Review of Production, Completions, and Future Potential of the lower Tyler Formation – Central Williston Basin, North Dakota

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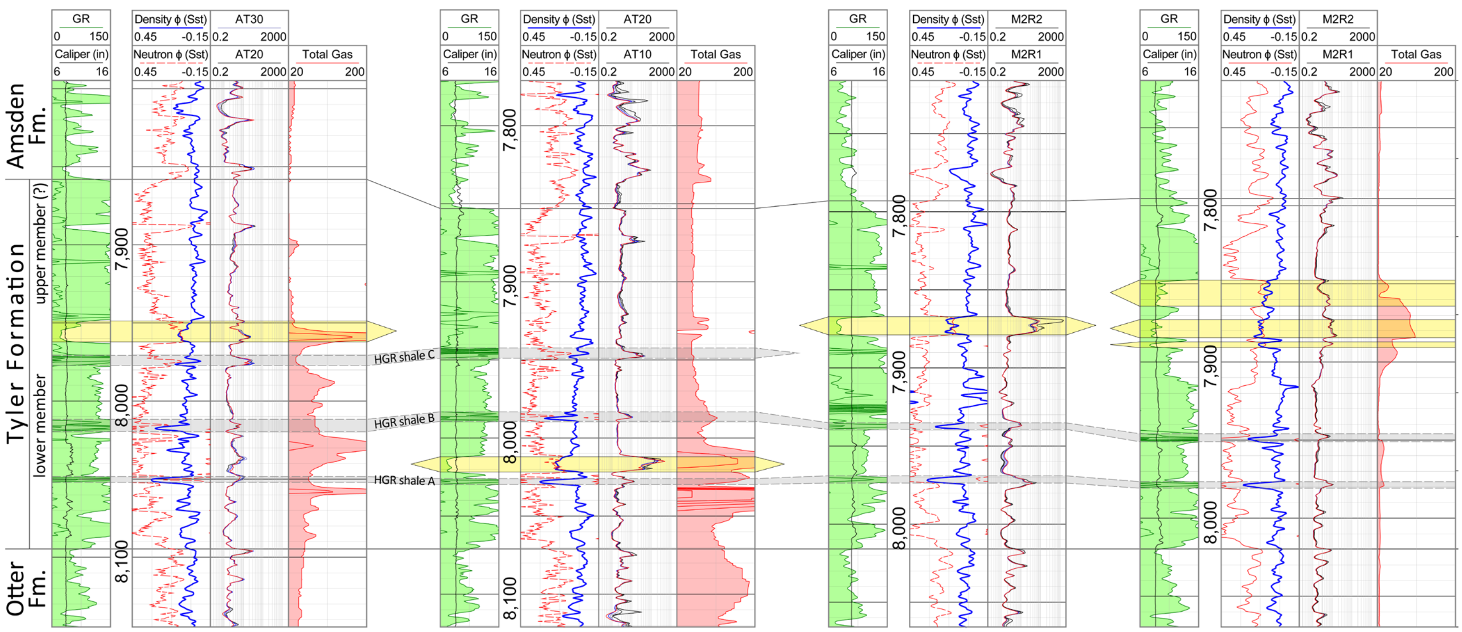

GEOLOGIC INVESTIGATION NO. 222
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Introduction

Commercial oil production from the Tyler Formation began in 1954. To date, the cumulative Tyler oil production from more than 300 wells is over 86 million barrels within North Dakota (Nordeng and Nesheim, 2012; ND Oil and Gas Division statistics). While most of the Tyler oil wells have been vertical, a handful of horizontal wells have been drilled and completed within the past few decades. Several of the Tyler horizontal wells have targeted conventional sandstone reservoirs (Nesheim, 2012) while two horizontal wells have been unconventional tests (horizontal wells with multi-stage hydraulic fracturing) targeting tight (lower porosity) carbonate beds of the upper Tyler (Nesheim, 2017). The majority of Tyler production has come from bar-type sandstones in the upper Tyler along the east-west oriented Dickinson-Fryburg trend in southwestern North Dakota (Sturm, 1983; Sturm, 1987; Barwis, 1990), and to a lesser extent in the Rocky Ridge Field located slightly further to the south (Fig. 1). Further north, within the central portions of the Williston Basin, a handful of spatially distributed Tyler producers suggest a potentially greater and poorly developed petroleum resource potential (Fig. 1).

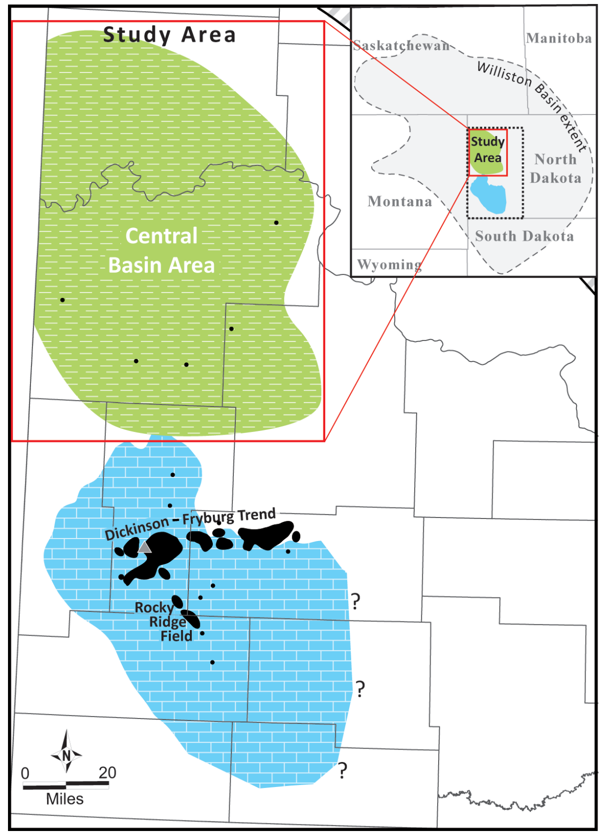

Figure 1. Maps depicting the location of the study area within western North Dakota and the Williston Basin (red outlines). Black fill (dots and larger areas) depict oil production from the Tyler Formation (upper and lower members). Green fill displays the approximate extent of the organic-rich, high-gamma-ray, black shales in the lower Tyler and blue fill shows the extent of organic-rich carbonate beds in the upper Tyler. The grey lines are county borders.

Beginning in 2010, the North Dakota Geological Survey embarked on reevaluating the Tyler with the focus of identifying and examining inter-formational petroleum source beds (Nordeng and Nesheim, 2010; 2012), which had been previously noted by Dow (1974) and Williams (1974). Two sets of thermally mature petroleum source beds were identified which include: 1) three high gamma-ray shales within the lower Tyler section that extend across the central portions of the Williston Basin, and 2) organic-rich limestone beds in the upper Tyler section of southwestern North Dakota (Nesheim and Nordeng, 2016) (Fig. 1). These two sets of petroleum source beds are stratigraphically and spatially separated, and, in part, are thermally mature with respect to oil generation thus forming two distinct petroleum systems: the upper Tyler petroleum system towards the southern margins of the Williston Basin (southwestern North Dakota) and the lower Tyler petroleum system within the central basin area (west-central North Dakota) (Nesheim and Nordeng, 2016). The bar-type sandstones of the Dickinson-Fryburg trend and the Rocky Ridge Field fall within the extent of the upper Tyler carbonate source beds (Fig. 1). Separately, the limited number of northern-positioned producers in the central basin area extend across much of the high gamma-ray shale source bed area (Fig. 1). Through the exploration and development of the Bakken-Three Forks unconventional oil play, numerous wells have yielded several new Tyler cores as well as thousands of additional wireline logs useful for further geologic investigations. The following report will review the limited historical Tyler production in the central basin area and use some of the recent core and wireline logs to further investigate future hydrocarbon resource potential. Reviewing and evaluating historical oil and gas production attempts in the lower Tyler, both successful and unsuccessful, may provide useful insight for continued exploration and development of the recently recognized petroleum system.

Geologic Background

The Tyler Formation (Tyler) has previously been subdivided into two informal members: the lower Tyler that is predominantly siliciclastic and an upper member comprised of interbedded carbonate and siliciclastic beds (Sturm, 1983; Sturm, 1987; Nesheim and Nordeng, 2016) (Fig. 2). In the central portions of the Williston Basin, the lower Tyler is mostly comprised of darkly colored shale interbedded with green-grey mudstones (paleosols) and thin carbonates (Nesheim and Nordeng, 2016). While the entire Tyler has been interpreted as Early Pennsylvanian, based on faunal evidence observed in core samples (Grenda, 1977), the Early Pennsylvanian section may only include the upper Tyler. The lower Tyler may instead be Late Mississippian based upon previous regional correlations and revisited limited faunal evidence (Nesheim and Nordeng, 2016) (Fig. 2).

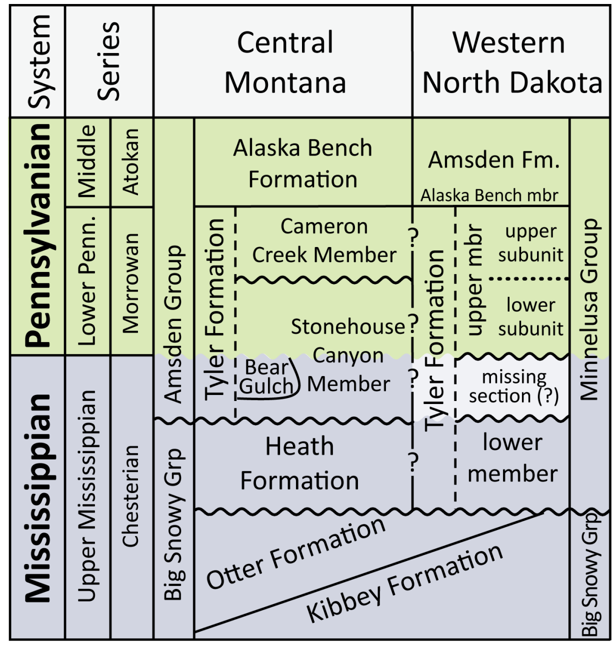

Figure 2. Stratigraphic chart of the Tyler Formation and surrounding strata for North Dakota and central Montana. Modified from Nesheim and Nordeng (2016).

The lower Tyler, the focus of this report, is primarily composed of variable types of dark grey to black colored shales within the central portions of the study area (Fig. 3a-3c) (Nesheim and Nordeng, 2016). Some of the shale intervals contain low to moderate amounts of bioturbation and diverse marine faunal assemblages including: brachiopods, crinoids, and small corals (Fig. 3a). Black, organic-rich (10-20% TOC, by weight herein) shales are also present and intermittently contain abundant concentrations of marine brachiopods (Fig. 3b). A third very dark grey shale facies is also present, which is only marginally organic-rich (<2% TOC) and contains negligible fauna (Fig. 3c). Interbedded with the darkly colored shales are paleosols that can be correlated laterally between cores and range from several inches to several feet in thickness (Fig. 3d-f). Towards the

