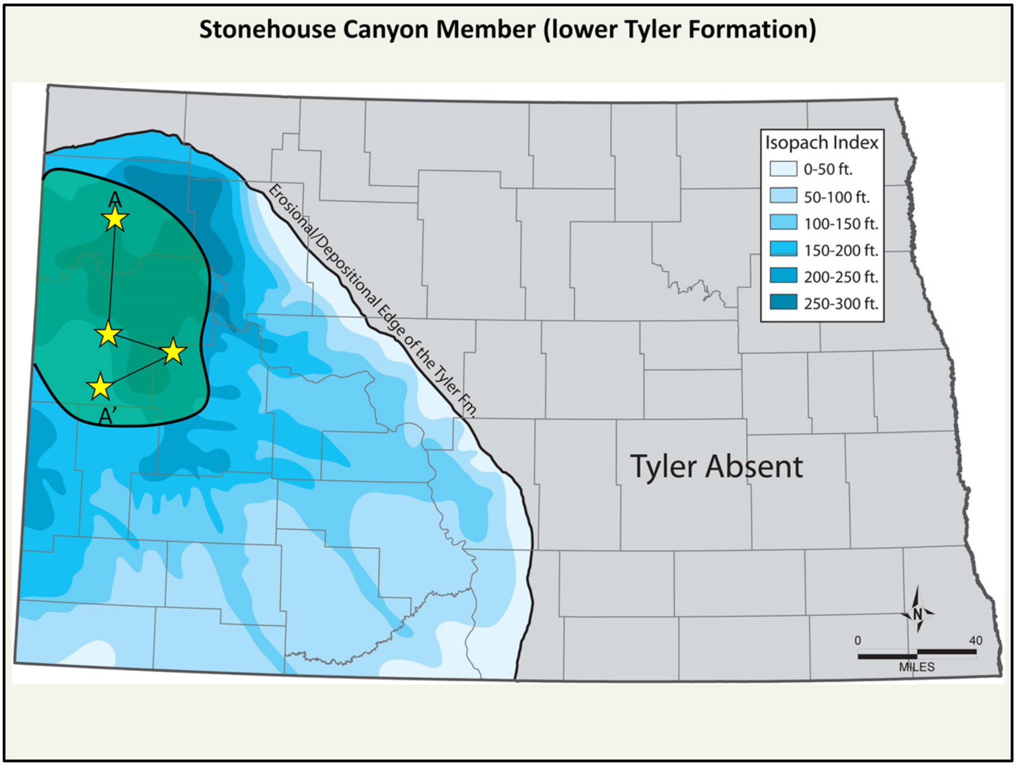
Bivalve fossils within the low gamma ray shale appear to correlate with Grenda's (1977) Lingula fossil community, which Grenda interpreted to indicate a shoreline to deeper water, brackish to marine depositional setting. The minor bioturbation, and occasional presence of Eolissochonetes, suggests an oxygenated, non-restricted (open) marine water setting.



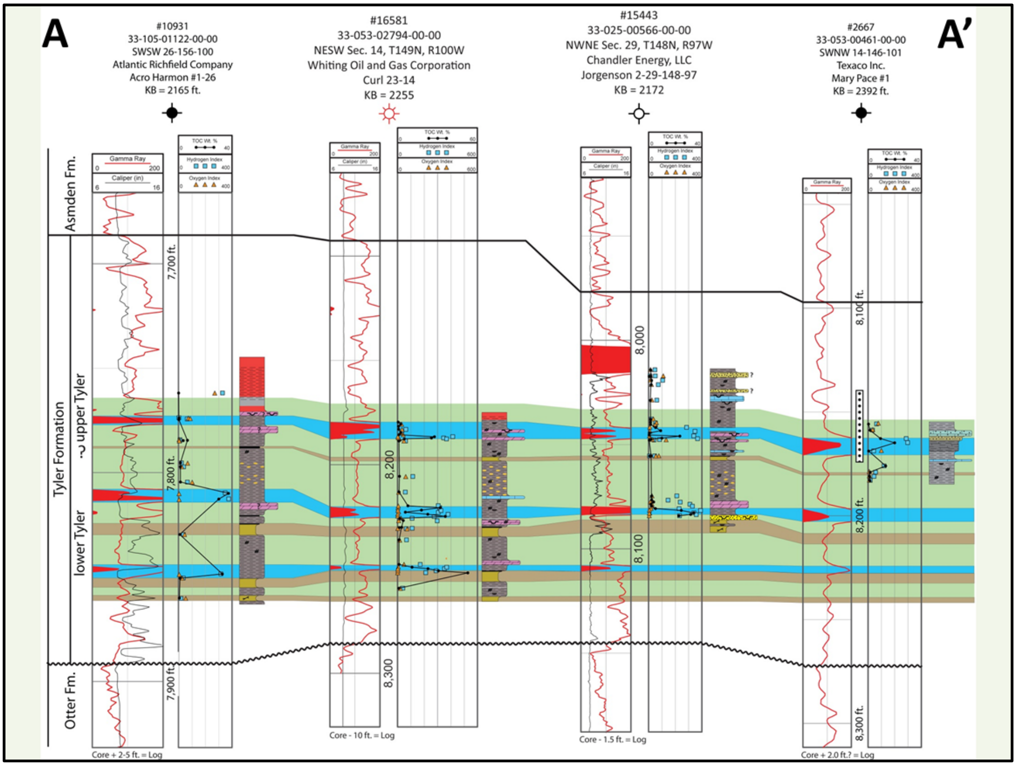
There are also several greenish colored mudstone intervals that contain nodules and/or pebble sized clasts. These mudstones likely represent paleosols (buried soil horizons) that formed through periodic terrestrial exposures during regressions of the Tyler seaway. These mudstone intervals are organic-lean and tend to be very poorly indurated.



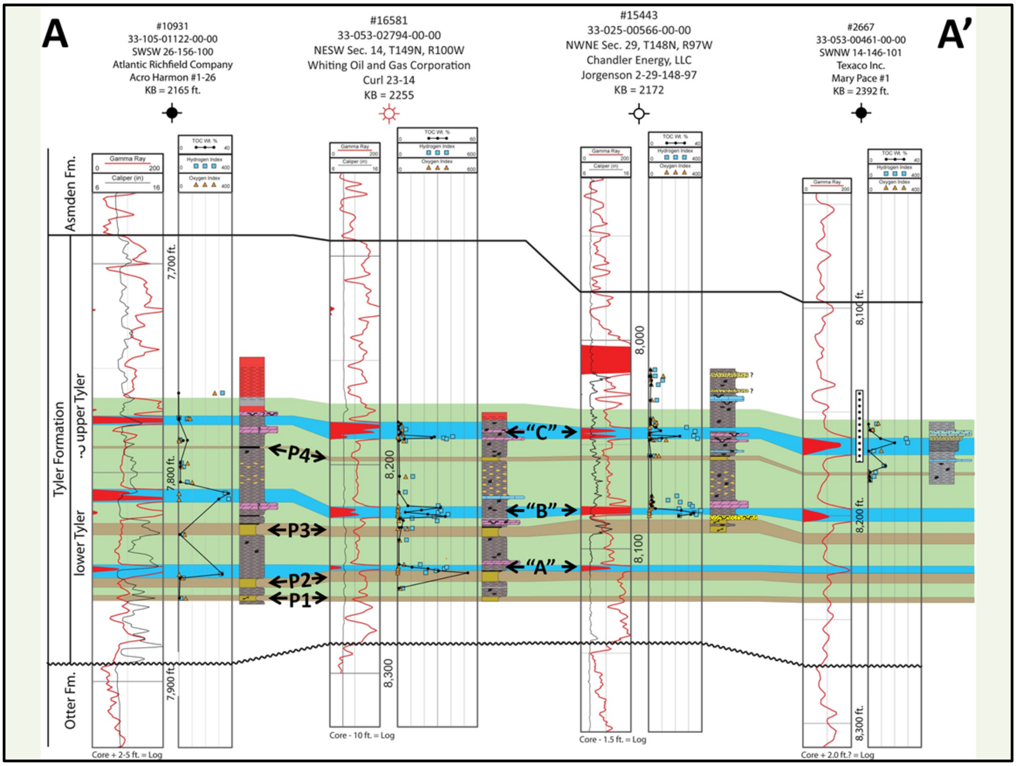
Thin, dark grey, microcrystalline dolomite layers are also present which are all located in close stratigraphic proximity to the high gamma ray shale intervals. These finely crystalline dolomites vary in texture from being faintly laminated to massive to bioturbated.



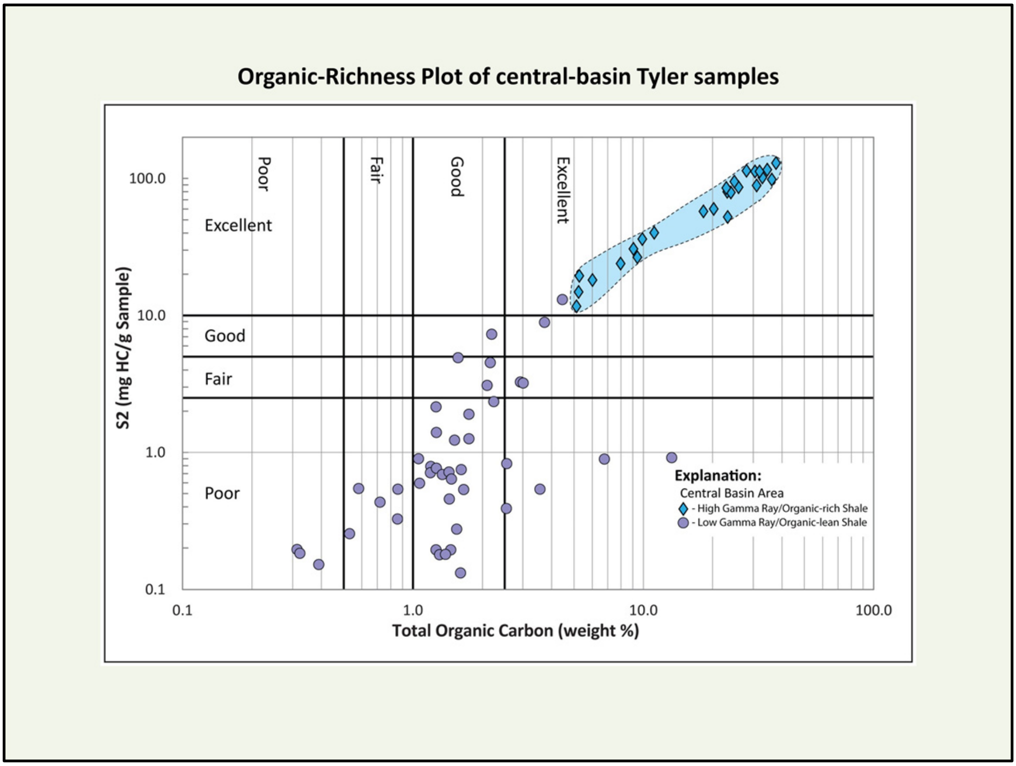
The following north-south cross-section examines the continuity of the various lithologies previously reviewed . . .



