Sedimentology, Stratigraphy, and Regional Facies Architecture of the Middle Three Forks Formation (Upper Devonian), Western North Dakota

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ABSTRACT

The middle Three Forks is a productive reservoir within the Bakken-Three Forks Petroleum System but has limited corresponding published literature focused on the sedimentology and stratigraphy of the unit. A total of 27 spatially distributed cores, over 100 thin sections, and XRD data of the middle Three Forks and bounding stratigraphic units were examined for this study. The middle Three Forks can be subdivided into three primary facies associations (FA): 1) wave-rippled to planar laminated dolostone, 2) poorly laminated silty mudstone, and 3) conglomeratic facies associations (FA). The conglomeratic FA is comprised in part of dolostone, mudstone, and claystone clasts, appearing to be a mixture of the laminated dolostone FA and silty mudstone FA. Deposition is interpreted to have occurred along a low-angle ramp in which the laminated dolostone FA was deposited within a predominantly subaqueous, wave-influenced tidal/mudflat setting adjacent to a coastal plain (silty mudstone FA). The conglomeratic FA developed along the shoreline, intermediate of the laminated dolostone FA and silty mudstone FA. Within the primary area of horizontal well production for the unit, the middle Three Forks reservoir largely consists of the variably textured conglomeratic FA, which may range from a relatively poor-quality to excellent quality reservoir facies.

INTRODUCTION

The Bakken and Three Forks Formations combine into the most prominent oil and gas play within Williston Basin of North Dakota. More than 15,800 horizontal wells have been drilled and completed between the two units within the state during the past 15 years. Cumulative Bakken-Three Forks production presently totals more than 3.7 billion barrels of oil and 5.8 trillion cubic feet of gas (Fig. 1) (NDOGD, 2021a). Additionally, drilling and production activity in the Bakken-Three Forks extends into Montana, Saskatchewan, and Manitoba (Fig. 1). The majority of horizontal wells within the Bakken-Three Forks petroleum system have targeted either the Middle Bakken Member or the upper Three Forks.

The middle Three Forks has developed into an additional reservoir within the Bakken-Three Forks petroleum system during the early 2010's. Coring activity of the middle Three Forks began to notably increase in 2011, followed by horizontal test well drilling initiated in late 2012 and completions in early 2013 (Nesheim, 2020a). To date, drilling and completion activity targeting the middle Three Forks peaked in 2014 when approximately 73 horizontal wells were drilled within the unit along with 56 total well completions (Nesheim, 2020a). An additional 99 horizontal middle Three Forks wells were drilled with 169 well completions from 2015 through the end of 2019 (Nesheim, 2020a). More than 280 horizontal wells have been drilled and completed within the middle Three Forks Formation to date (Nesheim, 2020b). During 2018 and 2019, production from middle Three Forks wells accounted for approximately 3% of the total Bakken-Three Forks oil production with cumulative production totals of over 57 million barrels of oil and 120 billion cubic feet of gas through the end of 2019 (Nesheim, 2020a).

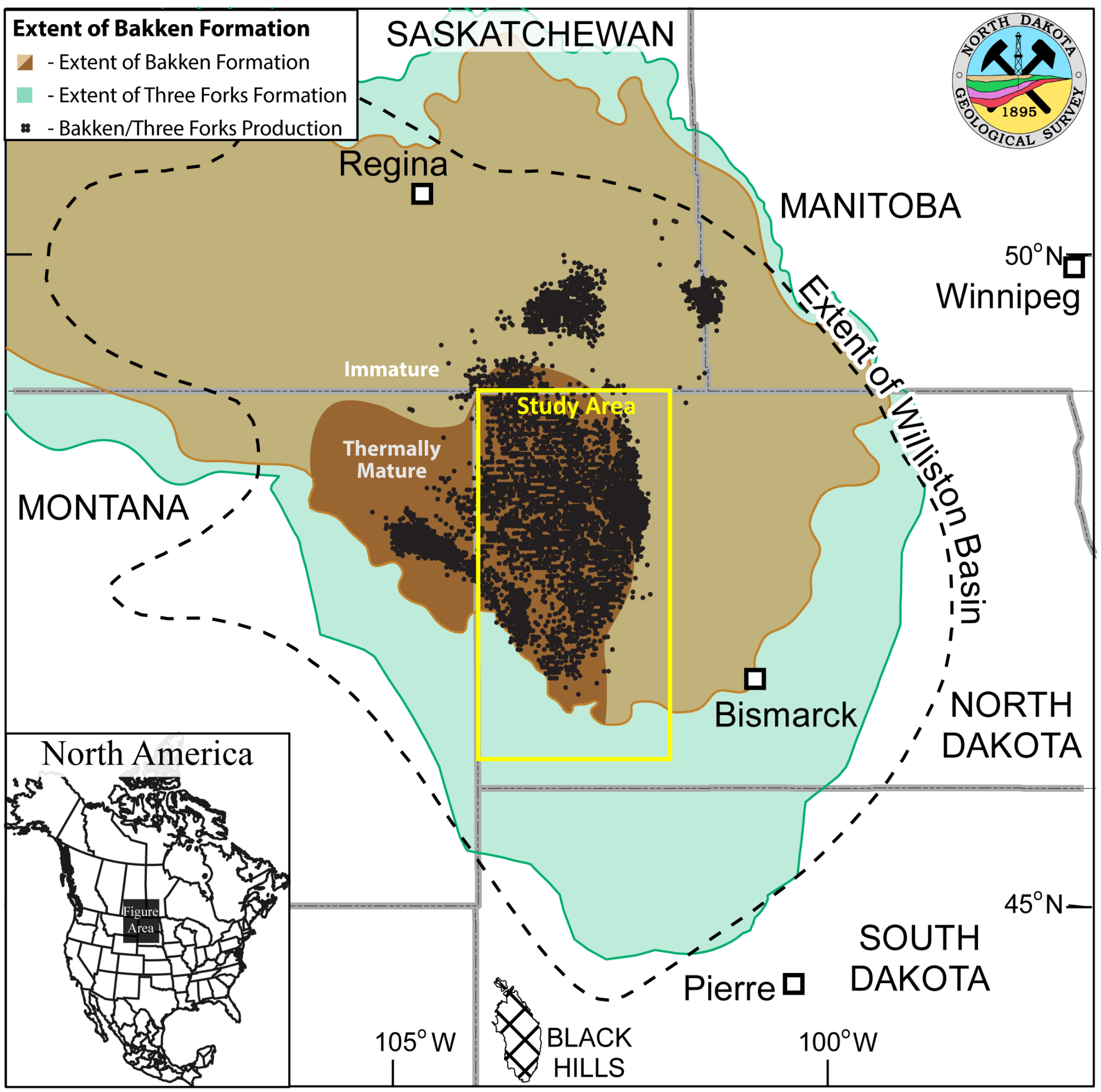


Figure 1. Regional map of the Williston Basin displaying the extent of the Bakken and Three Forks Formations. The yellow outline approximates the extent of the Figure 4 study area.