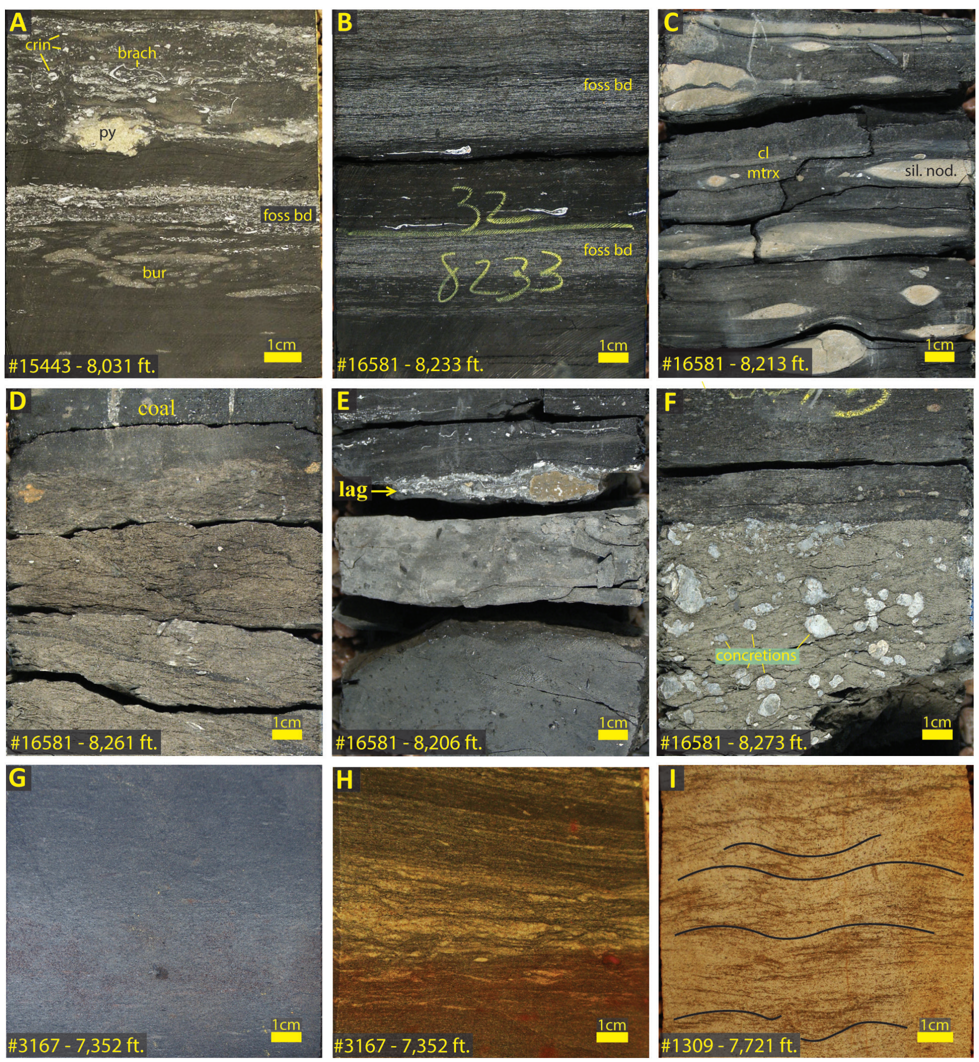

Figure 3. Core photographs of common lithological facies observed in the lower Tyler Formation across the study area. A) Very dark grey shale with burrows, brachiopod shells, and crinoid stem fragments. B) Black, organic-rich shale with fossiliferous (brachiopod) beds that correspond with the high gamma-ray petroleum source beds (10-20% TOC by weight). C) Very dark grey, fissile shale with siliceous nodules and negligible macroscopic fossil content. D) Paleosol overlain by a thin coal. E) Paleosol overlain by thin lag and fossiliferous shale. f) Paleosol with pebble-sized concretions directly overlain by darkly colored, fissile shale. G) Massive, dark grey silty mudstone. H) Dark grey silty mudstone with sandy laminae. I) Light grey ripple-laminated sandstone.

margins of the study area, coarser grained, silty to sandy beds become more prevalent in core, generally replacing the various shale facies (Fig. 3g-3i).

Three shale intervals, comprised primarily of the organic-rich, black shale facies, can be regularly observed and correlated within the lower Tyler section across the central portions of the Williston Basin (Nesheim and Nordeng, 2016). These shales display the following characteristics: 1) contain marine brachiopod fossil assemblages, 2) consist of organic-rich (≥10% TOC) mudstones with a corresponding type II, oil-prone kerogen signature, 3) interbedded with thin carbonate beds that may be diagenetic in origin, and 4) high gamma-ray wireline log signatures, as well as elevated resistivity and false-positive porosity log signatures, that can be easily correlated between wells (Nordeng and Nesheim, 2012; Nesheim and Nordeng, 2016) (Fig. 4). Nesheim and Nordeng (2016) informally referred to these three black shales as HGR (high gamma-ray) shale A to C in ascending stratigraphic order. The other darkly colored shale facies of the lower Tyler, which are only marginally organic-rich (<2%), range from containing diverse marine fauna to being absent of macro-fauna, do not appear to be significant petroleum source beds, and are referred to informally as MGR (medium gamma-ray) shales (Nesheim and Nordeng, 2016). Thermal modelling, RockEval pyrolysis (e.g. Tmax), elevated resistivity wireline log signatures, and fluid overpressure associated with hydrocarbon presence, all indicate that the HGR shales are thermally mature with respect to oil generation (Nordeng and Nesheim, 2012; Nesheim and Nordeng, 2016) (Fig. 5).

Methods

The North Dakota Oil and Gas Division database was queried to identify all wells that have perforations within the lower Tyler in and around McKenzie County. Well files were then reviewed to compile information regarding the lower Tyler completions,

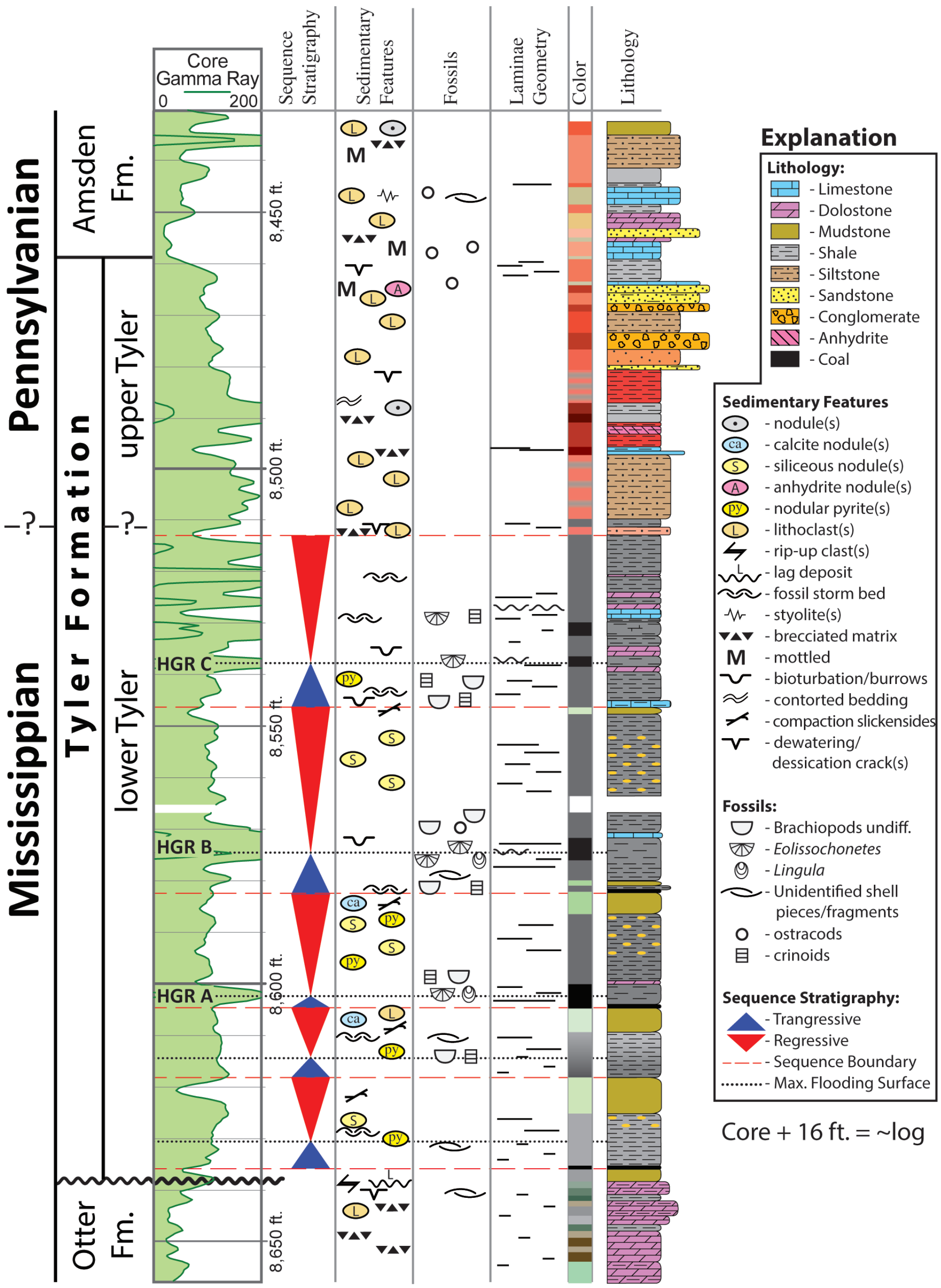

Figure 4. Example core illustrated (right) with core gamma-ray (left) of the Tyler Formation from Continental Resources Morison 1-14H (NDIC #22104, API: 33-053-03913-00-00, Sec. 14-T148N-R99W) located in central McKenzie County.

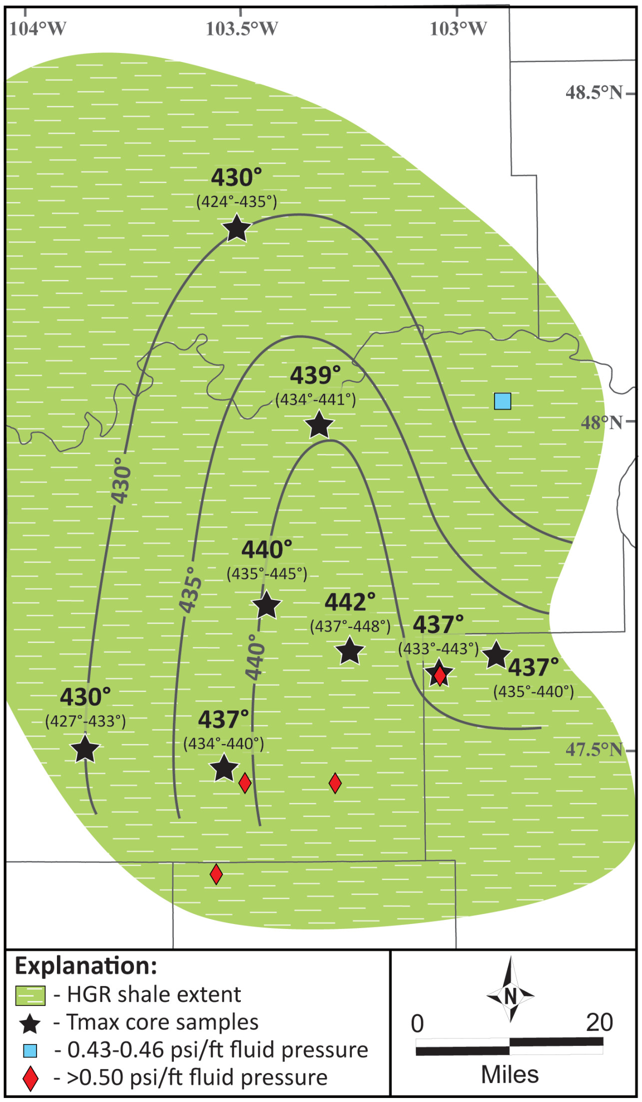

Figure 5. Thermal maturity (Tmax) and fluid pressure data for the lower Tyler Formation. Higher Tmax values indicate higher levels of thermal maturity and greater oil generation from the high gamma-ray black shales. Fluid overpressure suggests a substantial amount of the generated oil has largely remained within the lower Tyler section.