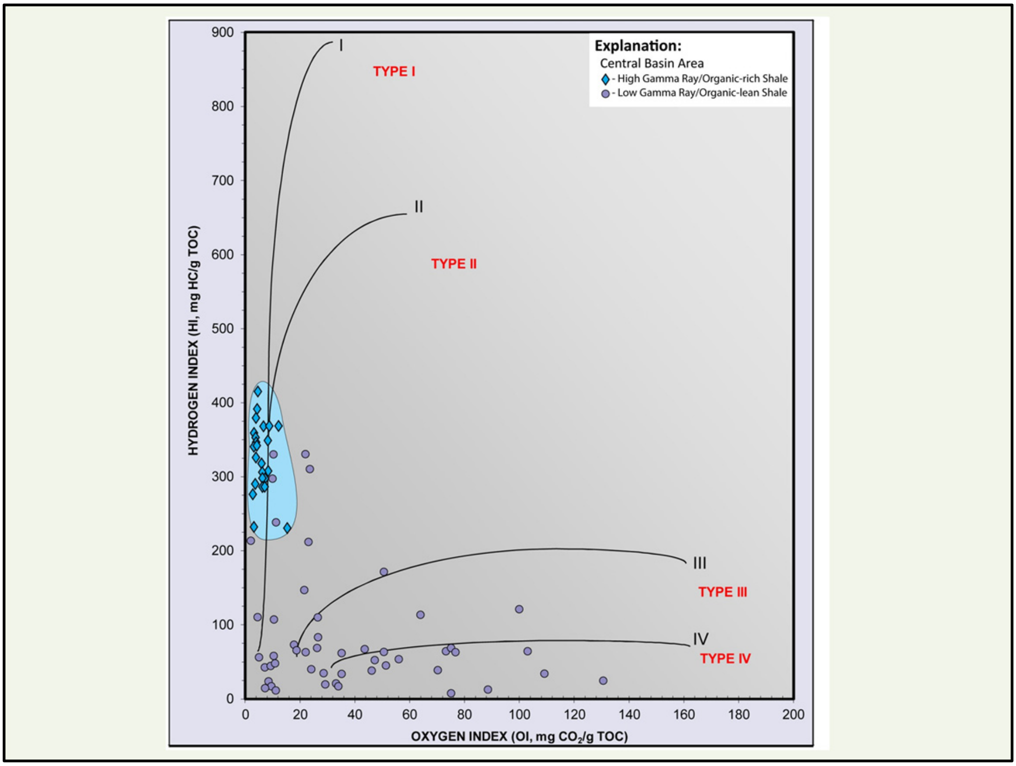
. . . most of the shale and mudstone intervals appear to be laterally continuous across the ~50 mile long north-south cross-section displayed. The high gamma ray shales can be easily traced using wireline logs and are similar in core lithologically, texturally, and geochemically. The various greenish mudstone/paleosol intervals can also be readily correlated in core and therefore may represent basin-wide regressive events. However, the greenish mudstone/paleosol horizons are not easily discernable from the surrounding low-moderate gamma ray shale in log signature. The low/moderate gamma signature shale also can be readily correlated across Tyler cores, including the interval with siderite (?) lenses/laminae. While the finely crystalline dolomite layers tend to be located either directly above and/or below the high gamma-ray shale beds, the dolomite layers appear to be more discontinuous.



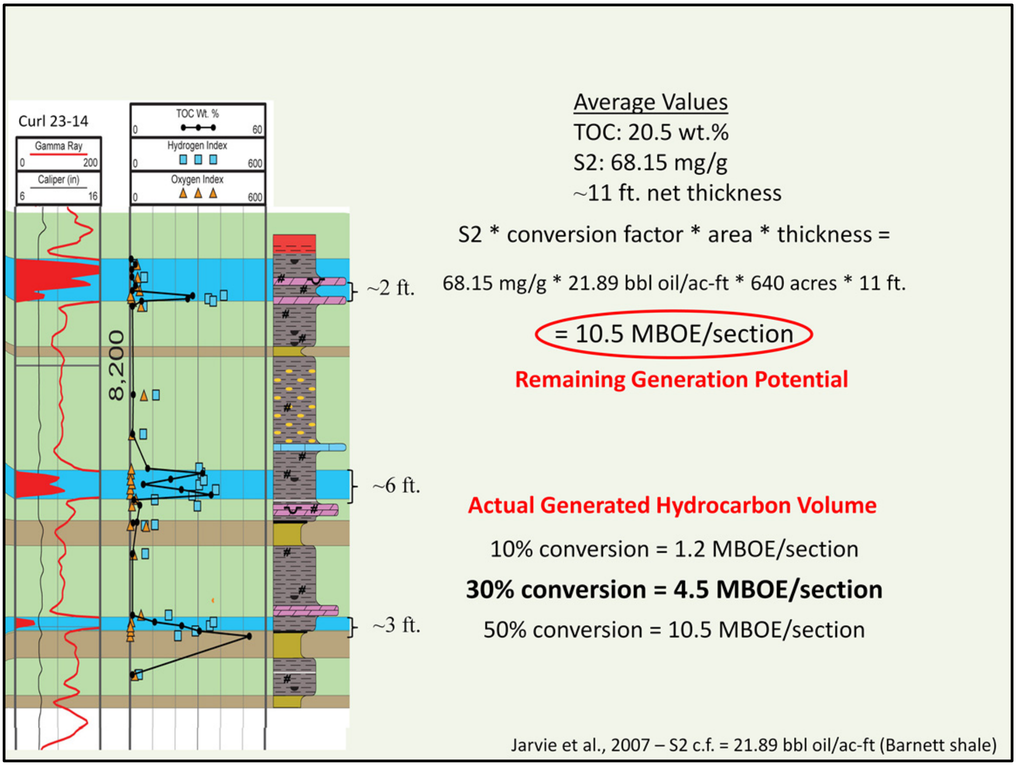
P1-P4 = interpreted paleosol intervals, “A”-”C” = organic-rich, high gamma ray shale beds



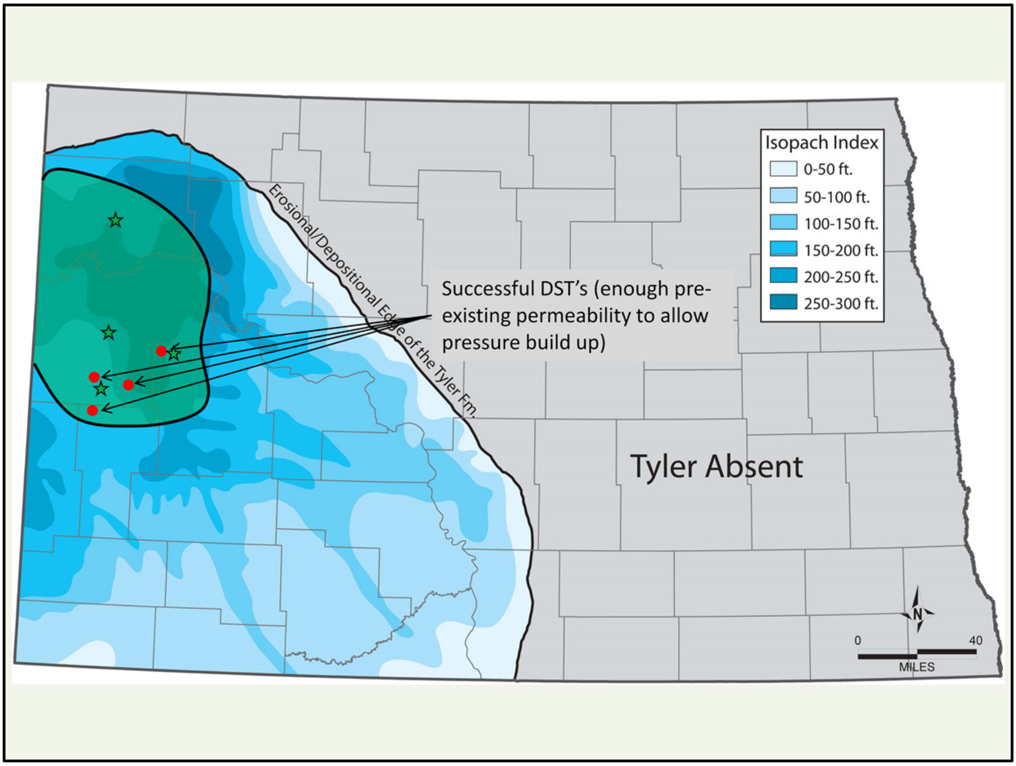
Most core samples from the high gamma ray shale beds plot as excellent quality source rock, both in terms of TOC wt. % and S2 content. Samples from the remaining low gamma ray shale sometimes plots as fair to good quality source rock, but due to low S2 values generally classify as poor quality source rock.