Multiple studies have examined the sedimentology and stratigraphy of the entire Three Forks Formation (Bottjer et al., 2011; Franklin and Sarg, 2018; Garcia-Fresca et al., 2018; Hogancamp et al., 2019) or just the upper Three Forks (Berwick and Hendricks, 2011; Sesack, 2011; Kolte, 2014). However, there has been limited published information focusing on the middle Three Forks. Droege (2014) is the only publicly available study that examines the sedimentology, stratigraphy, and reservoir quality of the middle Three Forks. However, Droege's study was completed within a relatively limited area of extent and with a limited number of cores spanning the entire middle Three Forks section. Therefore, the focus of this report is to examine the sedimentology, stratigraphy, and regional facies architecture of the middle Three Forks.

GEOLOGIC BACKGROUND

The Three Forks Formation in western North Dakota has previously been described as a mixed carbonate-siliciclastic unit comprised of claystone, dolomitic to siliciclastic mudstone, dolostone, conglomerates/breccias with lesser amounts of anhydrite and sandstone (Bottjer et al., 2011; Droege, 2014; Franklin and Sarg, 2018; Garcia-Fresca et al., 2018). The Three Forks lacks fossil assemblages, making direct biostratigraphic age constraints impossible. However, biostratigraphy from the overlying Bakken and underlying Birdbear Formations dictate that the Three Forks was deposited during the Late Devonian (Famennian) (Fig. 2) (Sandberg and Hammond, 1958; Holland et al., 1987; Thrasher, 1987). The Williston Basin was connected to the open ocean during the Devonian through a linear trough-like depression referred to as the Elk Point basin. The Sweetgrass arch formed a paleo-topographic high within the Elk Point Basin in the Late Devonian, restricting communication between the open ocean and the Williston Basin during Three Forks deposition (Fig. 3) (Franklin and Sarg, 2018; Garcia-Fresca et al., 2018).

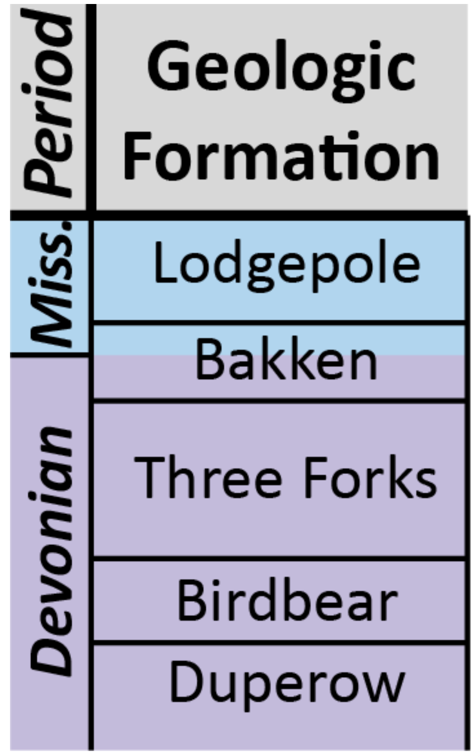


Figure 2. Stratigraphic column of the Three Forks Formation and bounding units. Modified from Murphy et al., (2009).

Multiple depositional settings have been proposed for the Three Forks Formation. Most recently, Franklin and Sarg (2018) interpreted that the Three Forks was deposited within an intrashelf siliciclastic-enriched basin with a variable, restricted marine connection. Alternatively, Garcia-Fresca et al. (2018) proposed that Three Forks deposition occurred within a continental setting with minimal to negligible marine influence, comparable to a playa lake or continental sabkha setting. Examining the middle Three Forks, Droege (2014) interpreted deposition along a shallow carbonate-siliciclastic ramp within an overall restricted marine, hypersaline water conditions.

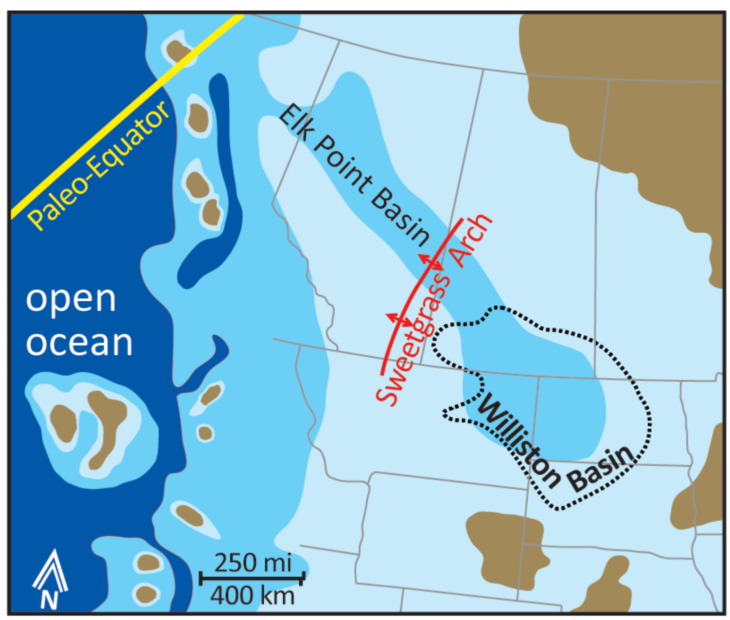


Figure 3. Paleogeographic map of central North America during the Devonian, interpretation based upon Blakey's Deep Time Map series. Brown areas depict exposed land while blue areas depict water.