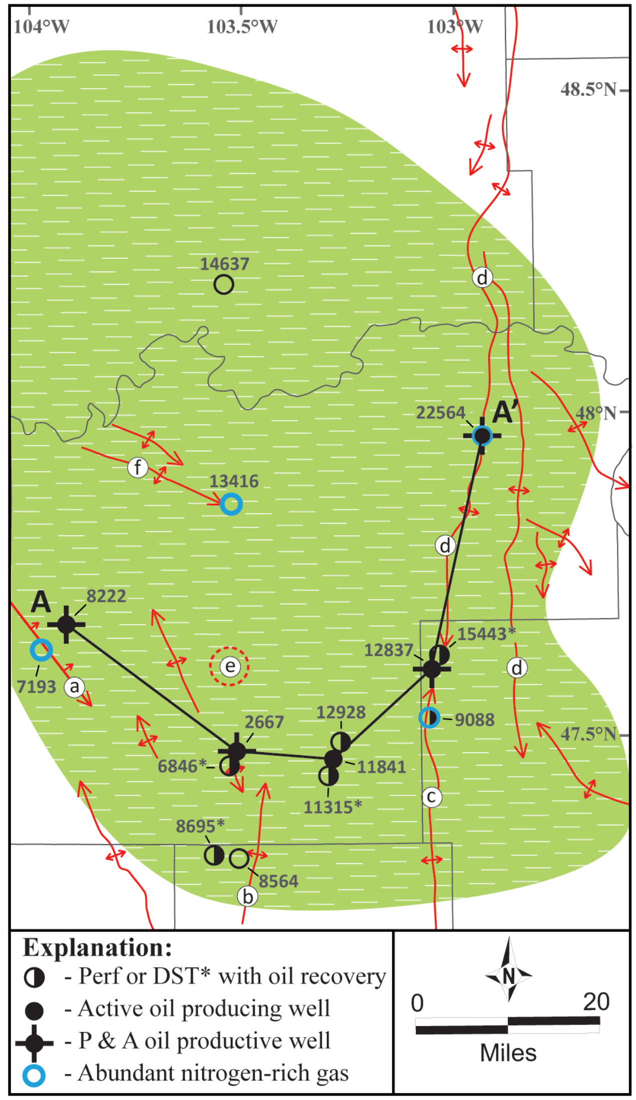

Figure 6. Map depicting the locations of wells that have either commercially produced and/or tested the lower Tyler Formation reservoirs through drill stem tests, perforations, and/or relatively small hydraulic fracture treatments. Red lines depict anticlines and a monocline. a = Mondak monocline; b = Rough Rider anticline; c = Little Knife anticline; d = Nesson anticline; e = Red Wing Creek structure; f = unnamed anticline

Table 1

General Well Information				Location					Test Interval		Cumulative Production		
NDIC #	API	Original Well Name	Original Operator	Section	Township	Range	Latitude	Longitude	Gross Perfs	DST Interval	Oil (BBLS	Gas (MCF)	Water (BBLS)
2667	33-053-00461-00-00	MARY PACE #1	TEXACO INC.	SWNW 14	T146N	R101W	47.467444	-103.520521	8140-8174	8134-8183	446	333	30
6846	33-053-00859-00-00	BN #15-44	PENNZOIL CO. & DEPCO	SESE 15	T146N	R101W	47.460236	-103.525223		8180-8282			
7193	33-053-00941-00-00	FEDERAL #18-44	PENNZOIL CO. & DEPCO	SESE 18	T148N	R104W	47.636737	-103.970882	7814-7829				
8222	33-053-01234-00-00	USA #43-3-116	SHELL OIL CO.	NESE 3	T148N	R104W	47.666468	-103.906472	8056-8114		5,833	2,777	60,261
8564	33-007-00704-00-00	F-7-144-101 #1	SUPRON ENERGY CORP.	NWNE 7	T144N	R101W	47.31118	-103.526063	7994-8018				
8695	33-007-00722-00-00	FEDERAL #2-3	APACHE CORPORATION	SWSE 2	T144N	R102W	47.314569	-103.569235		8178-8212			
9088	33-025-00277-00-00	CARUS #3-30-2	GULF OIL CORP.	NENE 30	T147N	R97W	47.52678	-103.082301	7928-7951				
11315	33-053-01997-00-00	GRASSY BUTTE #21-23F	PENNZOIL CO.	NESW 21	T146N	R99W	47.44956	-103.303415		8431-8563			
11841	33-053-02123-00-00	GRASSY BUTTE #21X-21F	PENNZOIL CO.	NENW 21	T146N	R99W	47.456144	-103.302941	8477-8549		9,532	702	19,512
12837	33-025-00450-00-00	9002 JV-P HAYSTACK #1	BTA OIL PRODUCERS	NENW 32	T148N	R97W	47.59968	-103.069321	8074-8095		45,632	1,052	1,260
12928	33-053-02333-00-00	GRASSY BUTTE #16-33	PENNZOIL EXPLOR. & PROD. CO.	NWSE 16	T146N	R99W	47.463355	-103.296537	8462-8470				
13416	33-053-02403-00-00	BERTINUSON #1-31	COLUMBUS ENERGY CORP.	NENW 31	T151N	R100W	47.861355	-103.532721	7957-7962				
14637	33-105-01433-00-00	JEFFREY #33-33	UMC PETROLEUM CORP.	NWSE 33	T155N	R100W	48.203563	-103.547855	7870-7970				
15443	33-025-00566-00-00	JORGENSON 2-29-148-97	CHANDLER ENERGY, LLC	NWNE 29	T148N	R97W	47.615228	-103.062298		8030-8095			
22564	33-053-04030-00-00	WOLLAN 152-96-27B-1-3	PETRO-HUNT, L.L.C.	NENW 27	T152N	R96W	47.961549	-102.953659	7630-7634		40,606	361,253	128,630

both the initial completion information as well as any later re-stimulation work. If the Tyler perforations commercially produced oil, monthly production records were also evaluated. Wireline logs were examined to determine the log signatures of the perforated intervals and compared with previously described and log-correlated lower Tyler core samples in order to identify the general lithofacies of the tested interval(s). Completion information, production data, and reservoir lithologies were then compared between wells to interpret productive reservoir versus non-reservoir facies as well as variations in play types for the lower Tyler petroleum system. Additional wireline logs from wells across the study area were utilized for stratigraphic correlations and/or identifying prospective by-passed pay in the lower Tyler section.

Results

A total of 11 wells were identified within the study area that had perforations extending through the lower Tyler section (Table 1; Fig. 6). Five of these well completions commercially produced oil, while the other six well completions did not. The available information on each lower Tyler completion varied from one well file to another. The following is a summary for the 11 lower Tyler completions. Additional information may be present within each well file through the ND Oil and Gas Division database.

COMMERCIALLY PRODUCTIVE WELLS

Mary Pace #1 (#2667)

The Mary Pace #1 was spudded in 1960 by Texaco Inc. as a wildcat well in a location that later became part of the Flat Top Butte Field. A lower Tyler core was cut from the Mary Pace and a corresponding drill stem test (DST) across the Tyler recovered oil and gas cut mud. The lower Tyler was initially perforated at 8,140-8,146 ft. and acidized with 250 gallons of mud cleanup acid (Fig. 7). The cored section corresponding with the perforated interval is comprised of dark grey to black shales interbedded with thin, micro-crystalline carbonate beds and includes HGR shale C. Core-plug porosity values were only 1.0-5.3% with negligible permeability (<0.1 millidarcies). After recovering 48 barrels (BBLS) of displacement oil and acid residue in 3 hours, only a small amount of gas flowed afterwards with no fluid. The perforated interval was then hydraulically fractured (frac'd) with approximately 110 barrels of gelled diesel (4,750 gallons) and 4,500 lbs. of sand with a maximum injection pressure of 6,000 psi. Several days after the first frac, the casing was notched at 8,154 and 8,174 ft. and a second, similar frac treatment was completed about a week after the first. The notching and 2nd frac essentially expanded the perforated interval from 8,140-8,146 ft. to 8,140-8,174 ft. Most of the injected diesel fluid was recovered after each frac job along with crude oil and minor water. The Mary Pace #1 Tyler completion then had pumping equipment installed to test the well. The well was then produced for a total of 38 days over the course of 4 months, producing 446 barrels of oil (BO), 333 thousand cubic feet (MCF) of gas, and over 30 barrels of water (BW). Oil production rates during that timeframe appears to have been relatively consistent at around 10-12 barrels of oil per day (BOPD) with limited water (<1 barrels of water per day; BWPD). The well was then shut-in and later plugged and abandoned. The relatively low oil flow rates in combination with the isolated location of the well at the time likely contributed to its brief phase as an active producer.

USA #43-3-116 (#8222)

The USA #43-3-116 was drilled on the northwestern margins of the Mondak Field by Shell Oil Company. Initially the Red River Formation and Mission Canyon (Madison) Formations were perforated and tested. Perforations were then made in the lower Tyler section at 8,056-8,065, 8,074-8,091, and 8,106-8,114 ft. (Fig. 7). These perforations primarily targeted the middle and upper high gamma-ray black shales (HGR B and C). The perforations were then acidized with 630 gallons of 10% HCl and flushed with 30 BBLS of 2% KCl. The well was noted to not flow after the completion but was swabbed for several days. Initially the swabbing only recovered 100% water, but after a few days oil cut water began coming from the perforations and the well was put on production. Initial Tyler oil production was 17 BOPD during the first two months of production and then declined slightly until settling around 12-14 BOPD with a 90-92% water cut for several months before Tyler production ceased. Gas production decreased from 12 to 6-7 MCF gas per day (MCFPD) with a gas to oil ratio (GOR) of <1 MCF/BO. Cumulative Tyler production from the USA totaled 5,883 BO, 60,261 BW, and 2,777 MCF gas. A few years after Tyler production ended, a recompletion was attempted in the Bakken Formation before the well was plugged and abandoned.

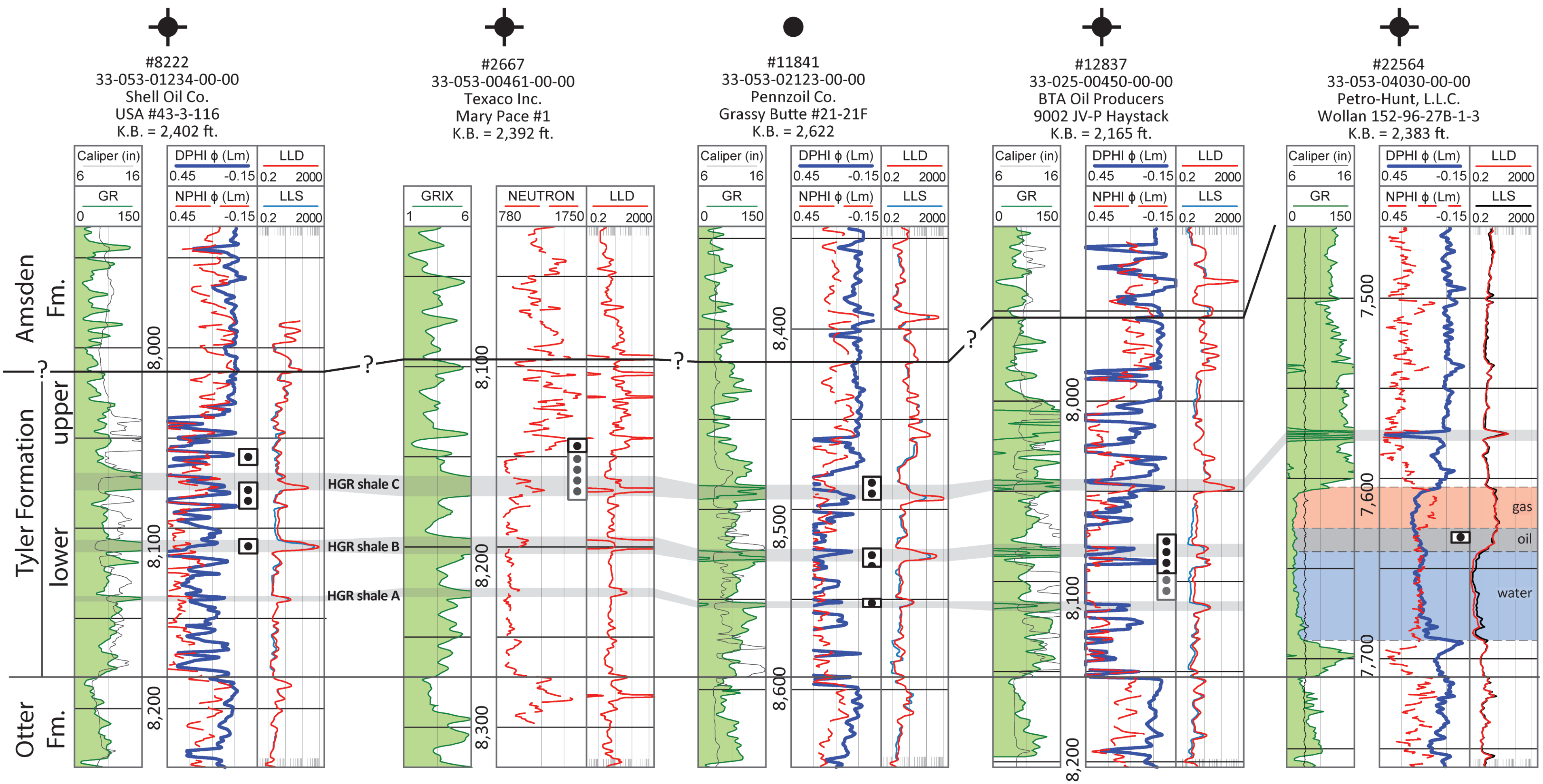

Figure 7. Stratigraphic cross-section of the lower Tyler showing the perforations of the five wells that have commercially produced from the Tyler within the study area. Outlined black dots indicate the perforated interval(s).