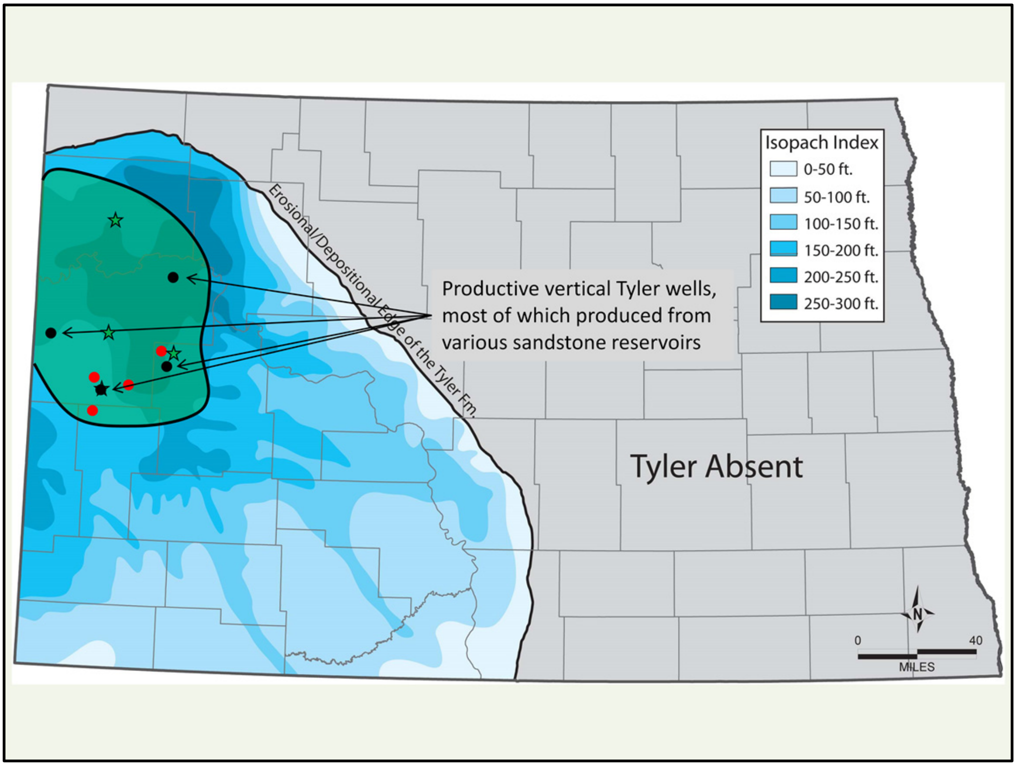
Hydrogen and oxygen index values measured from core samples of the high gamma ray shale beds plot along a Type I/II kerogen curve on a modified Van Krevelen diagram, indicating these source beds are prone to generating oil.



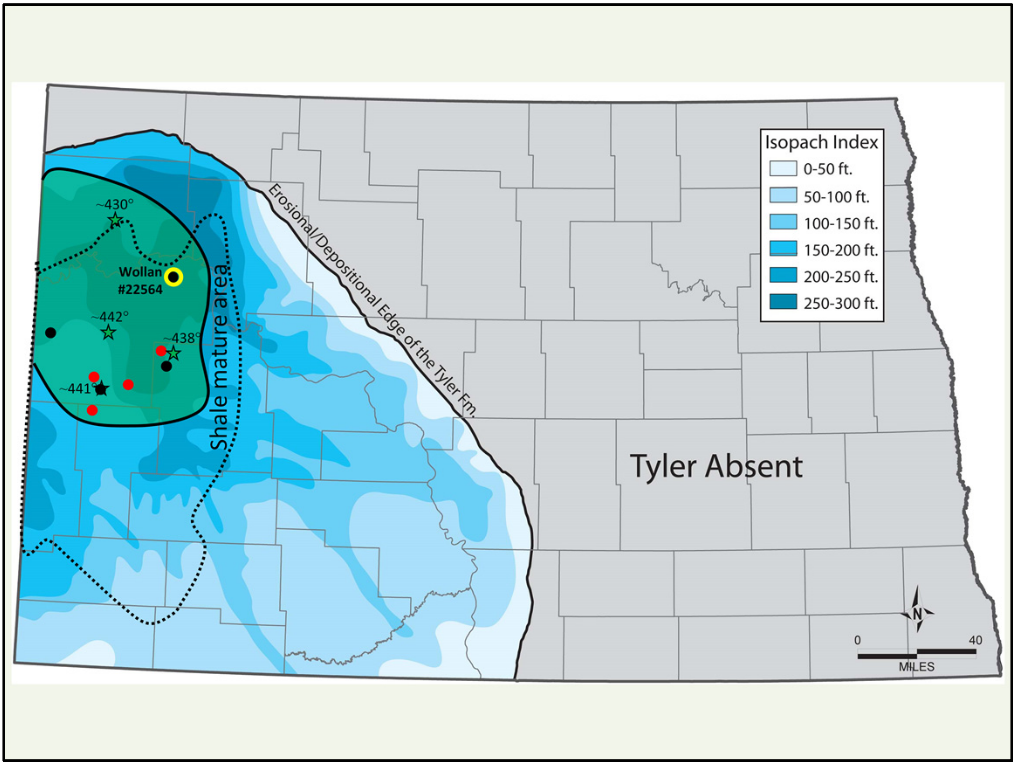
To estimate the amount of potential resource in place, a simple oil generation equation was borrowed from Javie et al. (2007). While Javie's equation was developed specifically for the Barnett shale, the equation may be useful to estimate the approximate amount of oil generated from Tyler source beds within the area of the Curl 23-14. The S2 measurement represents the portion of remaining organic carbon that is capable of converting to oil. Between the three high gamma ray shale beds within the Curl 23-14, there is a remaining generation potential of approximately 10.5 million barrels of oil per 640 acres. Approximately 30% of the original S2 (oil-prone kerogen) is estimated to have been converted to hydrocarbons (primarily oil) based on thermal modelling and measured Tmax values, which would indicate that approximately 4.5 million barrels of oil has been generated per 640 acres (9 million barrels/1280 acres).



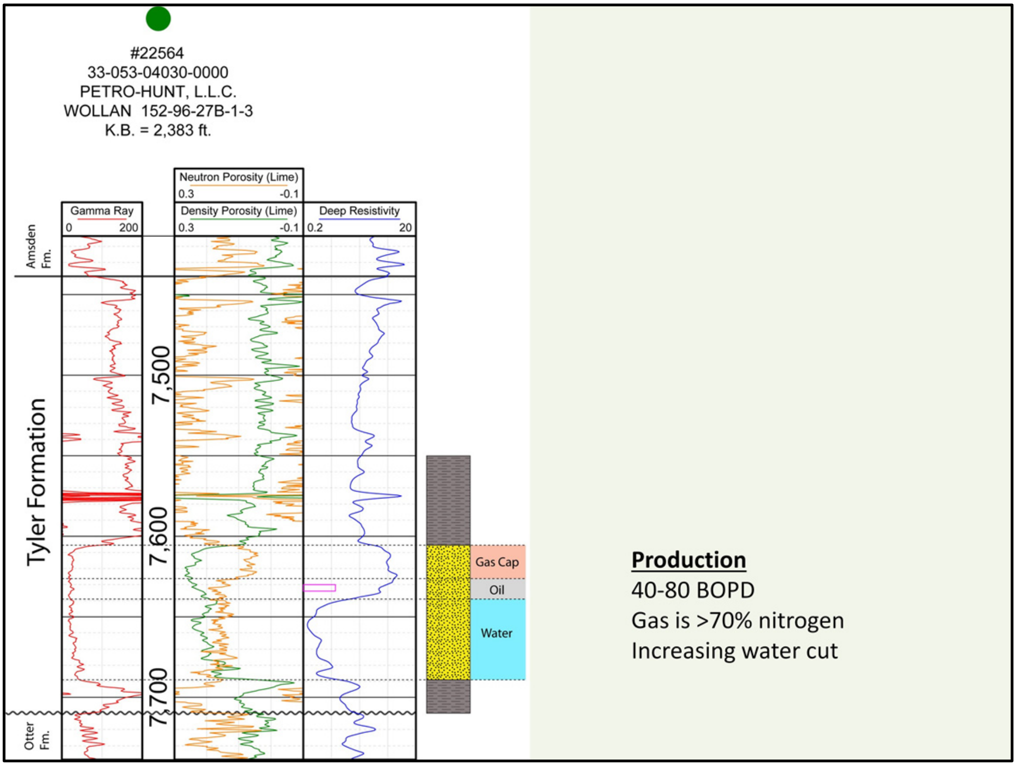
Successful drill stem tests (red dots) within the northern petroleum system area, where there was enough pre-existing natural permeability to allow for adequate pressure build-up to estimate the formation fluid pressure, are all located along the southern margins of the extent of the organic-rich high-gamma ray shale intervals (green shaded area). All four of these drill stem tests recovered oil and/or gas and yielded abnormally high calculated fluid pressure gradients (>0.46 psi/ft.). Other Tyler DST's from this northern petroleum system recovered only small amounts of drilling mud with minimal pressure build-up indicating negligible natural permeability (not displayed).