Multiple stratigraphic nomenclature systems have been developed and utilized for the Three Forks Formation within the Williston Basin (Fig. 4). Christopher (1961, 1963) developed a six-unit system reflecting broadly alternating dolomite-anhydrite versus more argillaceous horizons in the Three Forks equivalent Torquay Formation across southern Saskatchewan, which was later correlated into western North Dakota (LeFever and Nordeng, 2008; LeFever et al., 2009; LeFever et al., 2011). Bottjer et al. (2011) adopted a more simplified three-member stratigraphic nomenclature system (upper, middle, and lower members) that subdivides the section utilizing the tops of the high gamma-ray equivalent intervals of Christopher units 3 and 5 (Fig. 4). A five-member system has also been utilized in some publications (LeFever et al., 2013; 2014; Garcia-Fresca et al., 2018). Most recently in published literature, Hogancamp et al. (2019) subdivided

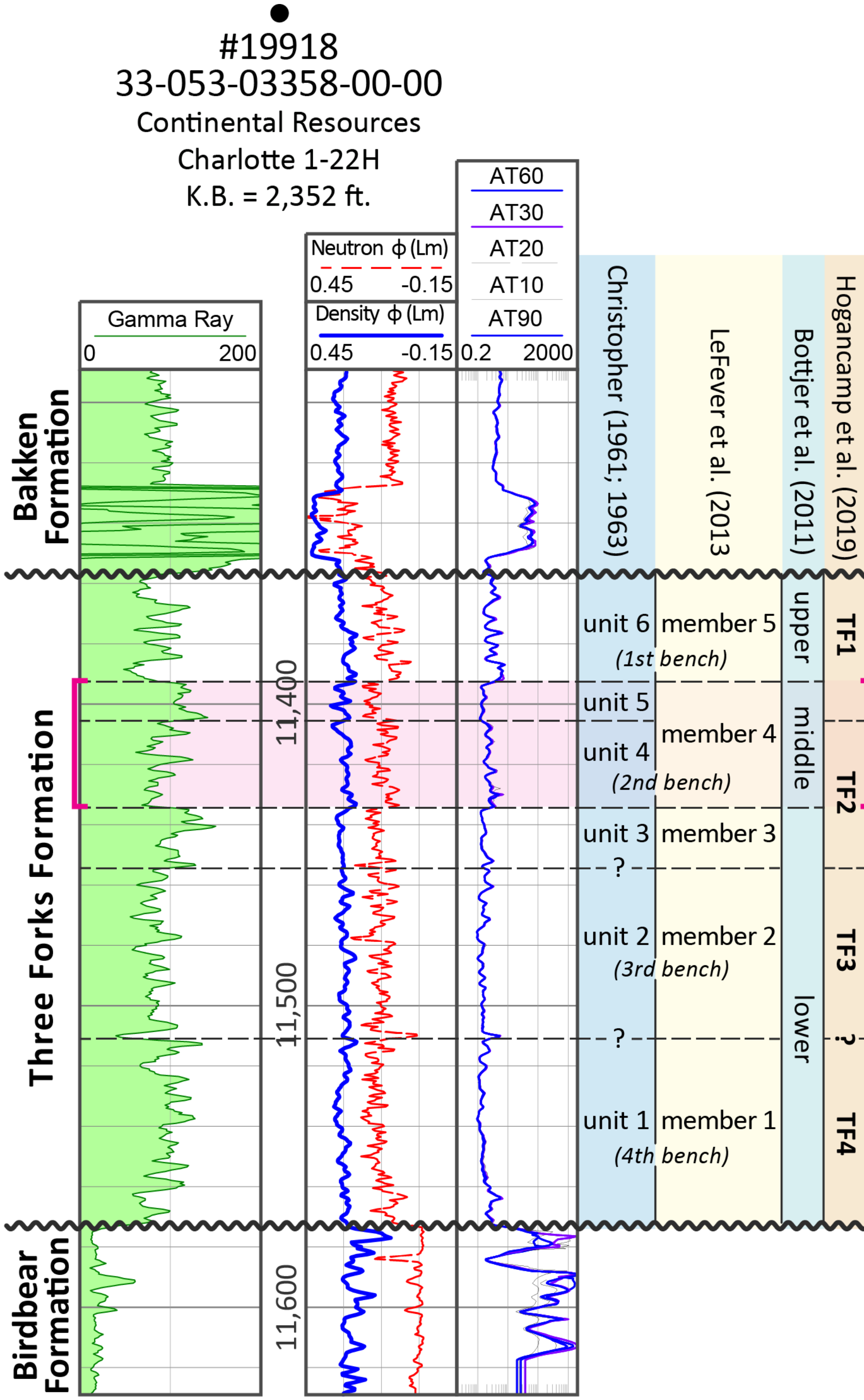


Figure 4. Wireline log example of the Three Forks Formation with various stratigraphic nomenclature systems that have been utilized to subdivide the formation. The pink bracketed and shaded interval depicts the primary stratigraphic section of interest.

the Three Forks into four subunits referred to as Three Forks 1 to Three Forks 4 in descending order. The Hogancamp Three Forks 1 and 2 subunits appear to be the combination of Christopher units 5-6 and units 3-4 (Fig. 4). Additionally, some Bakken-Three Forks operating companies have adopted a 4-bench terminology system which approximately corresponds with four generalized stratigraphic/reservoir target intervals (Fig. 4). A more complete summary and review of correlation comparisons of most of the above stratigraphic systems can be found in Nesheim (2019).

The Bottjer et al. (2011) upper-middle-lower member nomenclature will be utilized throughout this report with secondary reference to the Christopher (1961, 1963) six-unit system. Hereafter, the middle Three Forks will be abbreviated as MTF, which is approximately equivalent to the combined section of Christopher units 4 and 5. The lower MTF term is approximately equivalent to the Christopher unit 4 and the upper MTF approximately equivalent to Christopher unit 5.

METHODS

A total of 28 complete to near-complete MTF cores, spatially distributed across western North Dakota, were logged at the Wilson M. Laird Core and Sample Library (Fig. 5). For each core, the entire MTF section was logged as well as 10 to 20 feet or more of the overlying upper Three Forks and greater than 20 feet of the underlying lower Three Forks (typically 100+ feet per core). Additionally, over 100 thin sections were also examined and incorporated with the corresponding core descriptions.