Grassy Butte #21X-21F (#11841)

The Grassy Butte #21X-21F was drilled in the Grassy Butte Field which has primarily produced from the Madison and secondarily from the Duperow Pools. The well was initially completed in the Mission Canyon Formation (Madison Group) from which it produced 61 thousand barrels of oil (MBO) over the course of approximately 10 years. After sitting idle for nearly 20 years, the well was recompleted in the lower Tyler with perforations at 8,545-8,549, 8,517-8,527, and 8,477-8,490 ft. (Fig. 7). All three of these perforated intervals targeted each of the three lower Tyler HGR shales. The Tyler perforations were acidized with 3,000 gallons of 15% HCl, swabbed, and put on production. While the initial 24-hour production test yielded 22 BO, the Grassy Butte averaged around 10 BOPD during the first several months before production rates began slowly declining. The well is still actively producing from the Tyler, and in recent years has averaged 3-5 BOPD. Gas production is <1 MCFPD with a GOR of <1 MCF/BO.

9002 JV-P Haystack #1 (#12837)

The 9002 JV-P Haystack #1 (Haystack #1) was initially drilled by BTA Oil Producers in early 1990 as a wildcat well, and later became the discovery well of the Round Top Butte Field. The Madison was initially perforated and tested with unfavorable results. Shortly after, the Tyler was perforated at 8,074-8,095 ft. and acidized with 200 gallons of 10 acetic (Fig. 7). The following day the well then flowed 190 BO, 40 BW, and gas at a rate of 80 MCFPD over the course of 18 hours on a 18/64' choke. A few days later, during 44.5 production hours, the Tyler perforations flowed a total of 374 BO (202 BOPD), 20 BW, and a gas rate of ~41 MCFPD on 12/64" choke. The official initial production test was over a week later and yielded 130 BO, 30 MCF gas, and 6 BW. Oil production ranged from 50-70 BOPD during the first four full months of production and began declining after that, eventually leveling off at around 10 BOPD for several years (Fig. 8). The perforated interval was expanded to include 8,095-8,111 ft. approximately nine years after the initial completion, which did not appear to significantly bolster production (Fig. 8). Then, in December of 2012, the Tyler perforated interval from 8,074-8,111 ft. was frac'd with over 15,000 gallons of gelled water and reportedly 55,000 lbs. of sand. Production rates then climbed back up to 40-50 BOPD for approximately two months before steadily declining and leveling off at around 5-10 BOPD for a few years (Fig. 8). By the time the Haystack #1 was plugged and abandoned, the Tyler perforations had cumulatively produced 46 MBO with only 1,260 BW.

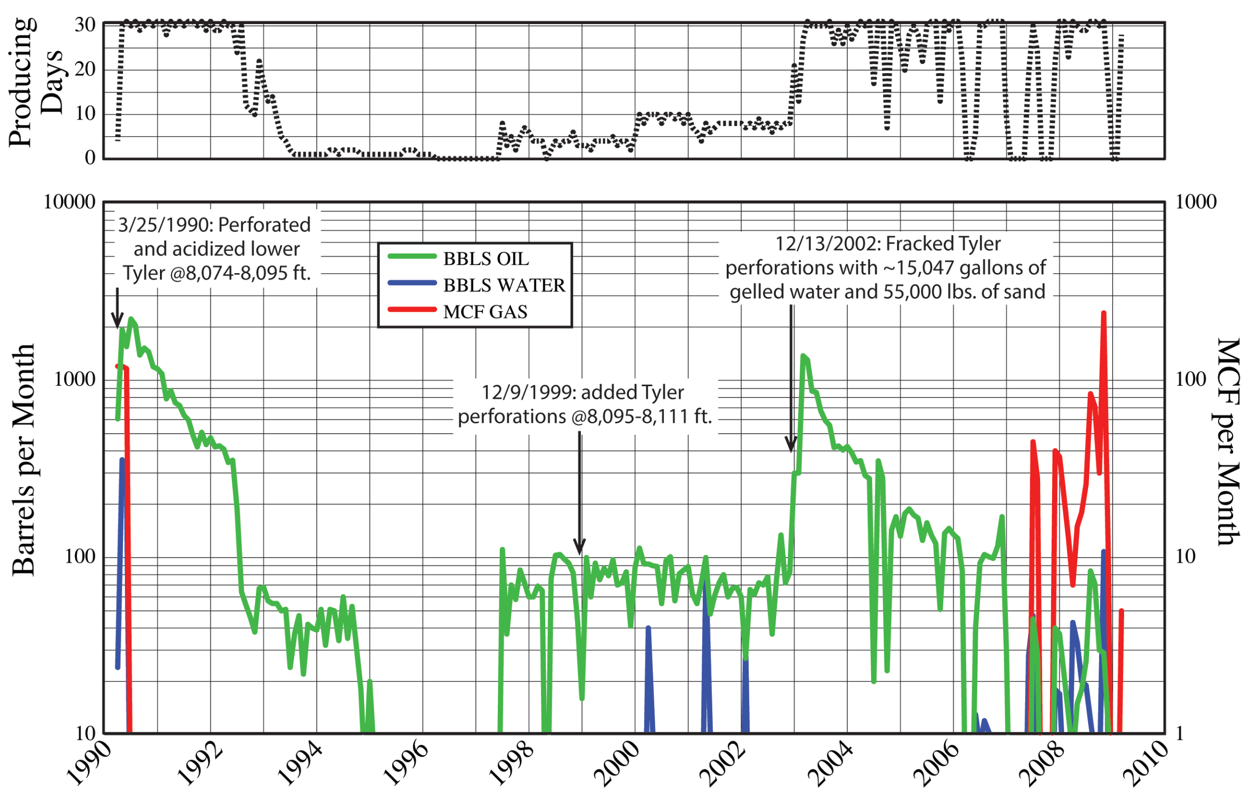

Figure 8. Monthly production diagram for the Tyler oil pool from BTA Oil Producers 9002 JV-P Haystack #1 (NDIC #12837, API: 33-025-00450-00-00, Sec. 32-T148-R97W).

Wollan 152-96-27B-1-3 (#22564)

The Wollan 152-96-27B-1-3 (Wollan), located within the Clear Creek Field, was initially discovered in 1958 and developed through the early 1960's targeting Madison reservoirs. Development of the Bakken-Three Forks play in the field began in 2009. During developmental drilling, one of the Bakken-Three Forks wells encountered a localized (spatially limited) >50 ft. thick porous sandstone within the lower Tyler that appeared to contain a hydrocarbon pay zone overlying a water column. The Wollan was drilled in 2012 as a vertical well targeting that localized Tyler sandstone. Wireline logs revealed a ~10-foot oil column sandwiched between an overlying ~20-foot gas cap and underlain by a ~50-foot water column (Fig. 7). Perforations were placed at 7,630-7,634 ft., which were positioned in the middle of the oil column (Fig. 7), likely to limit both gas and water production. The initial reported 30-day average oil production rate was 95 BOPD and the well was initially estimated to have a EUR of 87 MBO (the EUR was later revised to 101 MBO at the permanent spacing hearing). The oil produced was 36° API oil gravity, but the gas was nearly 80% nitrogen and proved difficult to flare. After 2 ½ years of production, the Wollan was still capable of producing 20-30 BOPD, but was shut in and plugged and abandoned after cumulatively producing just 41 MBO. Increasing water production, difficulties with gas flaring, and the drop in oil prices that began in late 2014 may have contributed to the end of the well's Tyler production.

ADDITIONAL TESTED COMPLETIONS

Federal #18-44 (#7193)

The Federal #18-44 was initially completed in and produced from the Madison Pool from 1980 through mid-1991. During June 1991, the Tyler intervals of 7,814-7,819 and 7,821-7,829 ft. were perforated and flow tested twice (Fig. 9). During the first flow test, a gas sample was collected, analyzed, and found to consist of 97.4% nitrogen with minor amounts of various hydrocarbon gases (<2% total), and minor carbon dioxide (<1%). The second flow test lasted 8 hours and had a reported flow rate of 4,000-5,000 MCFPD. Neither flow test recovered any reported oil or water. The day after the second flow test, the Tyler perforations were squeezed, and the well was later plugged and abandoned.

F-7-144-101 #1 (#8564)

The F-7-144-101 #1 was drilled in northern Billings County within the Devils Pass Field, along the Rough Rider anticline. Drill stem tests run in the Mission Canyon (Madison) and Duperow Formations both had free oil recoveries, and the well was eventually completed and produced 274 MBO from the Madison Pool. However, shortly after the well was drilled and before the Madison completion, two zones at 7,994-8,004 ft. and 8,008-8,018 ft., positioned at the base of the lower Tyler section (Fig. 10), were perforated and acidized with 2,000 gallons. No oil shows were reported by the well-site geologist in or around the Tyler perforated intervals. The Tyler perforations were noted to be non-productive and the well was completed in and produced from the Madison Pool.

Carus #3-30-2B (#9088)

Gulf Oil's Carus #3-30-2B was drilled in the Lone Butte Field, which is located in northwestern Dunn County along the northern portions of the Little Knife anticline. Following an initial completion with minor production from the Madison, perforations in the Tyler section of the Carus #3-30-2B were completed and tested (1988) (Fig. 11). The perforations extended across to above a ~15-foot thick sandstone with 8-16% porosity (density ϕ, sandstone matrix). Notable observations from the wireline logs include: a slight neutron porosity cross-over (an indication of gas in the reservoir), and a divergence of the shallow and deep resistivity (indicative of reservoir permeability). The reported final flow rates from the Tyler perforations were 2,700 MCFPD, 16 BCPD (interpreted as barrels of crude per day), and 16 BWPD. The gas composition was 68.5% nitrogen, 22.8% methane, and <5% ethane, propane, carbon dioxide, and several additional hydrocarbon gases. The Carus was eventually plugged and abandoned without any commercial Tyler production.