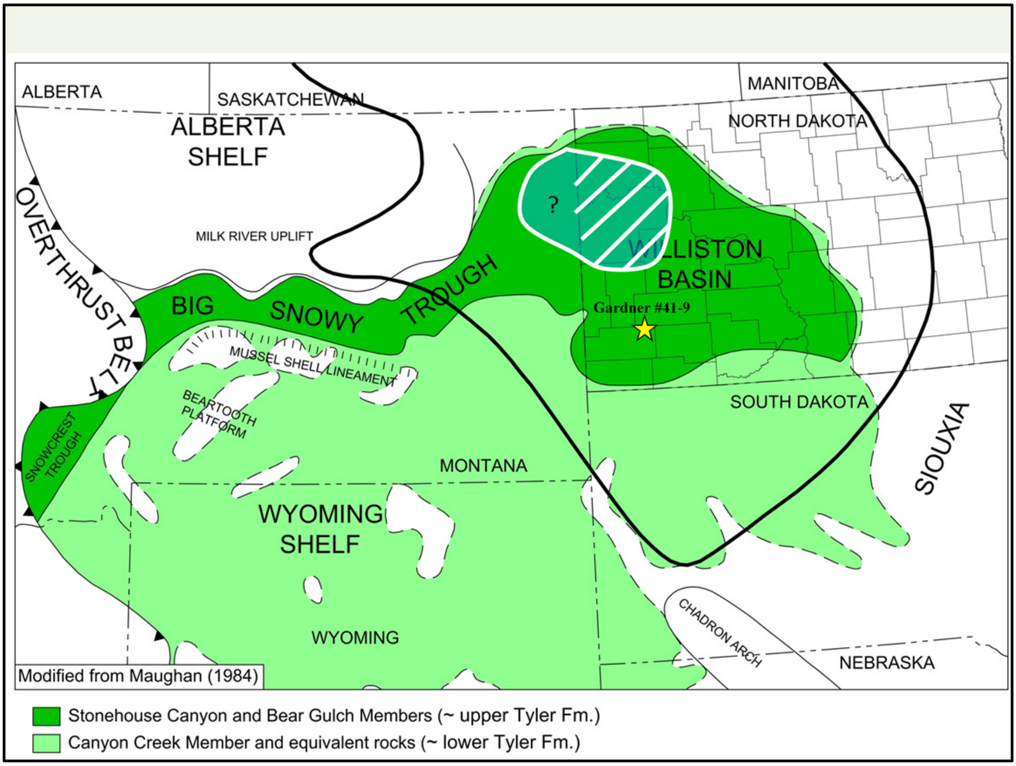
Four productive vertical Tyler wells from this northern area (black dots) are all located along the peripheral extent of the high gamma ray, very organic-rich shale intervals.



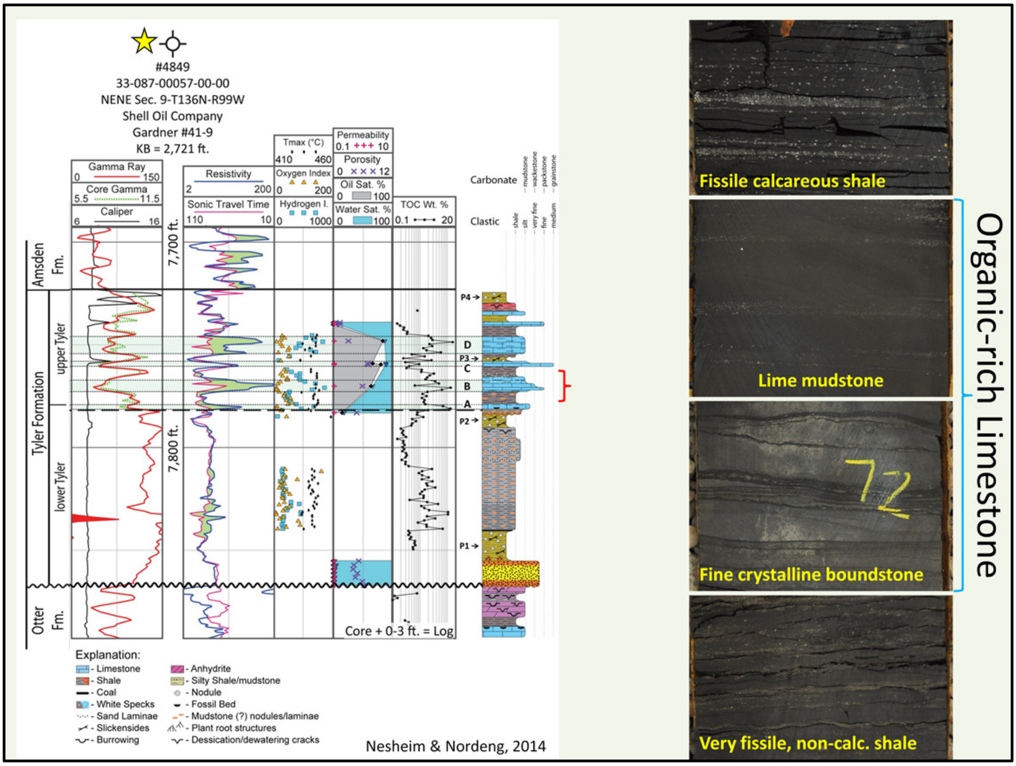
All of the successful DST's and productive vertical wells to date are located within the Tyler's modeled area of thermal maturity. There is currently no evidence of significant hydrocarbon migration within or out of the northern Tyler petroleum system. Perhaps the peripheral to southern areal extents of the northern Tyler source beds are more favorable to conventional, and possibly unconventional, exploration.



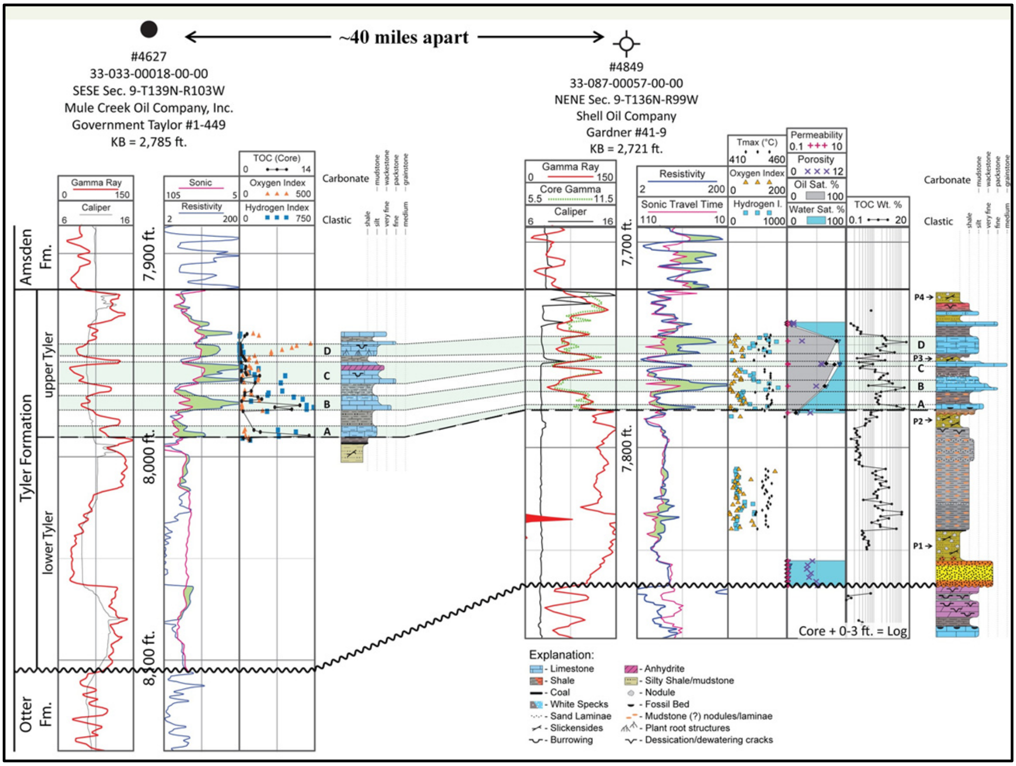
Petro-Hunt's Wollan 152-96-27B-1-3 is a recent vertical well discovery in the northern Tyler petroleum system. The Wollan encountered a 14 ft. oil column sitting upon 50 ft. of water within an 80 ft. thick porous sandstone located near the base of the Tyler section. The Wollan is located near the outer edge of the Tyler's modeled oil generation window and only contains 4-6 ft. of the high gamma ray/presumably very organic-rich shale (7,552-7,558 ft.). If this same sandstone body was encountered in an area of higher thermal maturity while containing a greater net thickness of the high gamma ray shale, there would likely be more than a 14 ft. oil column within the basal sandstone reservoir.



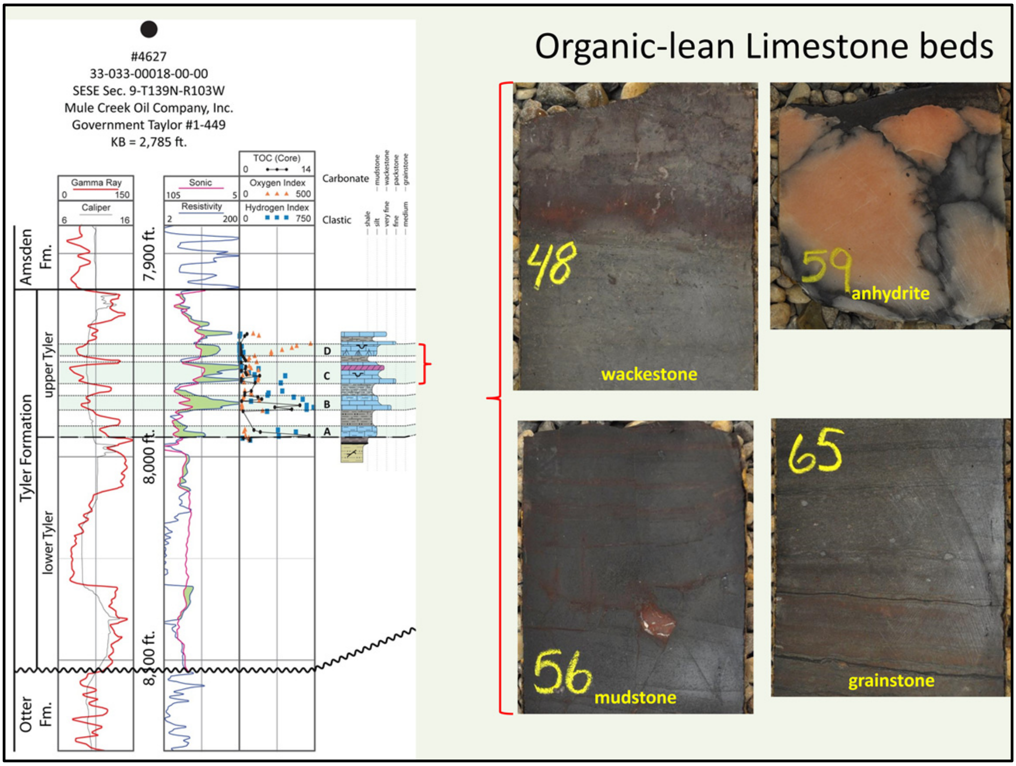
Next we'll look at the Tyler's southern petroleum system beginning with a Tyler core from Shell's Gardner #41-9.