A total of 117 X-ray diffraction (XRD) analyses of core chip samples from six of the Three Forks cores were compiled from the NDIC database (NDOGD, 2021b). Of those, 65 were from the MTF (units 4 and 5), 39 from upper Three Forks (unit 6), and 13 from the lower Three Forks (unit 3). XRD analyses were subdivided by both Three Forks stratigraphic subunits as well as facies associations for MTF samples. All XRD sample data presented herein is in weight percent, with analyses completed at multiple labs.

Detailed core-log illustrations were examined and compared with one another to determine the typical stacking pattern(s) of lithofacies (cycles) within the MTF section. Stratigraphic cross-sections were prepared using the core-log illustrations to further examine the vertical as well as lateral distribution of the various MTF lithofacies across the study area of western North Dakota.

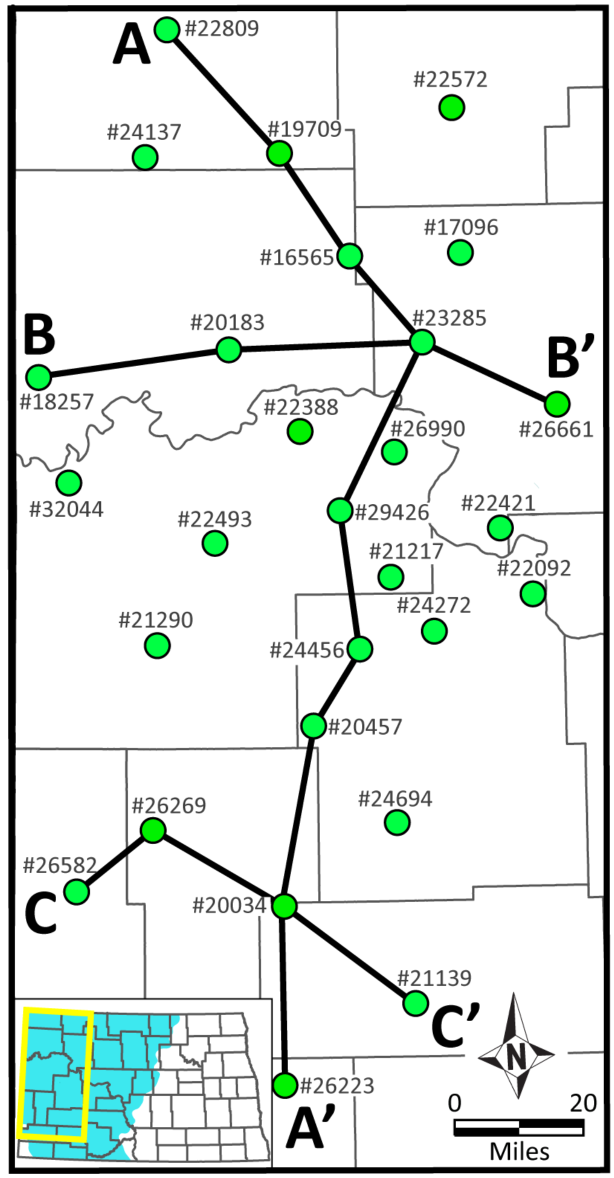


Figure 5. Map of the study area showing core locations (green circles), county outlines (light grey lines), North Dakota Industrial Commission well numbers, and cross-section locations. Index map of North Dakota in the bottom left corner with county outlines (grey lines), study area (yellow outline), and Three Forks Formation extent (blue area).

SEDIMENTOLOGY

The MTF can be subdivided into three primary lithofacies associations that comprise the section: laminated dolostone, silty mudstone, and dolostone-clast conglomerate. Comparable facies have been previously identified/described within the Three Forks Formation (Droege, 2014; Franklin and Sarg, 2018; Garcia-Fresca et al., 2018). Textural descriptions and interpretations from core- and thin-section analyses are listed below.

Laminated Dolostone Facies Association

Description:

This facies consists of pinkish tan to greyish tan, silty laminated dolostone (Fig. 6 & 7). Laminations vary in texture from flat, continuous, planar, and horizontal to gently inclined (≤5°) or wavy, discontinuous, parallel to non-parallel, and sub-horizontal (Fig. 6A-B). Scouring surfaces are occasionally present (Fig. 6A-B) as well as limited ball and pillow structures (Fig.6E). In thin-section, silt-sized rhombic dolomite crystals are present in addition to variable amounts of suban-