Grassy Butte #16-33 (#12928)

The Grassy Butte #16-33 was spudded on June 20, 1990 by Pennzoil Exploration and Production Company. The well was drilled vertically to a total depth of 12,020 ft. and had DST's run on the Mission Canyon, lower Lodgepole, and Duperow Formations. Perforations were initially attempted in the Bakken and Duperow Formations, both of which were unsuccessful. Based on daily activity reports in the well file, the Tyler was initially perforated and

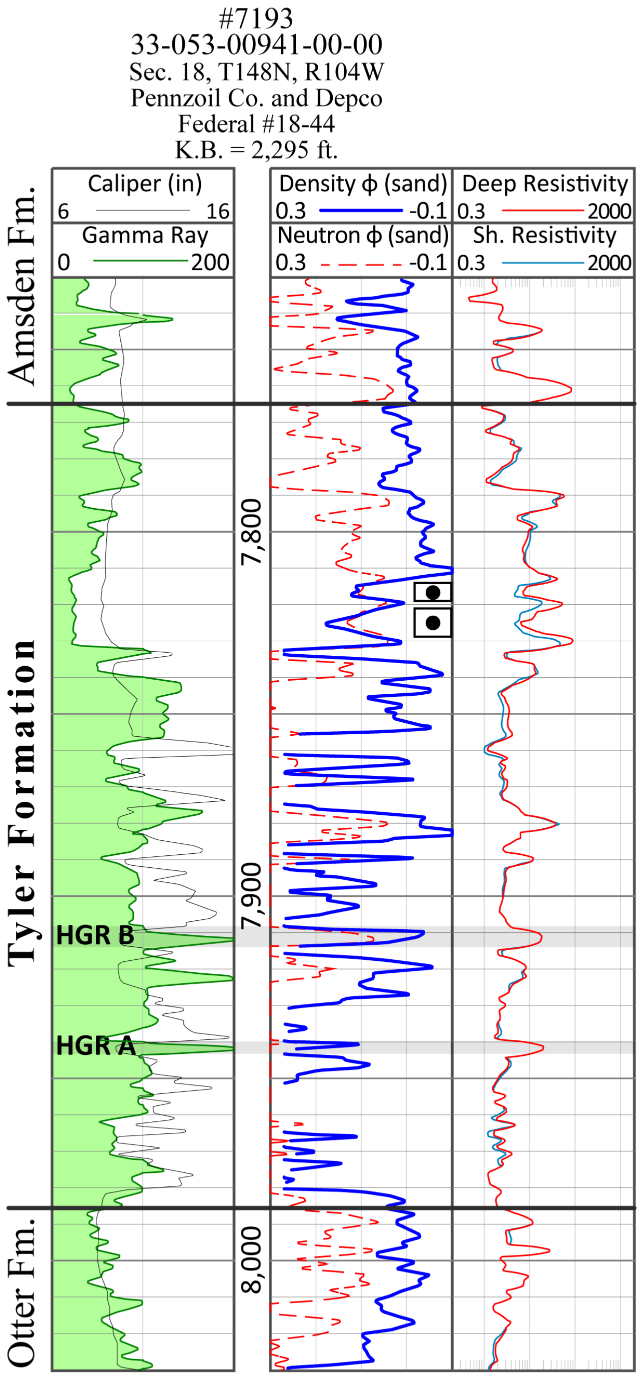

Figure 9. Wireline logs of the Tyler Formation section from Pennzoil's Federal #18-44 showing the perforated intervals (outlined black dots).

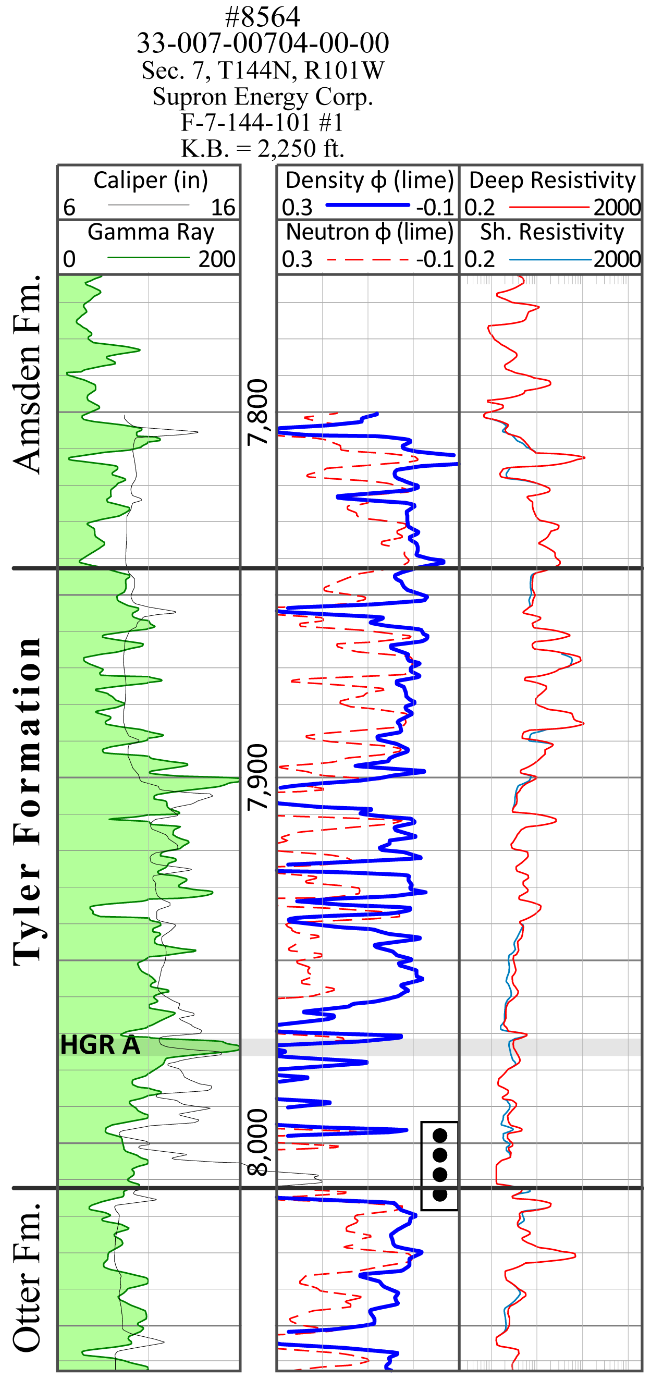

Figure 10. Wireline logs of the Tyler Formation from Supron Energy's F-7-144-101 #1 showing the perforated interval (outlined black dots).

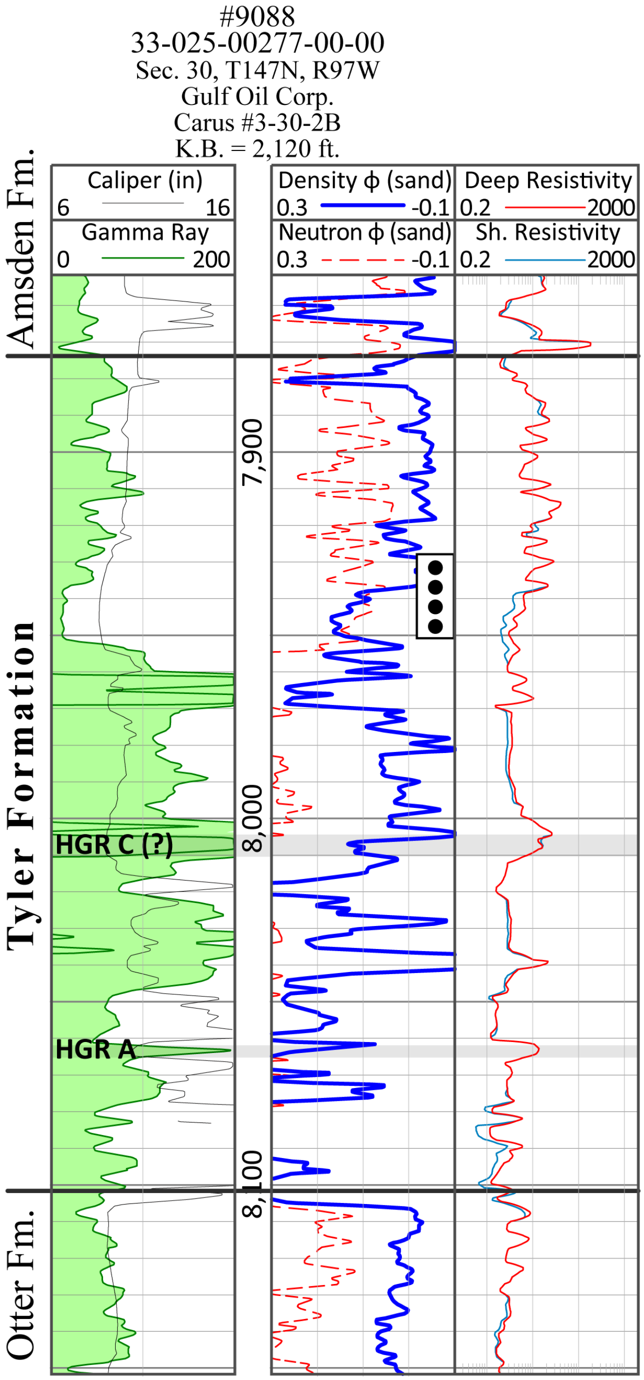

Figure 11. Wireline logs of the Tyler Formation from Gulf Oil's Carus #3-30-2B showing the perforated interval (outlined black dots).

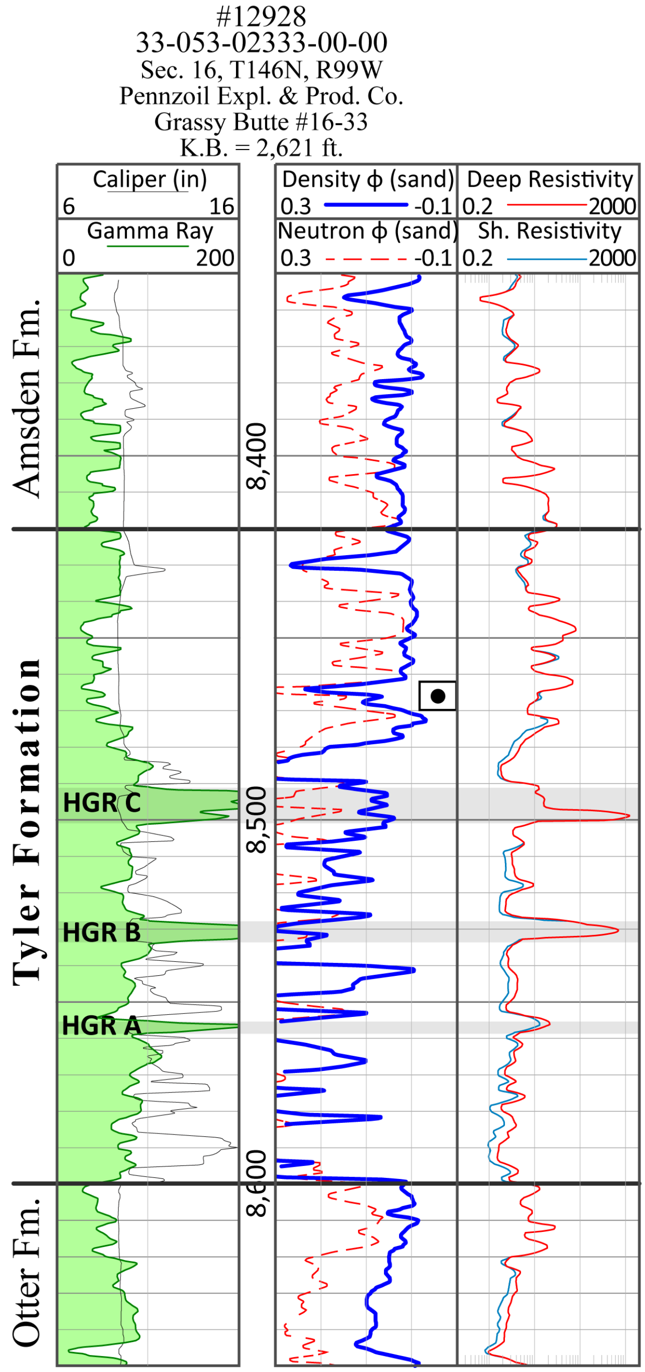

Figure 12. Wireline logs of the Tyler Formation from Pennzoil's Grassy Butte #16-33 showing the perforated interval (outlined black dot).

acidized at 8,462-8,470 ft. (Fig. 12) during August 1994. The wireline logs show an intermediate to low gamma-ray signature (30-50 API) for the perforated Tyler interval, which is higher than the porous sandstones and lower than the MGR and HGR shales. The wireline log porosity is intermediate to high (10-20% - density ɸ, sandstone matrix). The initial perforation attempt yielded only 7.5 BBLS of total fluid over the following few days with trace to minor amounts of oil (<0.2 BO total). The perforations were then hydraulically fractured twice during the following month (September, 1994). The first frac stimulation injected 670 BBLS of fluid with Carbolite (ceramic proppant). During the following 4 days, a total of 94 BW (mostly injected frac fluid) and 24 BO was recovered. During those 4 days, water production (frac fluid) decreased while oil production increased, and on the final day 9.6 BO was recovered with <3 BW (80% oil cut). A second frac stimulation was completed just a few days later which injected 1,488 BW with sand proppant into the Tyler. Somewhere on the order of 10-30 BBLS of total oil was recovered in the initial week following the 2nd frac, but only at a 2-5% oil cut. The well went on to reportedly produce nearly 4,000 BW during the following month (October), at a rate of around 200 BWPD with no reported oil. The well was then eventually recompleted in, and commercially produced from the Mission Canyon Formation (Madison Pool) for nearly 20 years before being plugged and abandoned. Even though the Grassy Butte #16-33 never sustained any commercial production, the first hydraulic fracture stimulation did appear to at least initially bolster production based on the reported daily fluids recovered while the second, larger frac appeared to have tapped into a water productive reservoir that overwhelmed any oil production potential.