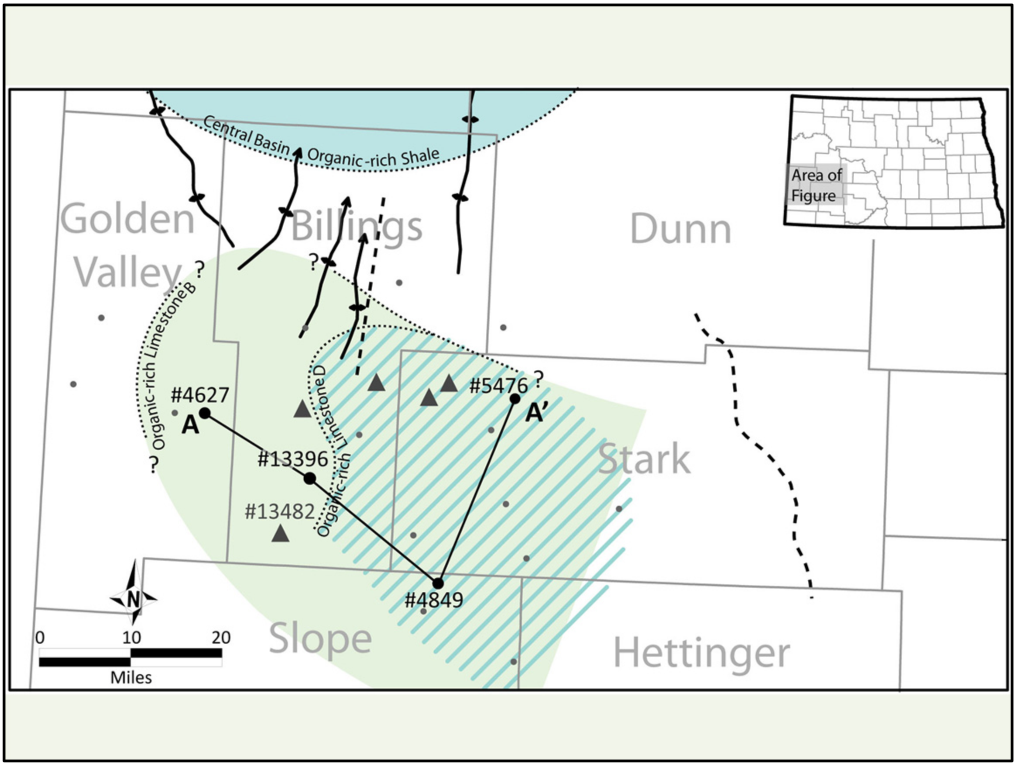
A near complete core of the Tyler Formation was cut from Shell Oil's Gardner #41-9. 1-2 gram samples were collected every ~1 foot across most of the Tyler portion of the core, where the core consists mostly of darkly colored shale/mudstone. Based on the geochemical data and core observations, there appear to be three organic-rich limestone beds (4-6% TOC average) in the upper Tyler section of the Gardner #41-9. These organic-rich limestone beds are argillaceous (shaly) in part and yield a low gamma ray along with a high resistivity log signature.



These upper Tyler limestone beds appear to correlate across much of the southwestern part of the state. The limestone beds also appear to undergo facies changes in which they transition from organic-rich source beds to organic-lean non-source beds.



When the limestone beds are organic-lean, they appear in core as light to medium grey lime grainstone to mudstone and often display reddish coloration in part. The key wireline log signature that seems to differentiate organic-rich vs. organic-lean limestone beds is the sonic travel time log. Organic-rich limestone beds average a sonic travel time of ~80 µs/ft. while organic-lean limestone beds average ~80 µs/ft.



On the displayed slide is a preliminary map outlining the approximate extent of where upper Tyler limestone beds B and D are organic-rich based on their sonic log signature. The black/grey circles and grey triangles represent control points. The black circles represent wells with cores that are used in the following cross-sections and the grey triangles represent additional upper Tyler cores examined.

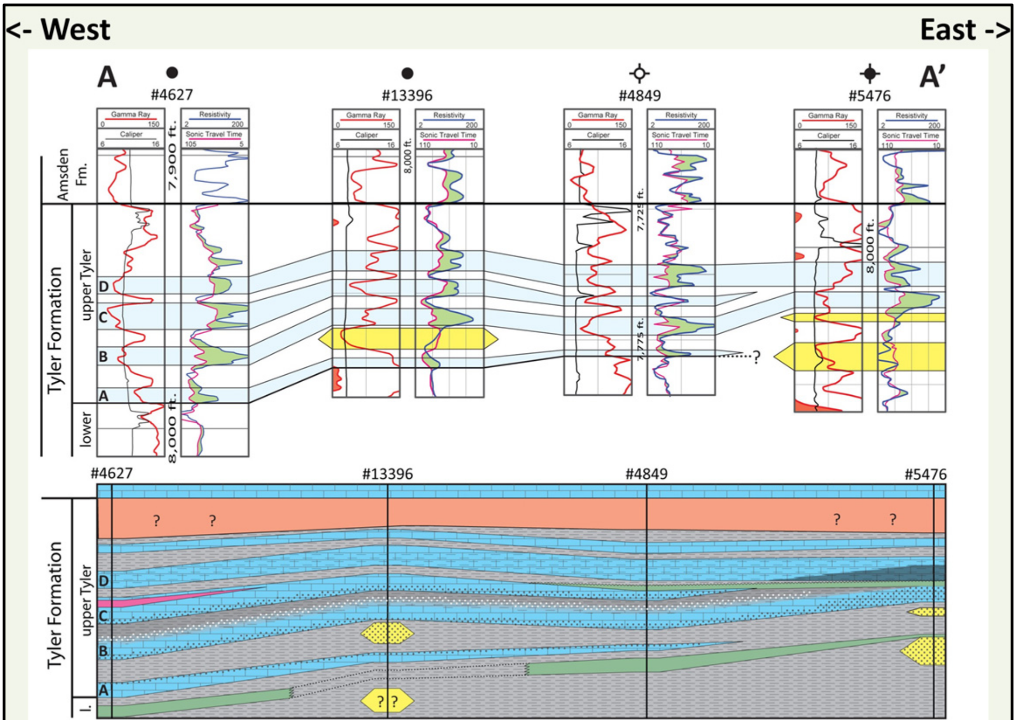
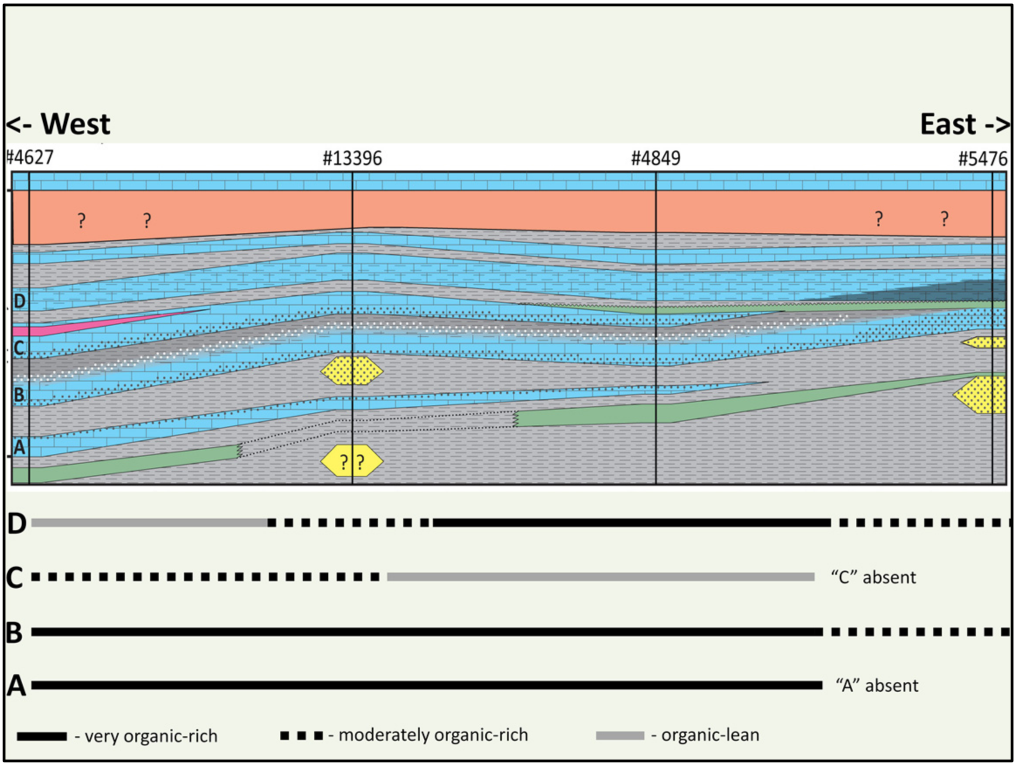
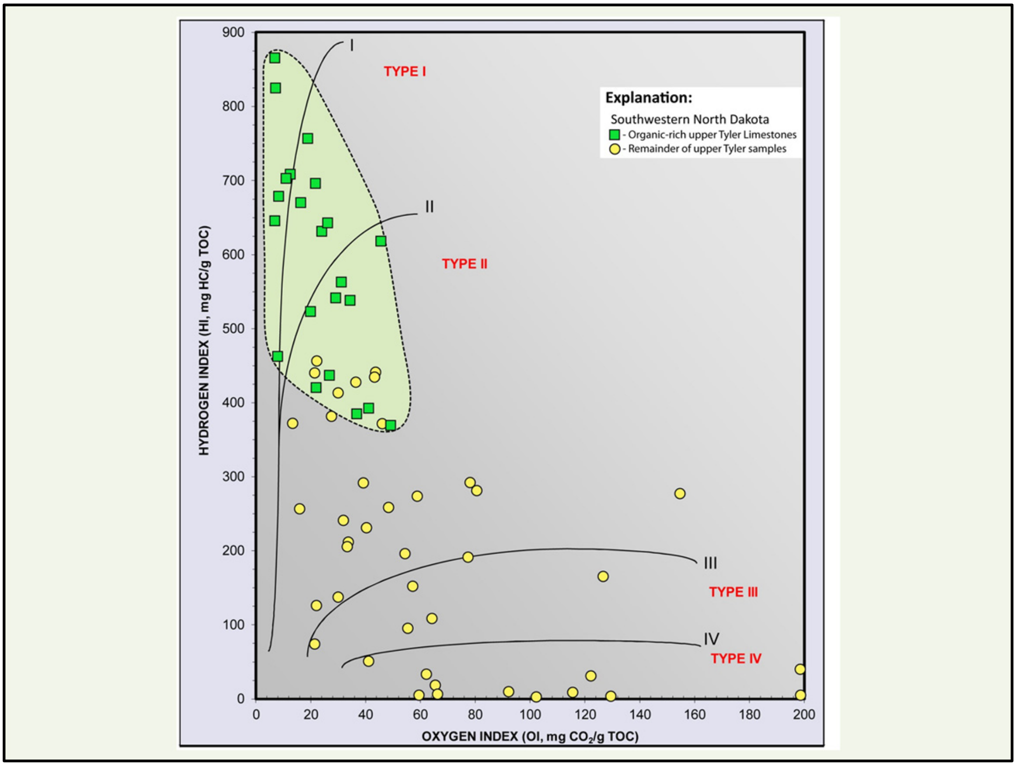