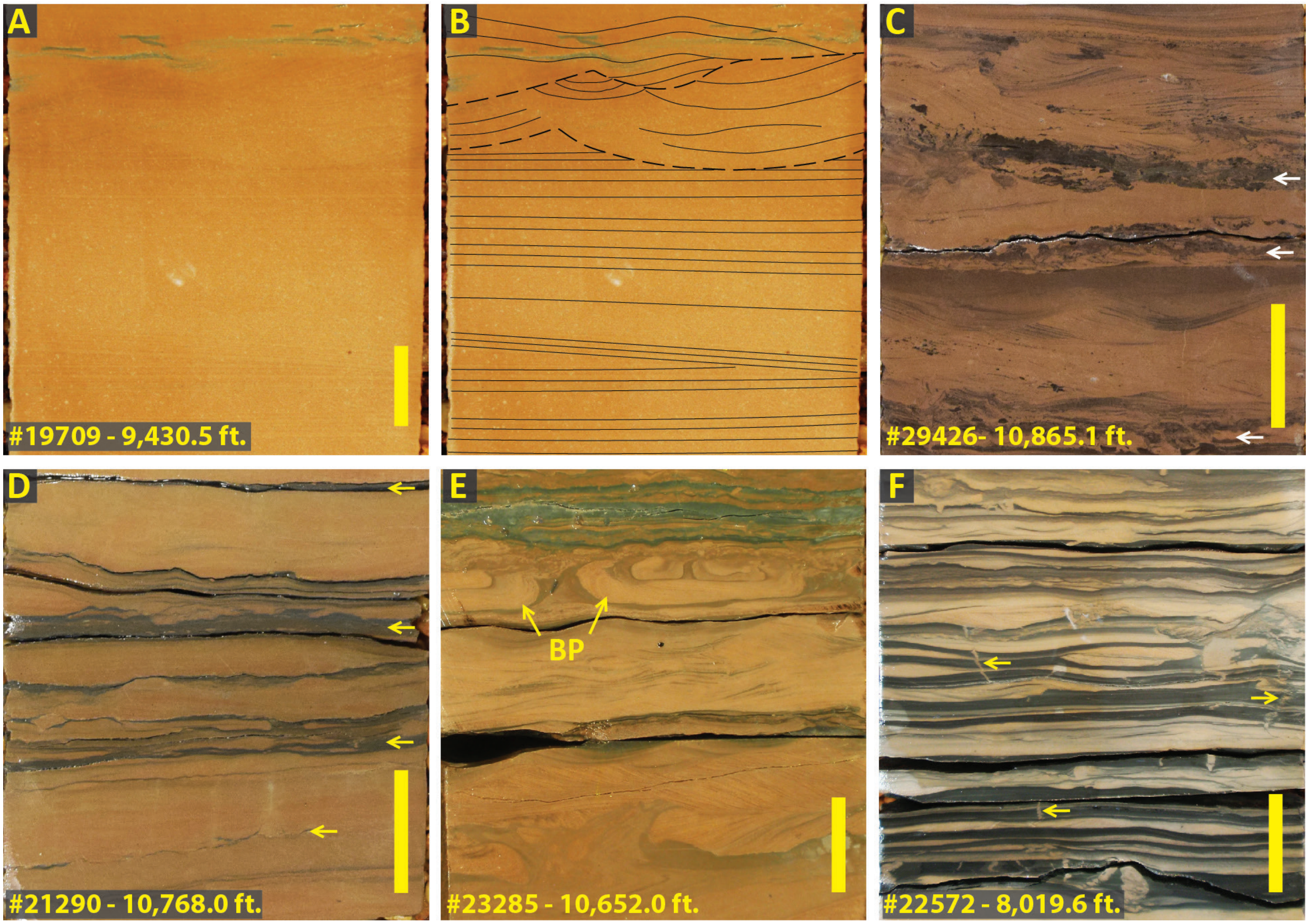


Figure 6. Core photographs of the laminated dolostone facies association. A-B) Light tan-brown, silty planar to ripple laminated dolostone with minimal clay content. A) is a clean photograph and B) is an illustrated copy with solid black lines tracing laminae surfaces and dashed lines tracing scouring surfaces. C) Medium to dark brown laminated dolostone with thin, horizontal brecciated intervals (white arrows). D) Silty laminated dolostone with semi- to discontinuous grey-green mudstone/claystone laminae (yellow arrows). E) Laminated dolostone with ball and pillow structures (BP). F) Intercalated tan-brown silty laminated dolostone and planar dark grey-green claystone with syneresis cracks (yellow arrows). Bottom left corner of each photograph includes NDIC (North Dakota Industrial Commission) well number and core depth. Thick yellow line in bottom right corner is a 1-inch scale bar.

gular to rounded, silt-sized quartz grains (Fig. 7A-D). Pebble-sized or smaller rip-up and/or claystone clasts are occasionally present (Fig. 6C). Grey-green mudstone/claystone is present in some of the laminated dolostone intervals in the form of discontinuous and sub-horizontal laminae (Fig. 6D-E). Distinct beds of the laminated dolostone facies range from approximately an inch to upwards of 2-feet in thickness. One- to two-foot-thick intervals are present in some cores in which the silty laminated dolostone facies is intercalated with approximately horizontal, dark to medium grey-green claystone that contains minimal silt-sized grains/crystals (Fig. 6F & 7E-F). Syneresis cracks are commonly associated with the intercalated sub-facies (Fig. 6F).

The laminated dolostone FA XRD analyses (12 samples) contain between 2% to 16% total clay (9.5% average) with 20.9% to 46% silicates (30.9% average) and 48% to 75% carbonates (59.5% average) (Fig. 8). Carbonate minerals are comprised entirely of dolomite. Negligible anhydrite was detected along with only trace amounts (1%) of pyrite in some samples.

<u>Interpretation:</u>

Low overall clay content combined with high concentrations of silt-sized grains indicates deposition within a relatively continuous, high-energy setting that has removed clay and concentrated silt. Minimal oxidation with negligible desiccation/mud cracks suggests deposition in a near-continuously submerged aqueous setting. Wave-ripple and planar laminations reflect grain transport through wave and current energy, likely occurring above fair-weather wave base (Kumar and Sand-