Bertinuson #1-31 (#13416)

The Bertinuson #1-31 was drilled as a development well within the Patent Gate Field of central/north-central McKenzie County. The well was initially completed in and produced from the Madison Pool. After several years of Madison production, cumulatively producing ~25 MBO, Tyler perforations were briefly tested at 7,957-7,962 ft. (Fig. 13). The production test lasted only 2 hours and flowed a total of 144 MCF gas (extrapolated 1,725 MCFPD) with a 12/64" choke and no reported oil or water. The collected gas sample consisted of 84,6% nitrogen with moderate amounts of carbon dioxide (8.6%), methane (5.6%), and ethane (1.2%). Based upon the wireline logs, the perforations were positioned at the top of a ~50-foot thick porous sandstone interval. The well was then plugged and abandoned within a year.

Jeffrey #33-33 (#14637)

The Jefferey #33-33 was initially drilled as a horizontal well in the Madison within the Williston Field and produced with an open-hole completion (1997-2013). Multiple sets of perforations were later attempted in the vertical Tyler section of the well (2014) followed by an acid frac (2017). These perforations targeted the medium gamma-ray (80-100 API units) sections which are intermediate of the high gamma-ray, petroleum source bed, black shales (Fig. 14). Only a "trace of oil" was noted from the perforation attempt and the frac was described as "unsuccessful."

Interpretations and Discussion

Review of Lower Tyler Reservoirs

Four of the five commercially productive Tyler wells in the central basin area produced from intervals in and around the HGR shales of the lower Tyler. The USA, Mary Pace, Grassy Butte, and Haystack wells all had lower Tyler perforations that stratigraphically overlapped one or more of the HGR shales (Fig. 7). Based on the wireline logs, none of these wells appear to have any porous sandstones of substantial thickness. The completions of these wells ranged from perforating and acidizing to perforating, acidizing, and hydraulic fracture stimulation.

Two of the lower Tyler fractured reservoir wells have either a corresponding or proximal core of the perforated interval. Only the Mace Pace well has a direct core of the perforated interval, and that core is comprised of dark grey to black shale (including HGR shale C) interbedded with thin, micro-crystalline carbonates. Core-plug porosity values from the Mace Pace core were only 1.0-5.3% with negligible permeability (<0.1 millidarcies). While the Haystack well does not have a corresponding Tyler core, a proximal well (~1 mile away), the Jorgenson 2-29-148-7 (NDIC: 15443), does have a corresponding core to the Haystack #1 perforated and frac'd Tyler interval. The Jorgenson Tyler core does have a sandstone positioned directly beneath the HGR shale B, which has permeability values of 0.08 to 4.09 millidarcy's, but the sand is thin (<3 ft. thick) with porosity values of only 6.3-8.2% and a Jorgenson DST on the Tyler yielded very low flow rates. Additional core-plug data reviewed from lower Tyler cores

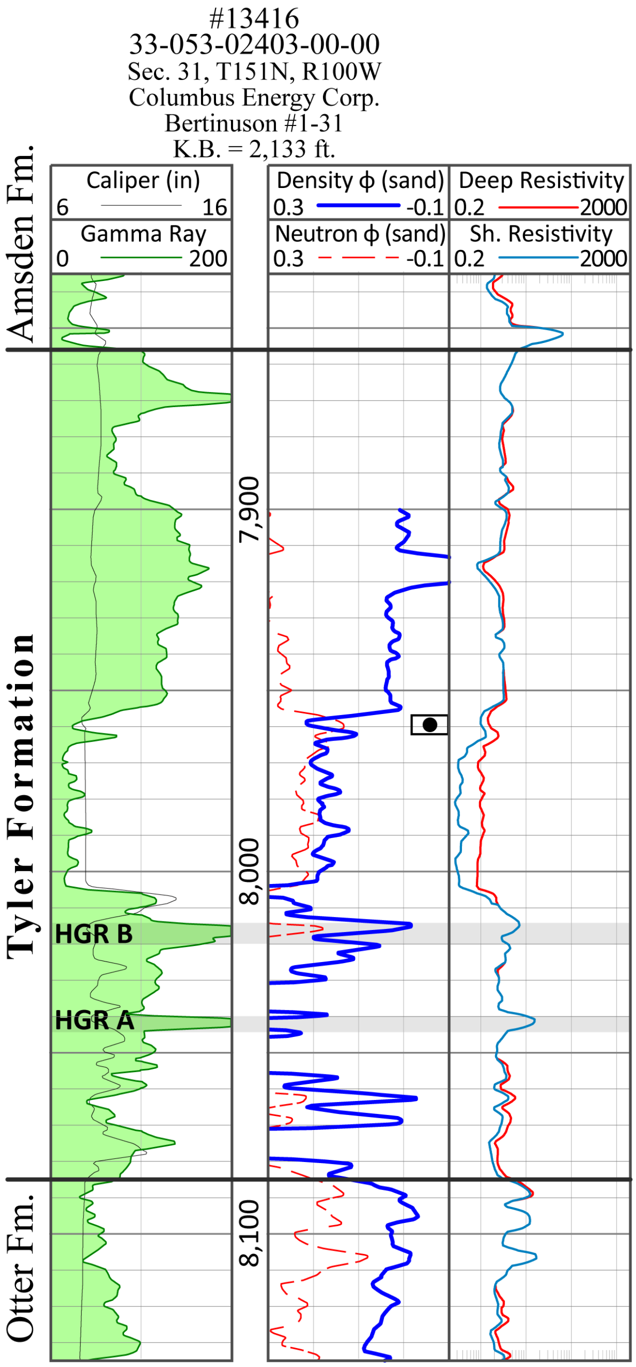

Figure 13. Wireline logs of the Tyler Formation from Columbus Energy's Bertinuson #1-31 showing the perforated interval (outlined black dot).

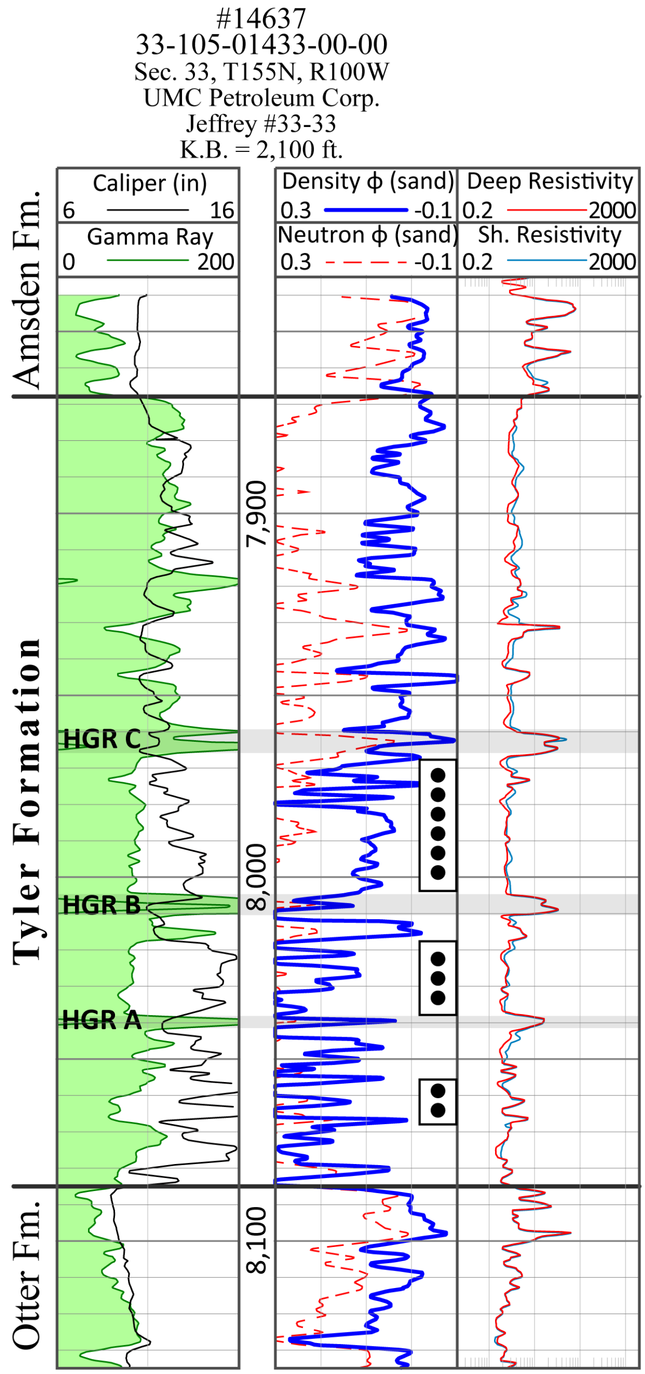

Figure 14. Wireline logs of the Tyler Formation from UMC Petroleum's Jeffrey #33-33 showing the perforated intervals (outlined black dots).

of the HGR shales and interbedded carbonates show porosity values that are usually <5% with permeability values of <<<1 millidarcy. Therefore, in order to produce from such facies, a natural fracture system would likely have to be present to allow for any substantial flow from a vertical well completion.

The fifth commercially productive lower Tyler well, the Wollan, produced from porous sandstone (Fig. 7). Despite the lack of Tyler core data from in and around the Wollan well location, the wellsite geologist report described sandstone through the low gamma-ray portion of the lower Tyler section and the porosity logs (neutron ϕ and density ϕ, sandstone matrix) indicate porosity values of ~20%. Therefore, production from the Wollan appears to represent the first true conventional reservoir production from the lower Tyler petroleum system.

Additional Perforations and Tests

In addition to the five vertical lower Tyler producers, six other vertical well perforations in the lower Tyler section have been attempted and tested. Three additional perforations tested low gamma-ray, porous sandstones that yielded high gas flow rates (1,700-5,000 MCF/day) of nitrogen-rich gas: Federal #18-44 (#7193), Carus #3-30-2B (#9088), and Bertinuson #1-31 (#13416). While the Federal #18-44 and Bertinuson #1-31 perforations flowed exclusively gas (no fluids), the Carus #3-30-2B reported some water and crude oil. This suggests that: 1) the low gamma-ray, porous sandstones in the lower Tyler can have good permeability (based upon high gas flow rates), and 2) the nitrogen-rich gas cap in the Wollan lower Tyler producer is not a spatially limited phenomena, but instead nitrogen-rich gas may be prevalent throughout much of the lower Tyler petroleum system.

Two of the other well perforations targeted the medium gamma-ray intervals, which likely consisted of the paleosol and MGR shale facies: the F-7-144-101 #1 (#8564) and Jeffrey #33-33 (#14637). Neither set of perforations were successful. The Jeffrey #33-33 perforations were treated with 14 BBLS of 15% HCl and was only noted to yield a “Trace of oil found,” with no reported gas or water. The Jeffrey was later acid frac’d, which was described as “unsuccessful.” The F-7-144-101 #1 perforations were located in the base of the lower Tyler section, below the lower most high gamma-ray shale. Also, similar to the Jeffrey #33-33, the F-7-144-101 #1 perforations were acidized, but did not recover any reported oil, water, or gas.