Figure X. Cross-sections of the upper Tyler Formation. A) Wireline log cross-section of the upper Tyler with blue shading indicating limestone beds A-D and yellow indicating sandstone intervals. B) Interpretive, illustrated cross-section of A-A.'

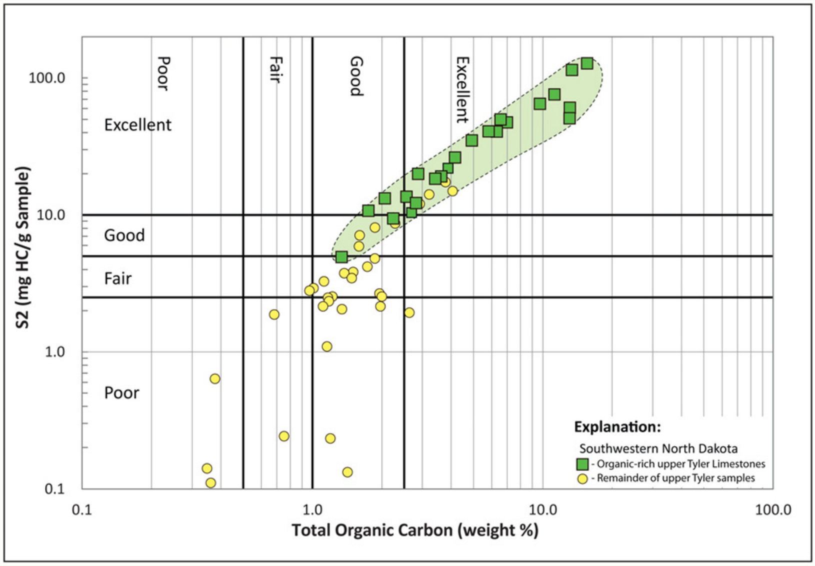
The A-A' cross section correlates four upper Tyler limestone beds A-D across southwestern North Dakota. Tyler cores were examined from all four wells, two of which have geochemical data sets previously displayed (#4627 and #4849).



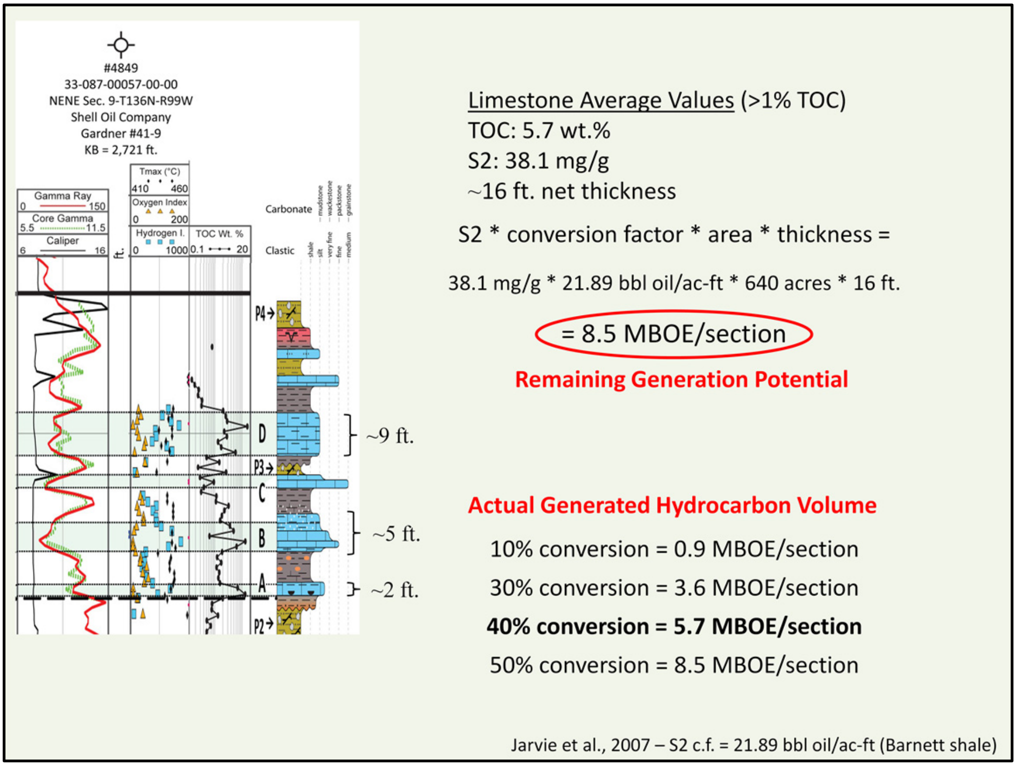
Based on core observations, geochemical core data, and wireline log signatures (sonic log), there appear to be areas where at least three of the limestone beds are organic-rich. In other areas, these limestone beds are absent and/or transition to moderate to poor quality source beds.



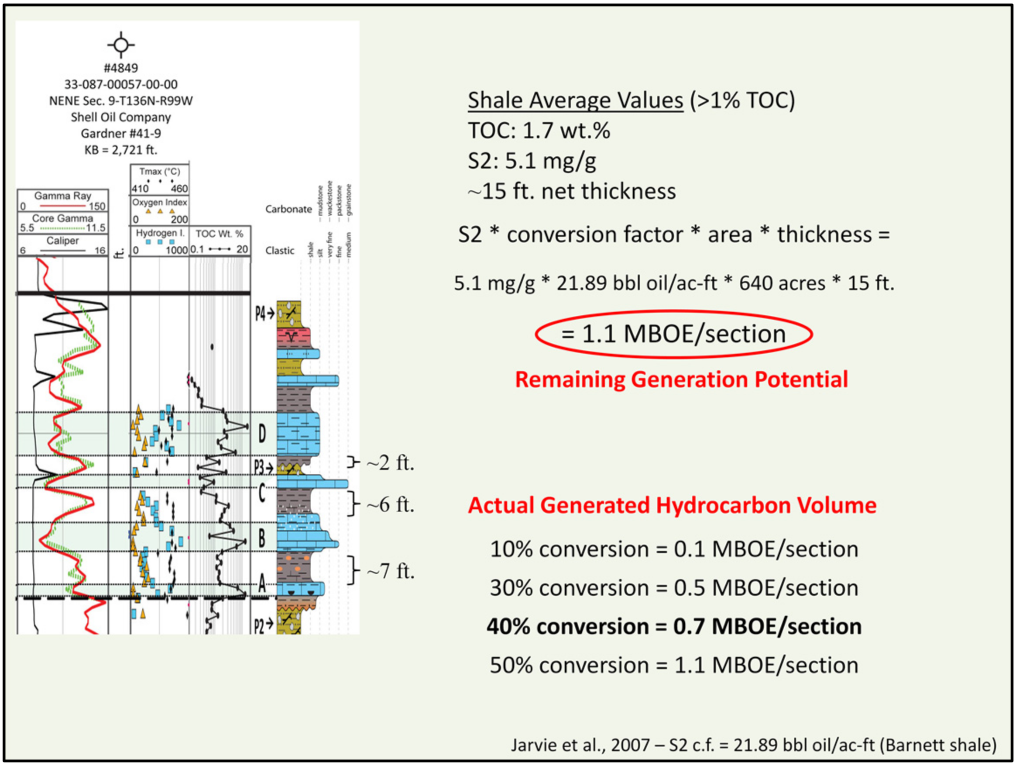
On a modified Van Krevelen diagram, samples from the organic-rich limestone beds plot along a Type I/II kerogen curve indicating they are prone to generating oil. Most of these samples yielded Tmax values of 440-445° indicating they are thermally mature and have undergone intense oil generation. Some of the interbedded shale intervals (yellow circles) also plot along a Type I/II kerogen curve.