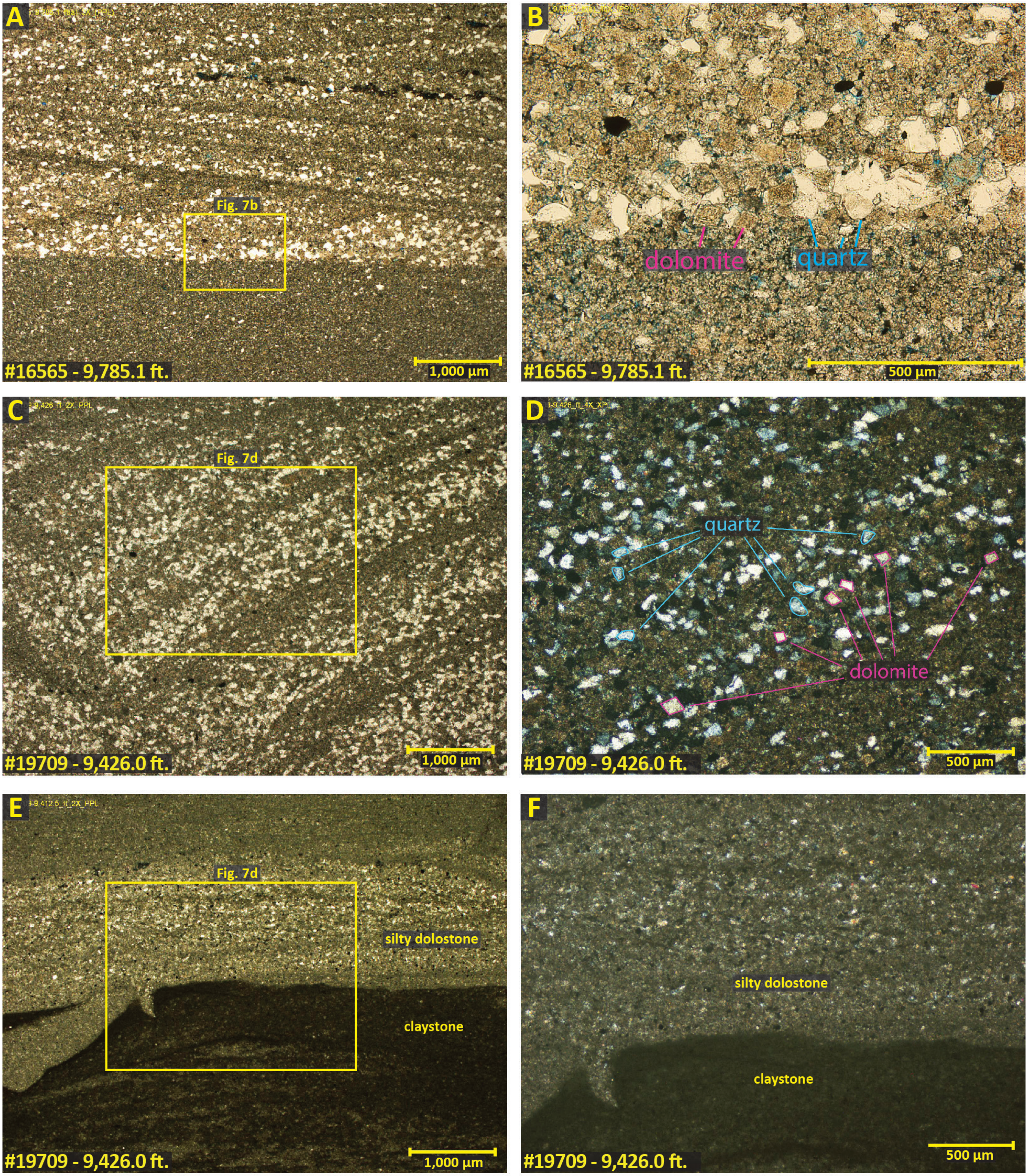


Figure 7. Photomicrographs from thin sections of the middle Three Forks silty laminated dolostone facies. A-B) Ripple laminated and cross bedded example at different magnifications showing notable amounts of porosity (blue-stain), both in plane polarized light. C-D) Cross-bedded example with alternating relatively finer- and coarser-grained laminae at different magnifications (5C in plane polarized and 5D in cross polarized light). E-F) Laminated silty dolostone underlain by grey-green claystone. NDIC (North Dakota Industrial Commission) well number and core depth in the bottom left corner and 1-inch scale bar in the bottom right corner of each photomicrograph.

ers, 1976). The grey-green claystone, when present, represents phases of lower energy deposition below fair-weather wave base in which clay accumulated on the sea floor through suspension settling in the water column. The intercalated finer-grained claystone and courser-grained laminated dolostone represent deposition within an environment that experienced alternating phases of low versus high energy. Syneresis cracks, which are subaqueously formed shrinkage cracks induced by increased water salinity, indicate relatively high variations in water salinity (Burst, 1965).

Silty Mudstone Facies Association

Description:

This facies consists of light to dark green to grey to red/maroon, poorly laminated, silty to sandy mudstone (Figs. 9 & 10). The silty mudstone beds are commonly oxidized (red/maroon in color). Silt-sized quartz grains and/or dolomite crystals are commonly present, observable in thin-section and suspended within the matrix (Fig. 10A-B). Fine-sand to granule-sized (~1 mm to 5 cm diameter) claystone and/or dolostone clasts suspended within the matrix are present in part (Fig. 10C-D). Lamination texture is typically discontinuous, horizontal to inclined, non-planar/gently wavy, and overall non-parallel.