The perforated interval from the Grassy Butte #16-33 appears to be a different, unknown lithology as compared to the other well completions. The Grassy Butte completion interval was drilled in a moderately to highly porous interval approximately 20 feet above the uppermost HGR shale C. This well may have been marginally to moderately productive from the Tyler after the first hydraulic fracture stimulation, but the second frac seemed to have brought in substantial water production that the first frac did not.

Hydraulic Fracturing

Four lower Tyler wells have been hydraulically fractured within the study area based upon available records: Mary Pace #1 (2667) Jeffrey #33-33 (#14637), Grassy Butte #16-33 (#12928), and 9002 JV-P Haystack #1 (#12837). All four of these lower Tyler hydraulic fracture attempts were vertical wells. The Jeffrey #33-33 (#14637) had an acid frac attempt on lower Tyler perforations extending across the MGR shale intervals, which are stratigraphically positioned between to below the HGR shales. The acid frac attempt was described as “unsuccessful” with no additional information in the well file.

The Haystack #1 and Mary Pace #1 wells were frac’d in and around the HGR shales. The Haystack frac, involving 360 barrels (~15,000 gallons) of gelled water with sand proppant, boosted production from around 9 BOPD pre-frac to 40-50 BOPD post-frac for a two-month stretch before once again declining. The gelled diesel and sand frac of the Mace Pace #1 extended across HGR shale C and afterwards sustained 10-12 BOPD for a few months with limited water. Had the Mary Pace completion also included the underlying HGR shales A and B, oil production rates may have been higher and the well might have produced for more than a few months. The Mary Pace frac extended across HGR shale C while the Haystack frac extended across the HGR shale B. When examining caliper logs and cores of the lower Tyler section (at least where the HGR shales are present and sandstone is absent), the most competent and well indurated facies are the HGR shales and interbedded carbonates. Being the strongest, most competent rock may make the HGR shale intervals the most conducive to hydraulic fracturing.

The Grassy Butte #16-33 completion targeted an intermediate/low gamma-ray (30-50 API), moderately to highly porous (10-25% - density ϕ, sandstone matrix) interval located ~20 feet above the uppermost HGR C shale. The initial hydraulic fracture treatment that injected 670 barrels of fluid with ceramic proppant appeared to have been moderately successful, yielding 12 BBLS of total fluid consisting of 80% oil (9.6 BO) on the final day of testing prior to the second frac. However, the second frac, which was slightly larger and injected over 1,600 BBLS of fluid with sand proppant, seemed to end the oil productive viability of this interval as water production went up to 200 BBLS a day with no reported oil. The 2nd frac may have connected into a water productive reservoir which drowned out/ overwhelmed the initial oil productive reservoir.

Based upon the apparent successes of the Mary Pace and Haystack hydraulic fractures, and the initial success of the first and smaller hydraulic fracture stimulation of the Grassy Butte, small fracs in lower Tyler vertical wells appear to be a viable method for stimulating lower porosity, non-sandstone reservoirs. Based on the application of sprayed water onto core samples, the lower Tyler does appear to at least intermittently contain moderate to abundant amounts of fresh water sensitive (swelling) clays. The upper Tyler in southwestern North Dakota also has moderate to high amounts of swelling (smectite) clays (Nesheim, 2017). The risk of using fresh water to drill and/or complete lower Tyler wells should be carefully considered with care. Utilizing diesel-based drilling and completion fluids (such as the gelled diesel used to frac the Mary Pace #1), or another non-aqueous fluid, may be the best alternative for the lower Tyler.

Nitrogen Gas

In addition to hydrocarbons, lower Tyler reservoirs also contain substantial quantities of nitrogen-rich gas in places. Three short-lived (≤24 hours) lower Tyler production tests yielded relatively high gas flow rates of 1,700 to 5,000 MCFPD day with minimal to negligible fluids (Fig. 15, Table 2). All three of those production tests appeared to be from porous sandstones based on the available wireline logs. Also, Petro-Hunt's Wollan lower Tyler conventional producer contained an apparent gas cap over the perforated oil column (Fig. 15). Gas production from the Wollan reached ~1,000 MCFPD of nitrogen-rich gas before declining, and the average GOR of the well was 8.9 MCF/BO when it was plugged and abandoned. Gas analyses from these four wells contained 69% to 97% nitrogen with variable amounts of hydrocarbon gases and carbon dioxide (Table 2). All four of these wells are positioned along anticlinal or monoclinal crests, suggestive of a structural relationship to nitrogen enriched gas (Fig. 15). Gas production from the fractured source beds has generally been <10 MCFPD, with GOR's of <1 MCF/BO. Therefore, nitrogen-rich high gas flow rates from the lower Tyler may be restricted to the porous sandstones, possibly with a structural relationship.

Additional Sandstone Pay

The lower Tyler periodically contains sandstones that range from a foot or so to upwards of 80 ft. thick. These sandstones extend laterally for only a few miles or less. Sandstone wireline log porosity (neutron ϕ and density ϕ, sandstone matrix) is commonly ≤15%, but occasionally reaches 20% or more. In some well penetrations, wireline logs and/or formation gas indicates Tyler sandstones in the central basin area are at least partly hydrocarbon charged (Figs. 16 & 17). In other wells, Tyler sandstones appear water saturated based on very low resistivity, as Tyler waters generally have high salinity and are very electrically conductive (Figs. 16 & 18). The apparent hydrocarbon-charged sandstones (≤10 ft.) are typically stratigraphically proximal to the HGR shales (Fig. 17). The water-charged sandstones are positioned either 10's of feet above or below the HGR shales or are in wells where the HGR shales are absent (Fig. 18). Exceptions, however, do exist (e.g. well #32822 - Fig. 18).

Table 2

Well Information		Perf'd Interval	Choke	Hours Tested	BOPD	BWPD	MCFGPD	Gas Composition**				
NDIC #	API Number							Nitrogen	Methane	CO2	Ethane	Propane
7193	33053009410000	7,814-7,829	20/64"	8	0 (?)	0 (?)	4,000-5,000	97.43	1.08	0.67	0.27	0.16
9088	33025002770000	7,928-7,951	30/64"(?)	?	16	16	2,700	68.55	22.76	1.27	4.19	2.24
13416	33053024030000	7,957-7,962	12/64"	2	0	0	1,725	84.6	5.58	8.61	1.21	0
22564	33053040300000	7,630-7,634*	8/64"	24	80	0	480	78.72	13.92	1.78	2.6	1.15

*Perforated below nitrogen-rich gas cap

**Any additional hydrocarbon gases were present at <1%, and no reported H2S in any of the gas analyses

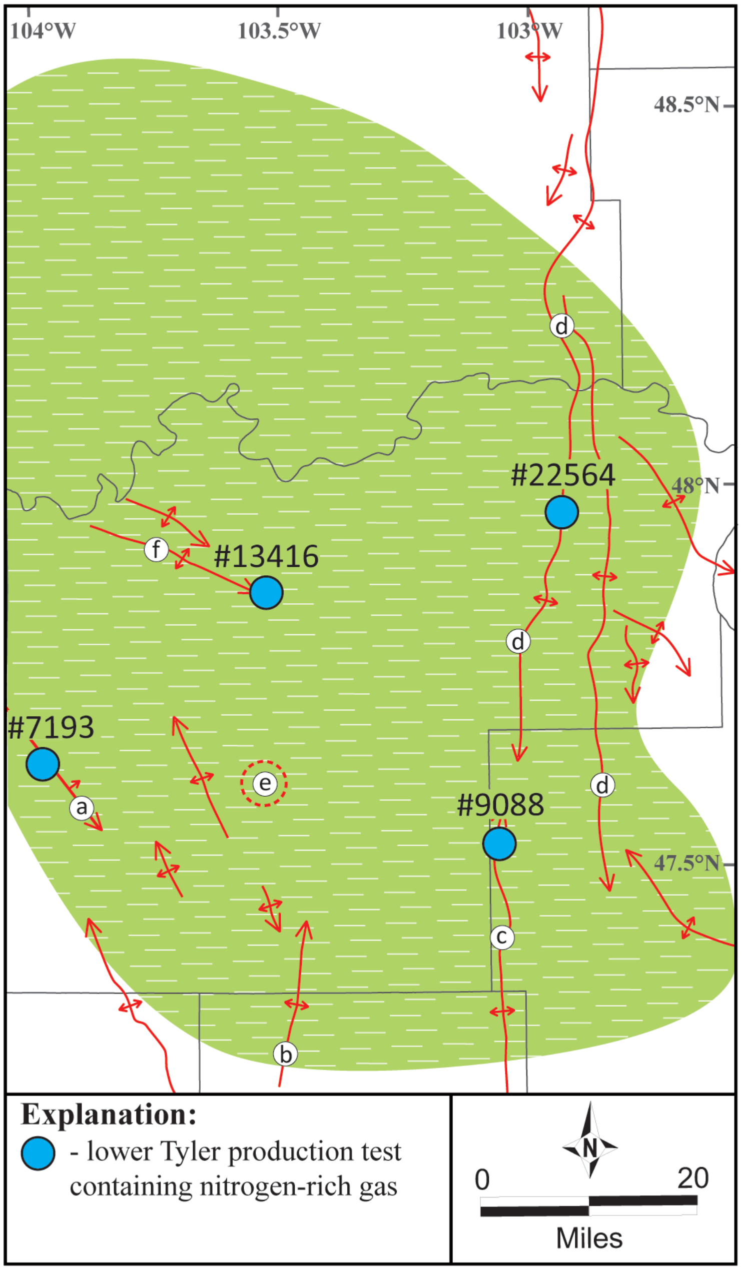

Figure 15. Map of the study area displaying wells that have yielded high gas flow rates (>1,000 MCFPD) of nitrogen-rich (>65%) gas from porous sandstones in the Tyler Formation. Red lines depict anticlines and a monocline. a = Mondak monocline; b = Rough Rider anticline; c = Little Knife anticline; d = Nesson anticline; e = Red Wing Creek structure; f = unnamed anticline

By-Passed Pay Zone for Bakken-Three Forks Wells

The lower Tyler is either Late Mississippian and/or Early Pennsylvanian in age (Grenda, 1977; Nesheim and Nordeng, 2016) which is geologically younger and stratigraphically shallower (by 2,000+ ft.) than the Late Devonian-Early Mississippian Bakken and Three Forks Formations. So far, over 10,000 horizontal Bakken-Three Forks wells have been drilled in western North Dakota, and current drilling rates in the state are adding hundreds of new wells per year. Every Bakken-Three Forks well drilled is another opportunity to gather information on the lower Tyler and other younger, stratigraphically shallower units. Most importantly, the lower Tyler, where present, is a prospective by-passed pay zone within every Bakken-Three Forks well. Any prospective by-passed Tyler pay in a Bakken-Three Forks well is an opportunity to drill an additional oil and gas well and/or a potential re-completion target for an existing well.

Conclusions

- To date, five wells have commercially produced hydrocarbons from the lower Tyler in the central portions of the Williston Basin. Four of these wells are postulated to have produced from fractured source beds while the fifth well produced from porous sandstone. Several additional wells have perforated the lower Tyler with varying production test results.
- Two vertical well play opportunities appear to exist within the lower Tyler across the central basin area: 1) fractured reservoirs consisting of the HGR shales (petroleum source beds) and stratigraphically proximal beds, and 2) localized porous sandstone lenses/beds.
- Small hydraulic fracture stimulations (<1,000 BBLS injected fluid) appear to have been at least moderately successful on the lower Tyler, particularly those that targeted the HGR shales.
- Wireline logs through the Tyler section from recent Bakken/Three Forks wells suggest that dozens of locations may exist where the lower Tyler contains hydrocarbon-charged porous sandstone.
- Three sets of additional Tyler perforations have yielded very high gas flow rates (1,700-5,000 MCFPD) comprised of nitrogen-rich gas (69%-97% nitrogen), which along with the nitrogen-rich gas produced from the one conventional sandstone well demonstrate the lower Tyler can contain notable nitrogen gas.
- Bakken-Three Forks well logs should be examined for potential bypassed pay in the lower Tyler in the form of fractured source beds and/or porous, hydrocarbon-charged sandstones.