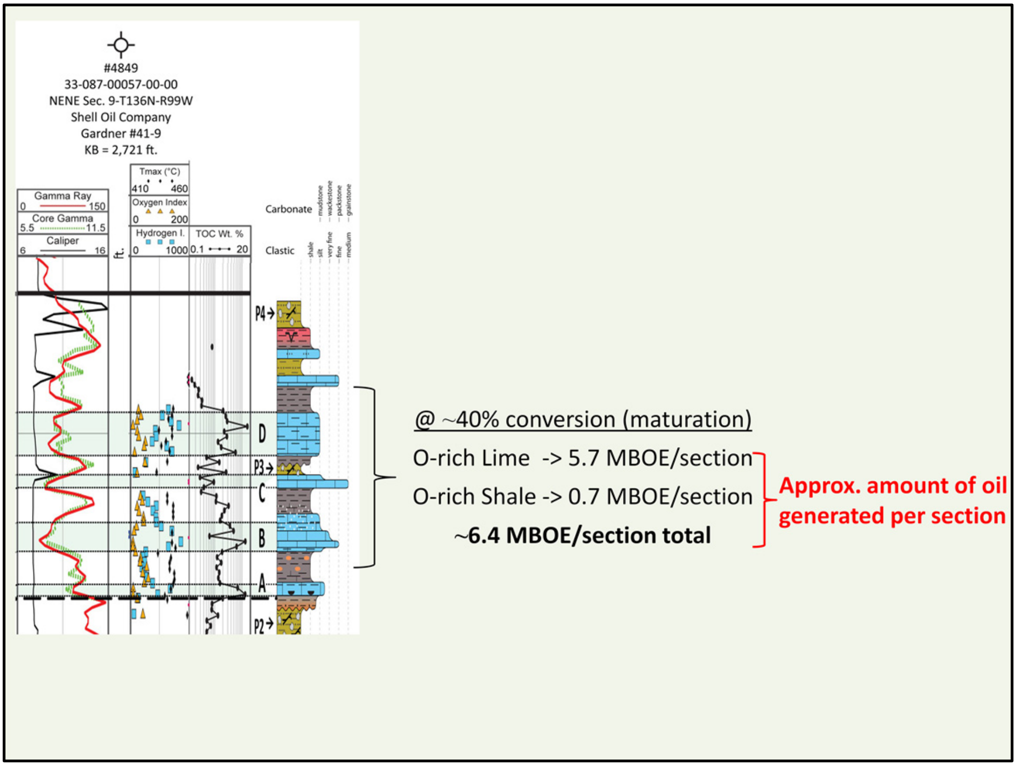
On an organic-richness plot, the organic-rich limestone bed samples plot as good to excellent quality source rock along with some of the interbedded shale samples.



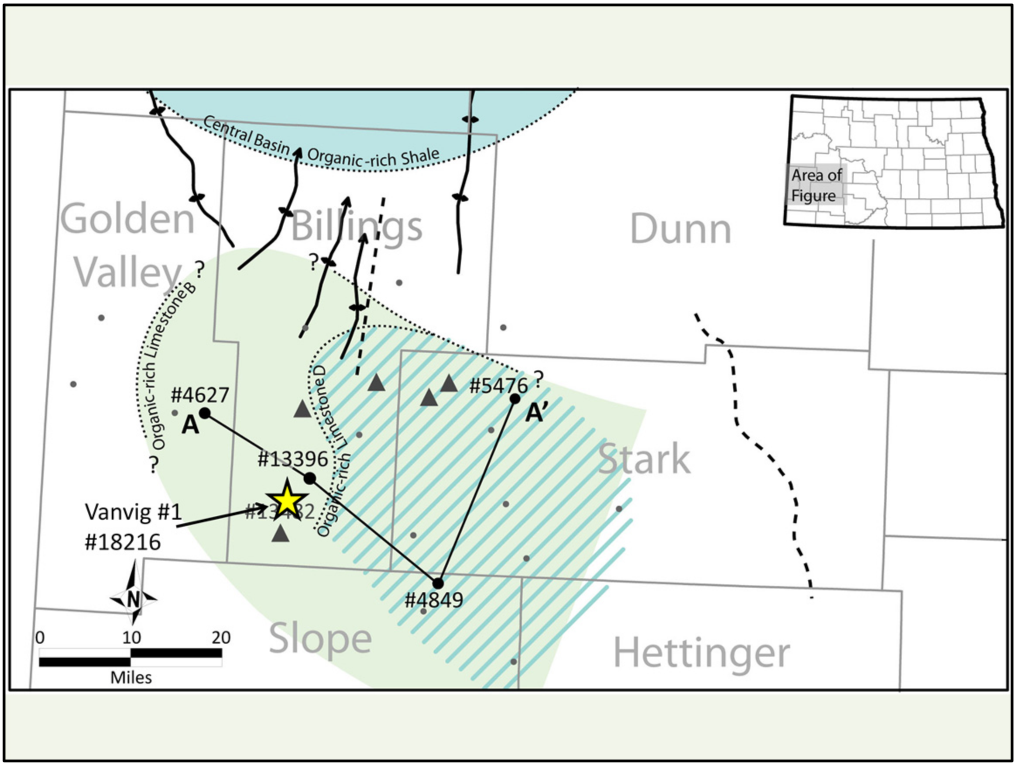
Approximately 5.7 million barrels of oil per 640 acres may have been generated from the organic-rich, upper Tyler limestone beds within the area of the Garnder #41-9 (assuming 40% kerogen conversion based on thermal modeling and Tmax values).



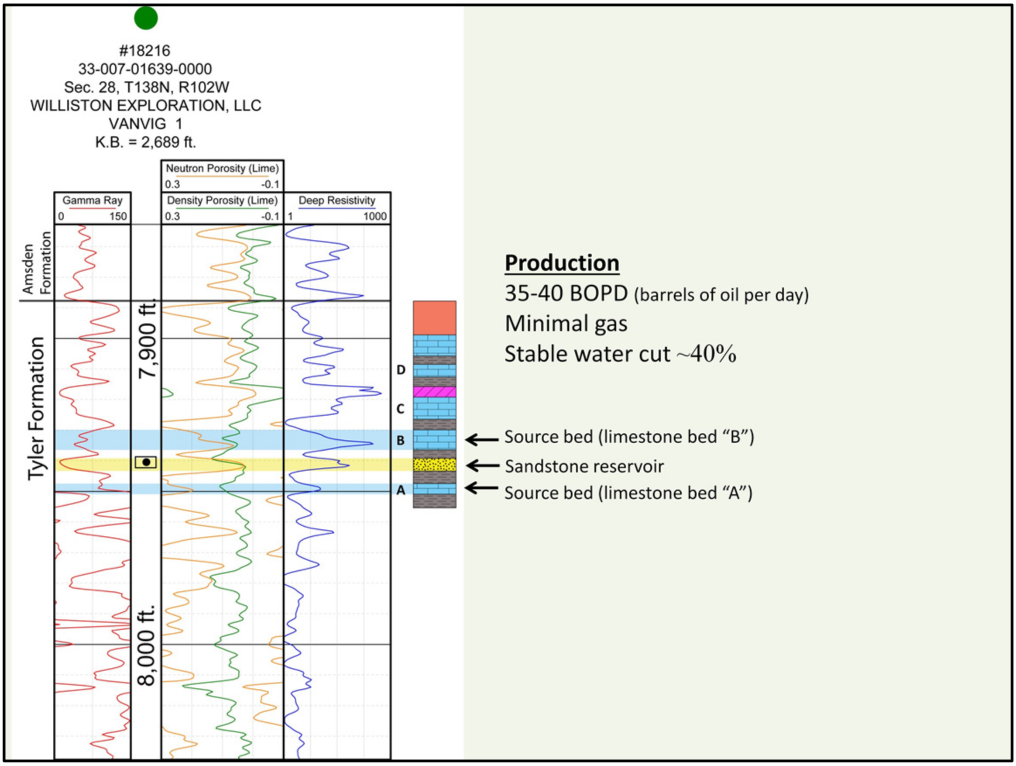
And while some of the interbedded shale layers are also moderately organic-rich, they are estimated to have generated only 0.7 million barrels of oil per 640 acres.



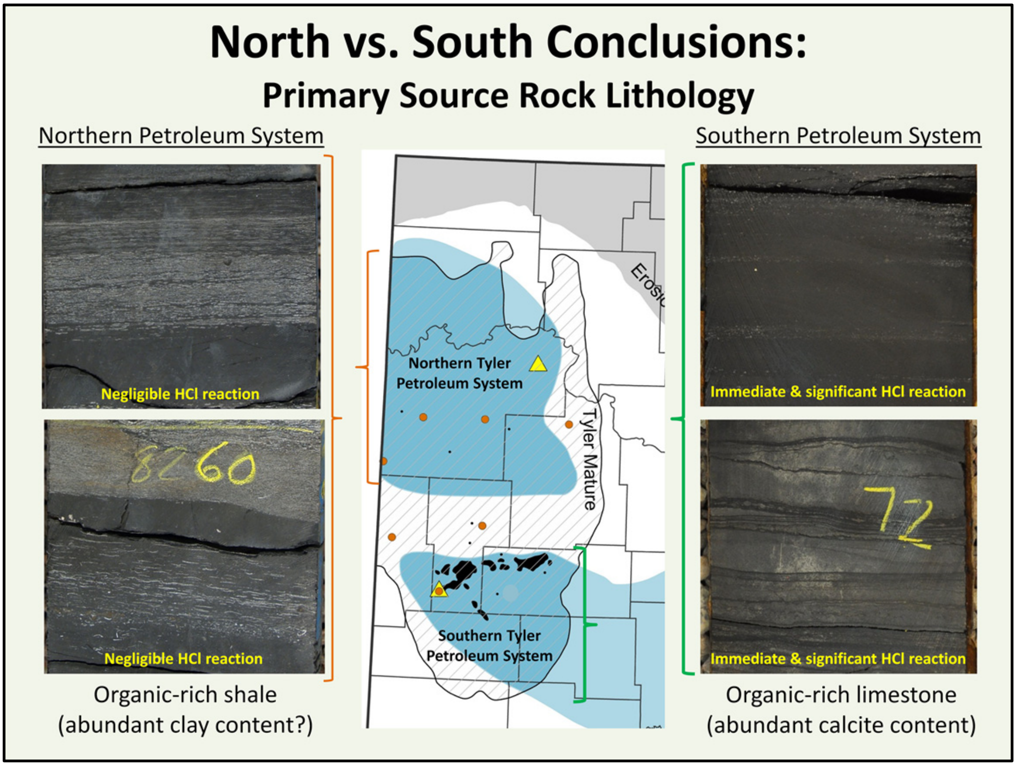
Between the organic-rich shale and limestone beds (>1% TOC), the upper Tyler Formation within the area of the Gardner #41-9 is estimated to have generated approximately 6.4 million barrels of oil per 640 acres.