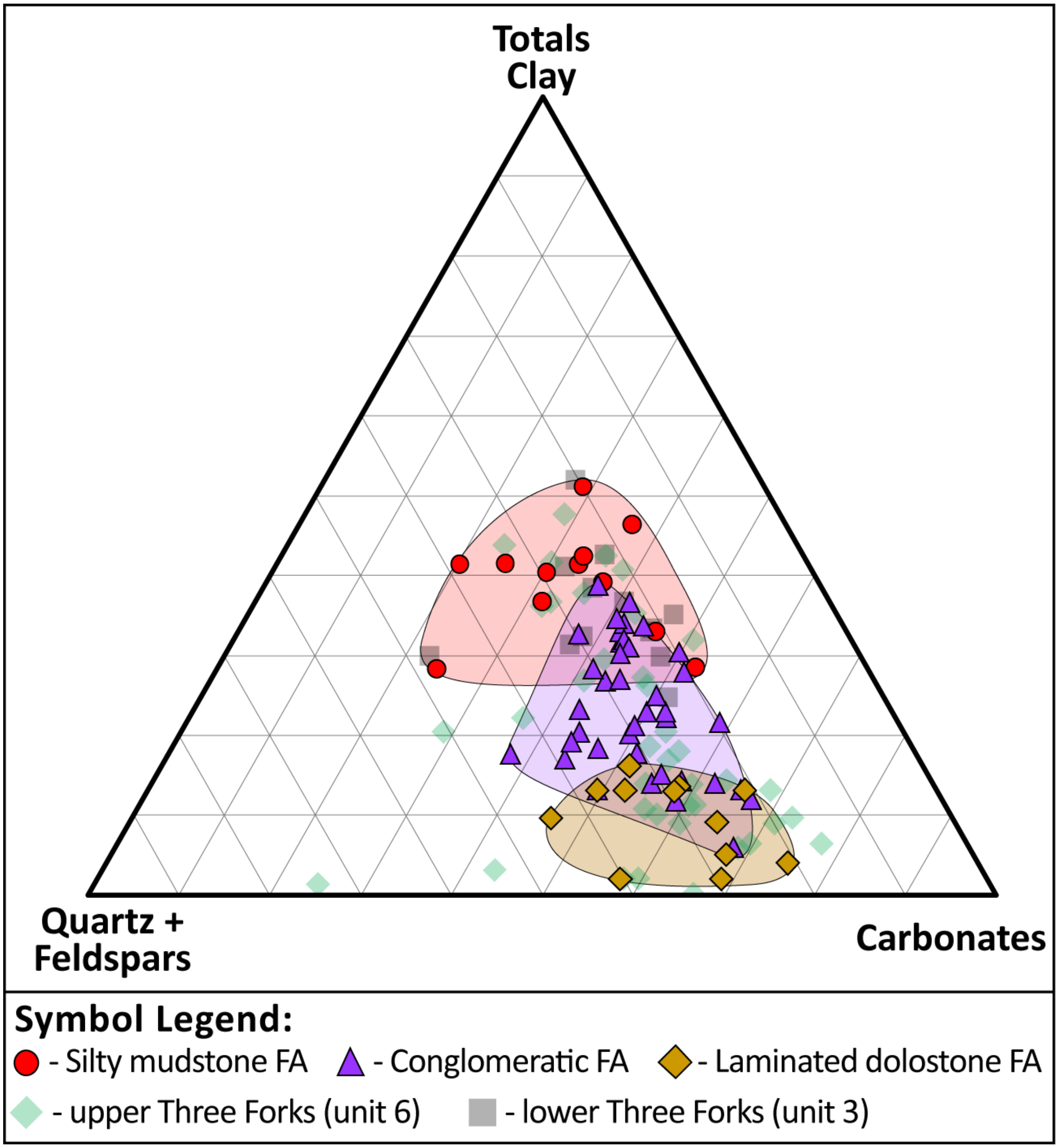


Figure 8. Ternary plot of compiled XRD (X-ray diffraction) Three Forks core chip samples plotting total clays versus silicates (quartz and feldspars) versus carbonates (primarily dolomite).

Based upon XRD analyses from 13 samples of the silty mudstone FA, total clay concentrations for the facies ranges from 28.0% to 50.8% (38.1% average) with 16.6% to 47.0% carbonates (26.6% average) and 20.0% to 51.9% silicates (32.4%) (Fig. 8). Within most analyzed samples, carbonate minerals were ~100% dolomite with the exception of two samples collected from near the base of the MTF section which contained 11% and 17% calcite. Negligible anhydrite was detected.

Interpretation:
Oxidation of the facies indicates either continual or prominent, periodic subaerial exposure. Variable clay/mud-sized matrix to silt-sized grains to granule-sized clasts suggest that the facies was deposited within a variable energy environment: relatively low energy to accumulate clay and mud versus relatively higher energy to transport and deposit silt to granule-sized grains/lithoclasts.

Conglomeratic Facies Association
Description:
The conglomeratic facies association ranges from clast-supported conglomerates to matrix-supported conglomerates with granule- to upwards of cobble-sized dolostone, mudstone and/or claystone clasts (Fig. 11 & 12). Dolostone clasts are light tan/brown and range from having a rigid, well-defined, rounded to angular outer-clast boundaries with undeformed internal laminations to irregular/deformed, poorly defined outer-clast boundaries with apparent deformed internal laminations or no observable internal structure (Fig. 11A-B). Red to green, granule to pebble-sized claystone clasts also appear sometimes alongside the dolostone clasts (Fig. 11E & H, Fig. 12D). Claystone clasts tend to be rounded, elongate in shape and are overall less common and abundant than the dolostone clasts. The matrix varies from being relatively clay-rich and green (non-oxidized) to red/maroon (oxidized) (Fig. 11A-D & F), to more dolomitic-rich and light to dark tan-brown (Fig. 11E-F). The matrix also ranges from being poorly to moderately well laminated (approximately horizontal, discontinuous, semi- to non-parallel) (Fig. 11C & E), to mottled/distorted (Fig. 11A-B), to massive/minimally textured (Fig. 11D). Minor concentrations of variable-sized anhydrite nodules occur within limited portions of the conglomeratic FA (Fig. 12C).

From a total of 42 analyses, conglomeratic core chip samples contained 6% to 38% total clay (23.6% average), 19.6% to 39.0% silicates (27.3% average), and 32.0% to 68.0% carbonates (48.0% average) (Fig. 8). Carbonate minerals were comprised exclusively of dolomite (negligible calcite) and negligible anhydrite was detected. Pyrite was generally found to be absent to present in only trace amounts. However, two samples from the upper portions of the MTF (unit 5) contained 6% and 9% pyrite.

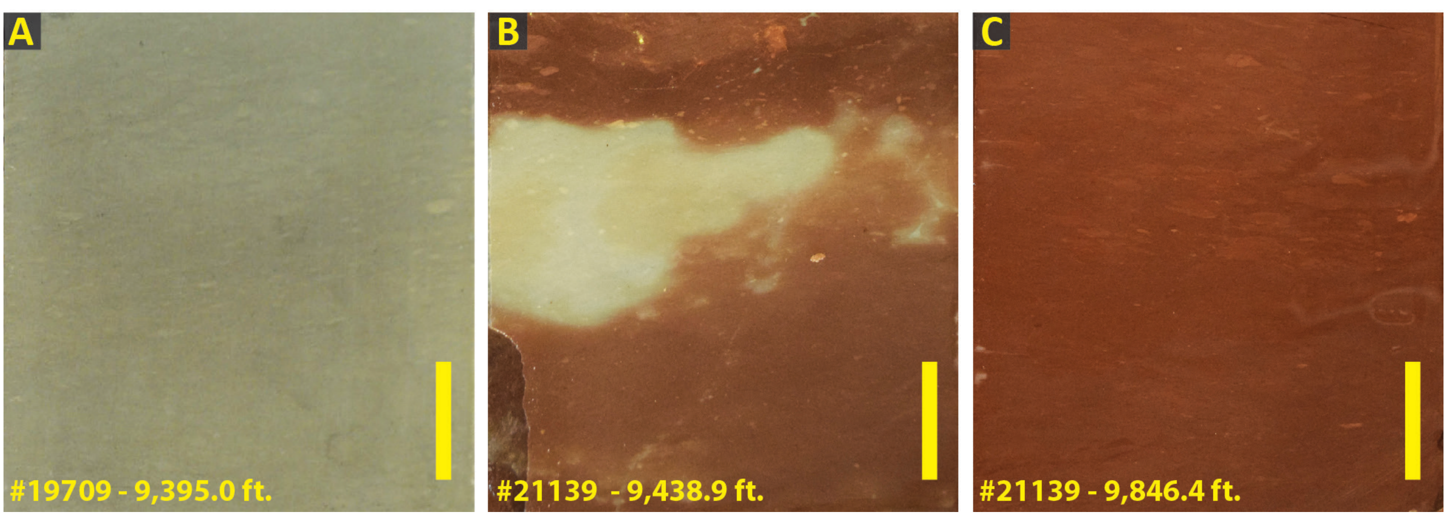


Figure 9. Core photographs of the silty mudstone facies association. A) Light green-grey, poorly laminated silty mudstone with intraclasts. B) Light green-grey and red-maroon, poorly laminated silty mudstone with sub-angular to sub-rounded, granule-sized lithoclasts. C) Red-maroon, poorly laminated silty mudstone with intraclasts. Bottom left corner of each photograph includes NDIC (North Dakota Industrial Commission) well number and core depth. Thick yellow line in bottom right corner is a 1-inch scale bar.