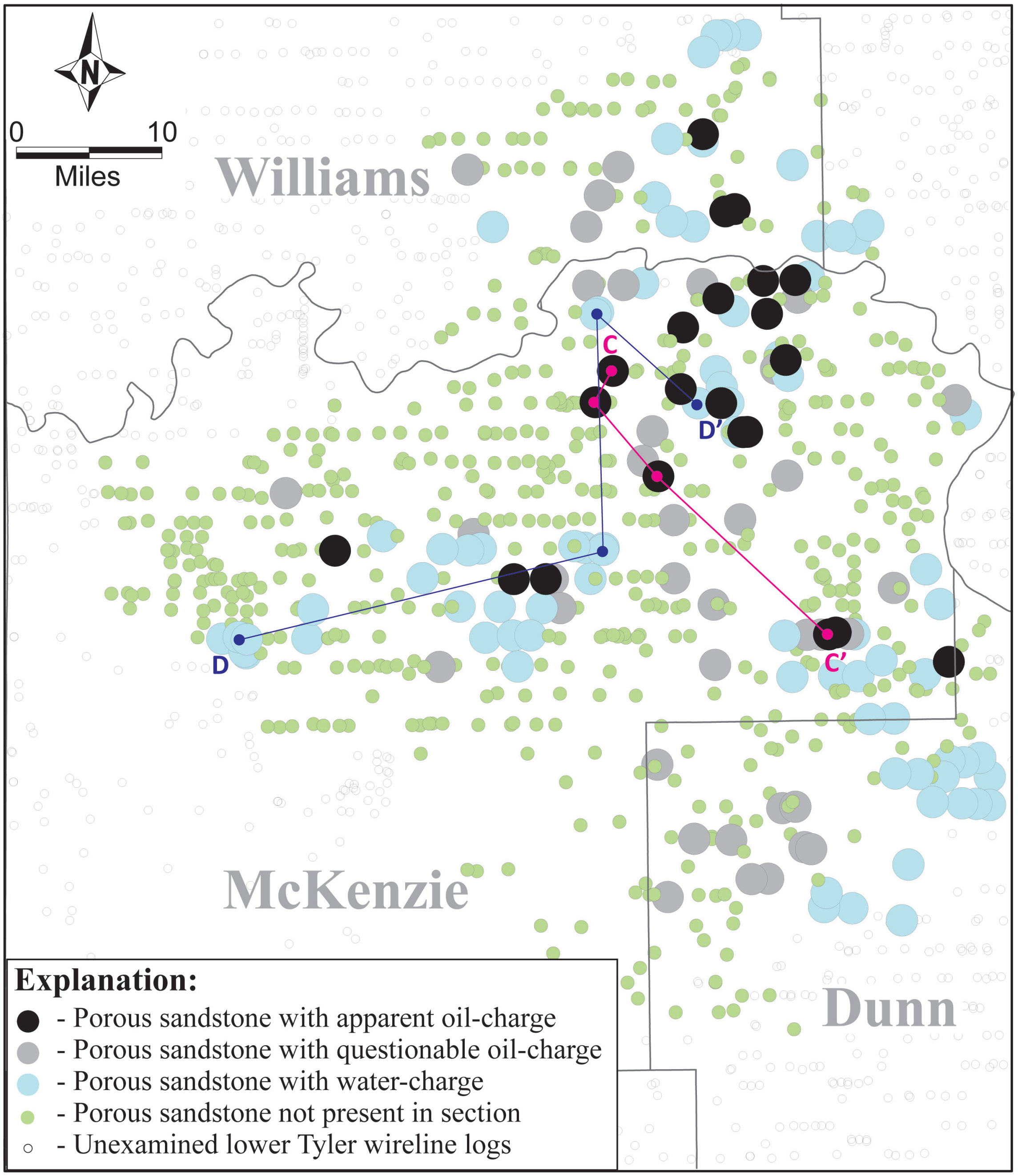

Figure 16. Map of the study area showing the distribution of wells with wireline logs that were examined for porous sandstones.

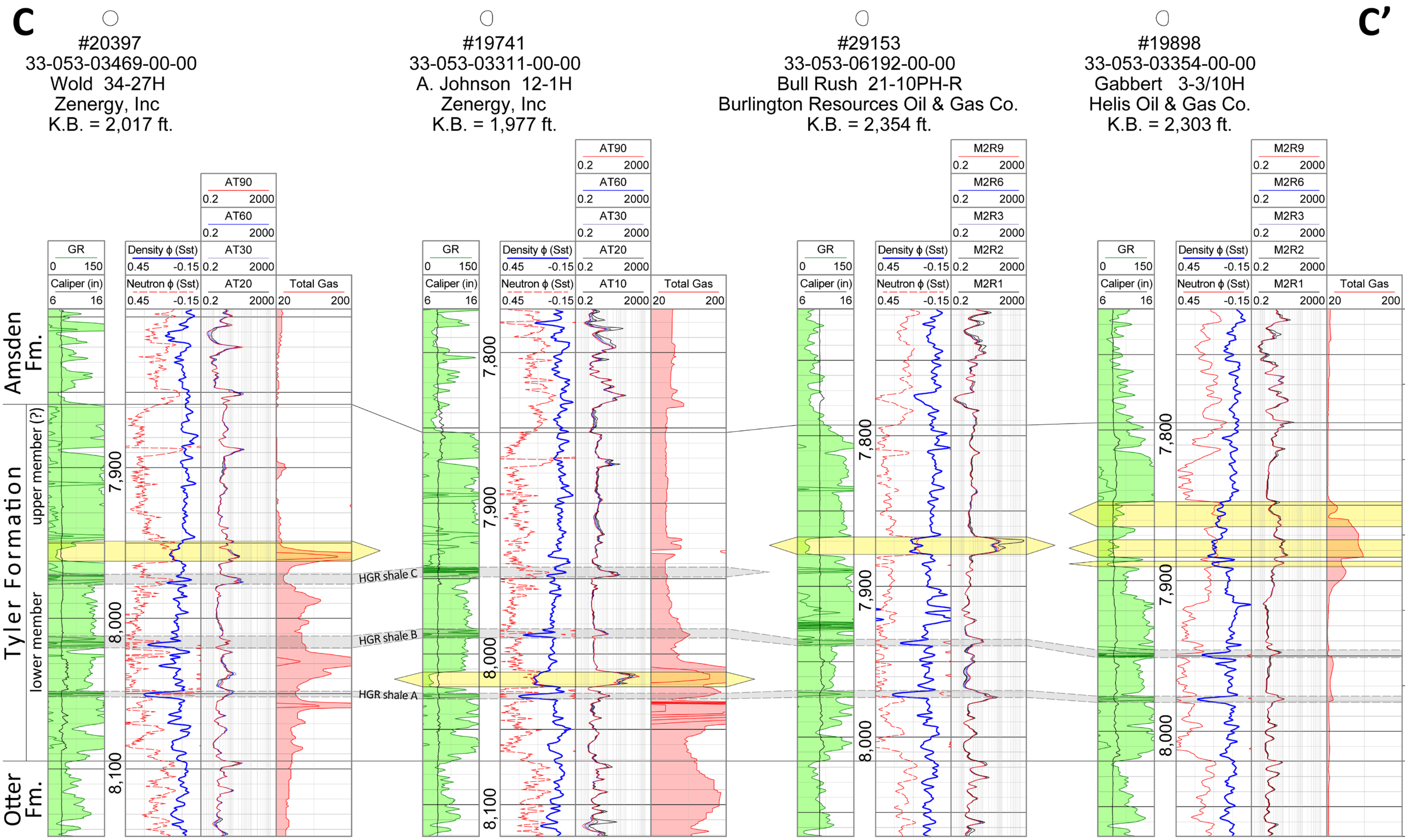

Figure 17. (Bypassed pay cross-section) wireline log cross-section of the Tyler Formation showing examples of bypassed sandstone pay (yellow fill) within the Tyler Formation. Note how the log porosity (neutron ϕ and density ϕ, sandstone matrix) is typically 10-15% with a low gamma-ray and notable increases in associated resistivity and total gas. The high gamma-ray (HGR) shale petroleum source beds are correlated with grey fill.

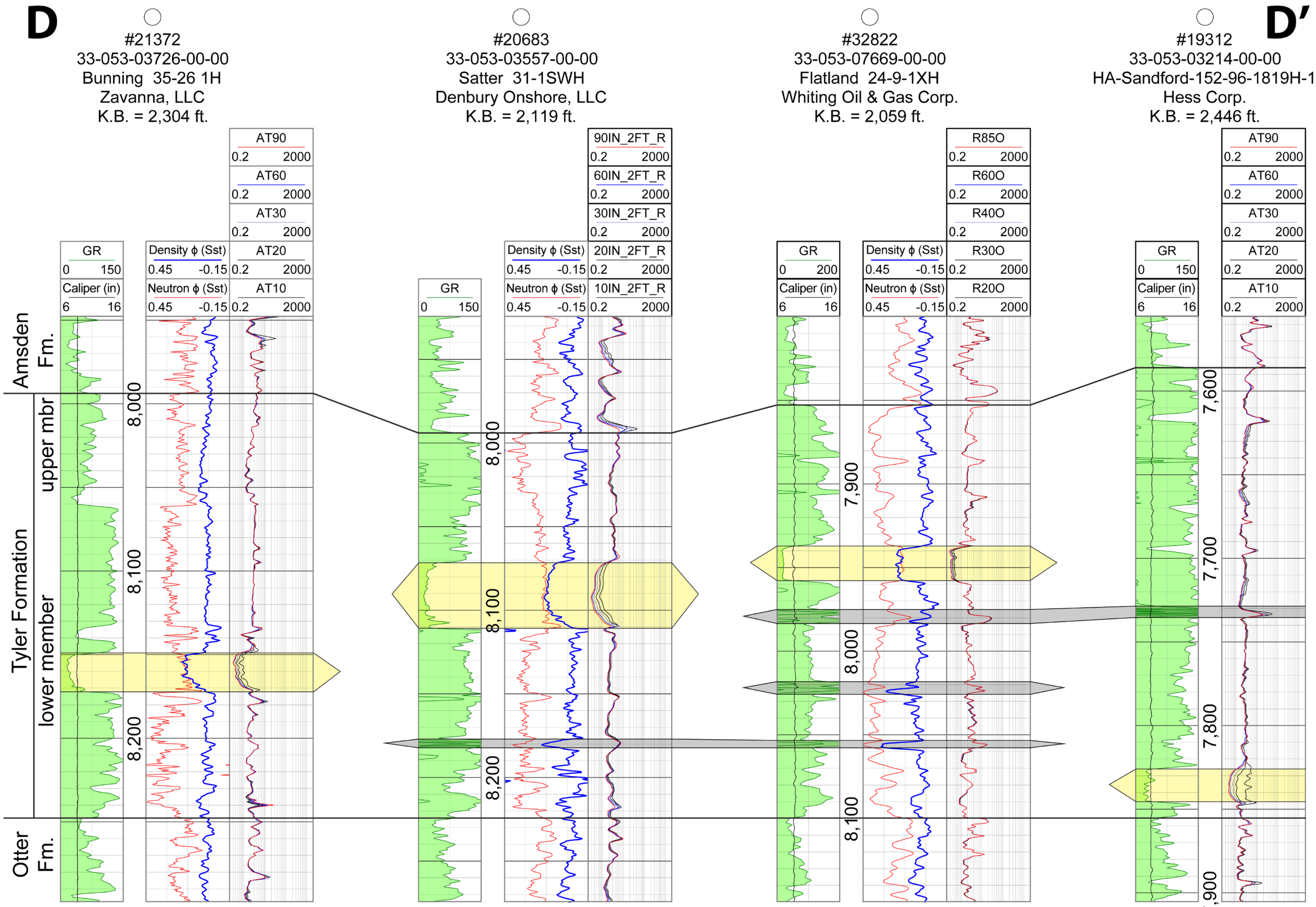

Figure 18. Stratigraphic cross-section of the Tyler Formation showing examples of porous sandstones (low gamma-ray signature with overlapping neutron ϕ and density ϕ, sandstone matrix) that appear to be primarily water saturated (low resistivity).

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