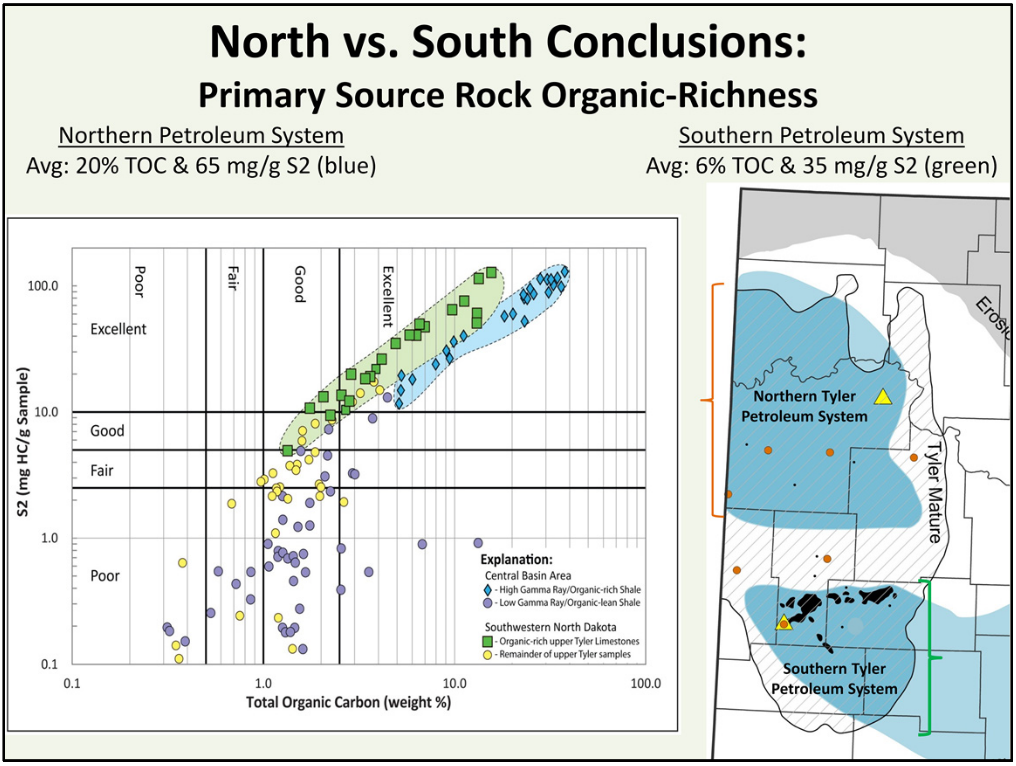
Williston Exploration's Vanvig #1 is a recent vertical well discovery within the Tyler Formation.



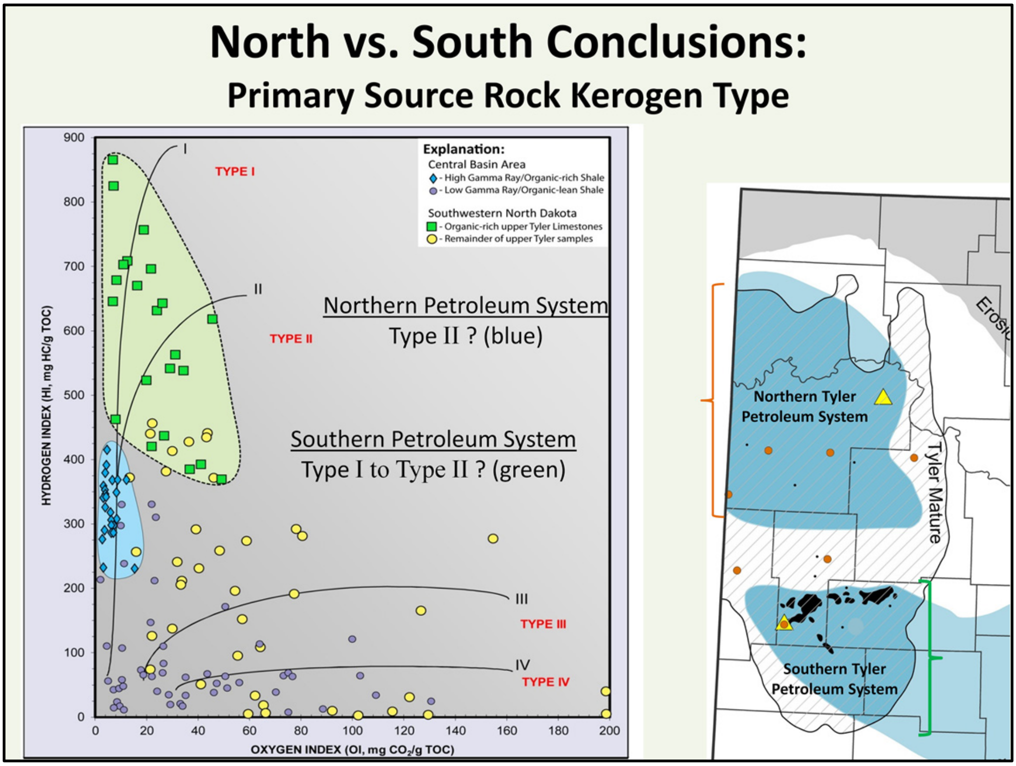
The Vanvig 1 appears to contain only 1-2 ft. of conventional sandstone reservoir and has been steadily producing 35-40 barrels of oil per day over the past two years. Similar to many of the other productive vertical wells within the Fryburg and Tracy Mountain Fields, the pay sandstone of the Vanvig 1 is "sandwiched" between two upper Tyler source beds, Limestone "A" and "B."



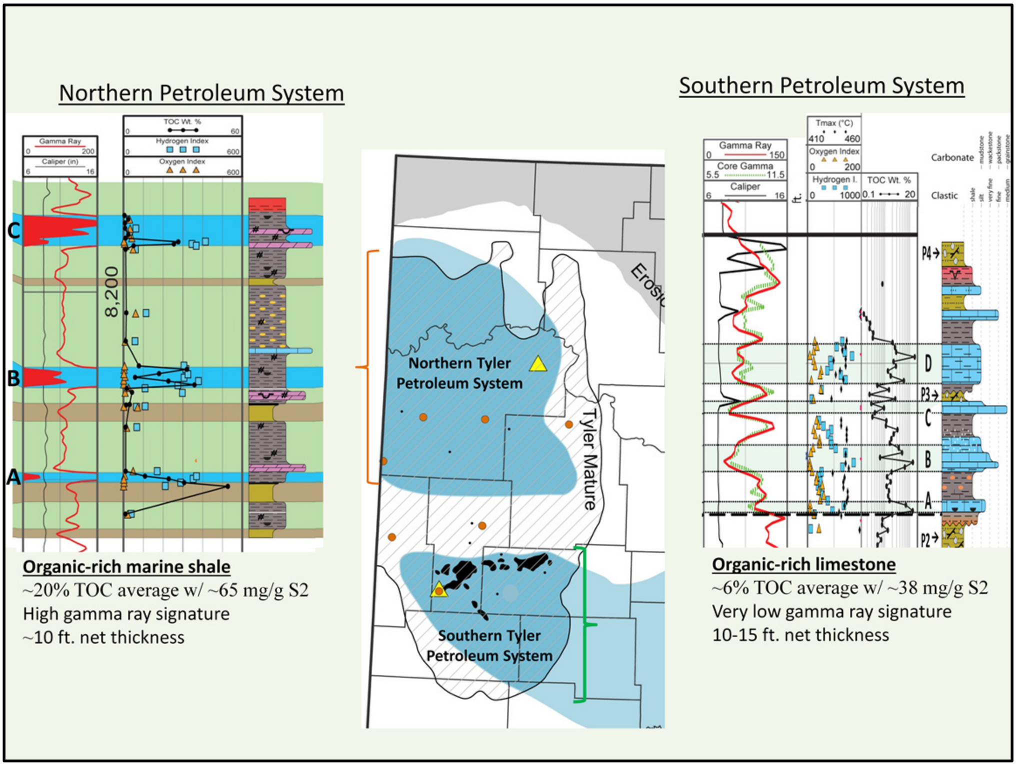
Differentiating the interpreted two Tyler Petroleum Systems, the primary source beds of the northern system consist of non-calcareous, fossil-bearing shale while the source beds of the southern system consist of organic-rich limestone (lime mudstone).



Examining the more organic-rich samples from each petroleum system on an organic-richness plot, they both plot as good to excellent quality source rock with slightly different S2 vs. TOC ratios. The differing S2 vs. TOC ratios may reflect a difference in the type/s of organic matter.



While samples from both sets of source beds plot along a Type I/II kerogen curve, they differentiate into two separate populations which suggests different types of organic-matter. Different types of organic matter would explain the differences in oils produced from the two systems (the paraffin concentrations varies from 20-40% in the southern system to <5% in the northern system) and also could mean differences in maturation parameters.



While both sets of source beds typically display high resistivity log signatures, their gamma ray signatures are opposite of one another. The northern organic-rich shale beds display very high gamma ray log responses while the southern organic-rich limestones display very low gamma ray signatures.

Thank you for your time!

Questions?

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