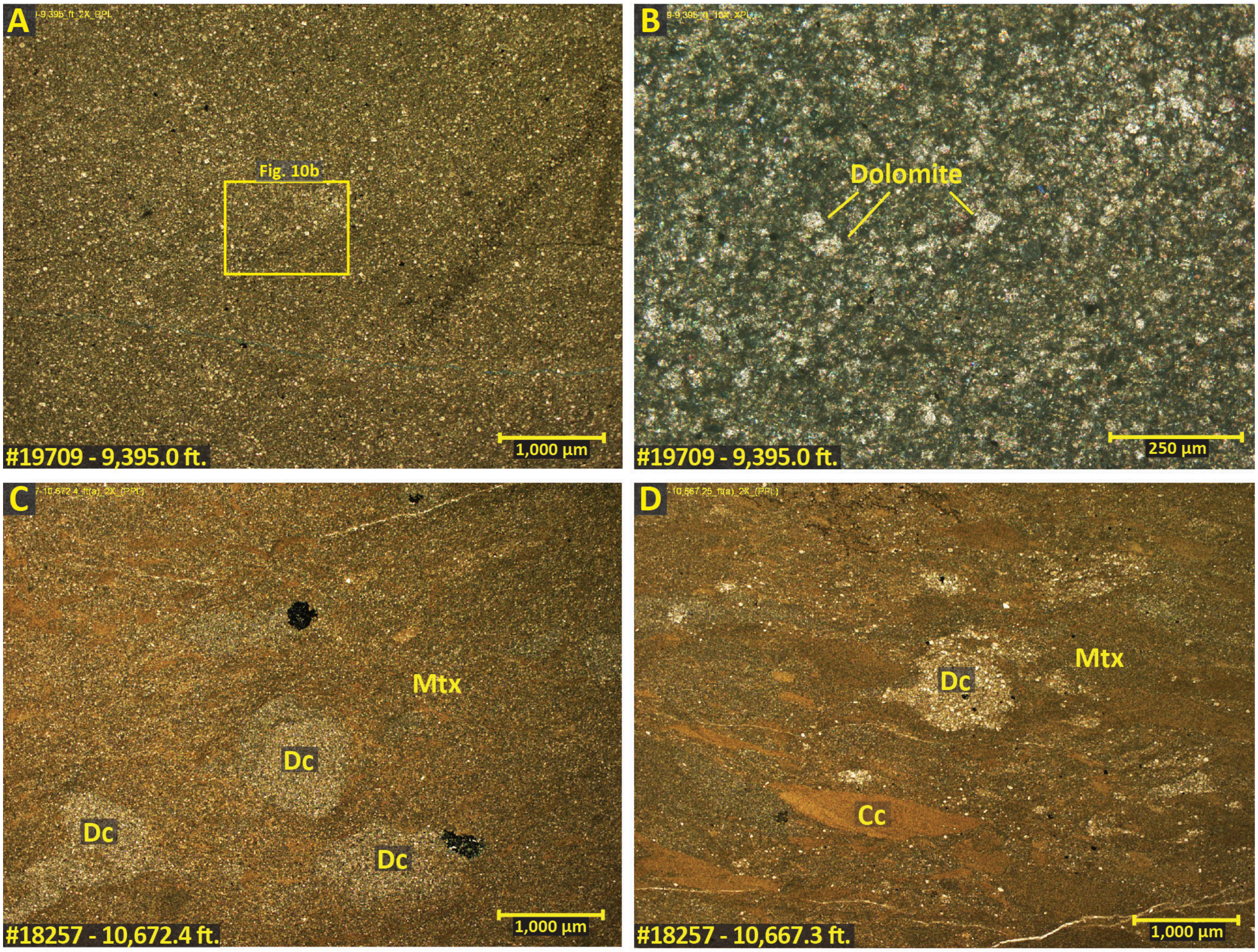


Figure 10. Photomicrographs of thin sections from the middle Three Forks silty mudstone facies association. A-B) Silty mudstone without any dolostone or claystone clasts/grains (10A in plane polarized and 10B is cross polarized light). C) Silty mudstone with subtle, coarse sand-sized (500-1,000 µm) dolostone clasts (plane polarized light). D) Silty mudstone with dolostone and claystone clasts that reached upwards of coarse sand in size (plane polarized light). NDIC (North Dakota Industrial Commission) well number and core depth in the bottom left corner and 1-inch scale bar in the bottom right corner of each photograph. Cc = claystone clast; Dc = Dolostone clast; Mtx = matrix

Interpretation:

Variable, commonly granule to pebble-sized dolostone clasts indicates one or more high-energy processes that have brecciated and/or ripped up the previously deposited silty laminated dolostone FA, as well as silty mudstone FA, and redeposited. Episodic high-energy events previously proposed included: storm surge events (Franklin and Sarg, 2018), rainfall-induced debris flows (Droege, 2014), sheet-like mudflows within a coastal plain setting (Hogancamp et al., 2019), and dissolution collapse (Bazzell, 2014). Debris flows could have formed along sea cliffs that developed proximal to the shore/coastline. Storm surges may have also contributed to dolostone clast development and transport, both proximal to the shoreline as well as in an offshore setting (Kumar and Sanders, 1976).

The variations in external and internal textures of the clasts demonstrates that some of the dolostone clasts were brittle upon displacement and redeposition while other such clasts behaved more plastically to varying degrees. The plastic deformation suggests that such dolostone clasts were well hydrated during reworking, or possibly were rehydrated and plastically deformed shortly after redeposition. The brittle dolostone clasts were either dry (non-hydrated) and/or well lithified upon displacement and redeposition.

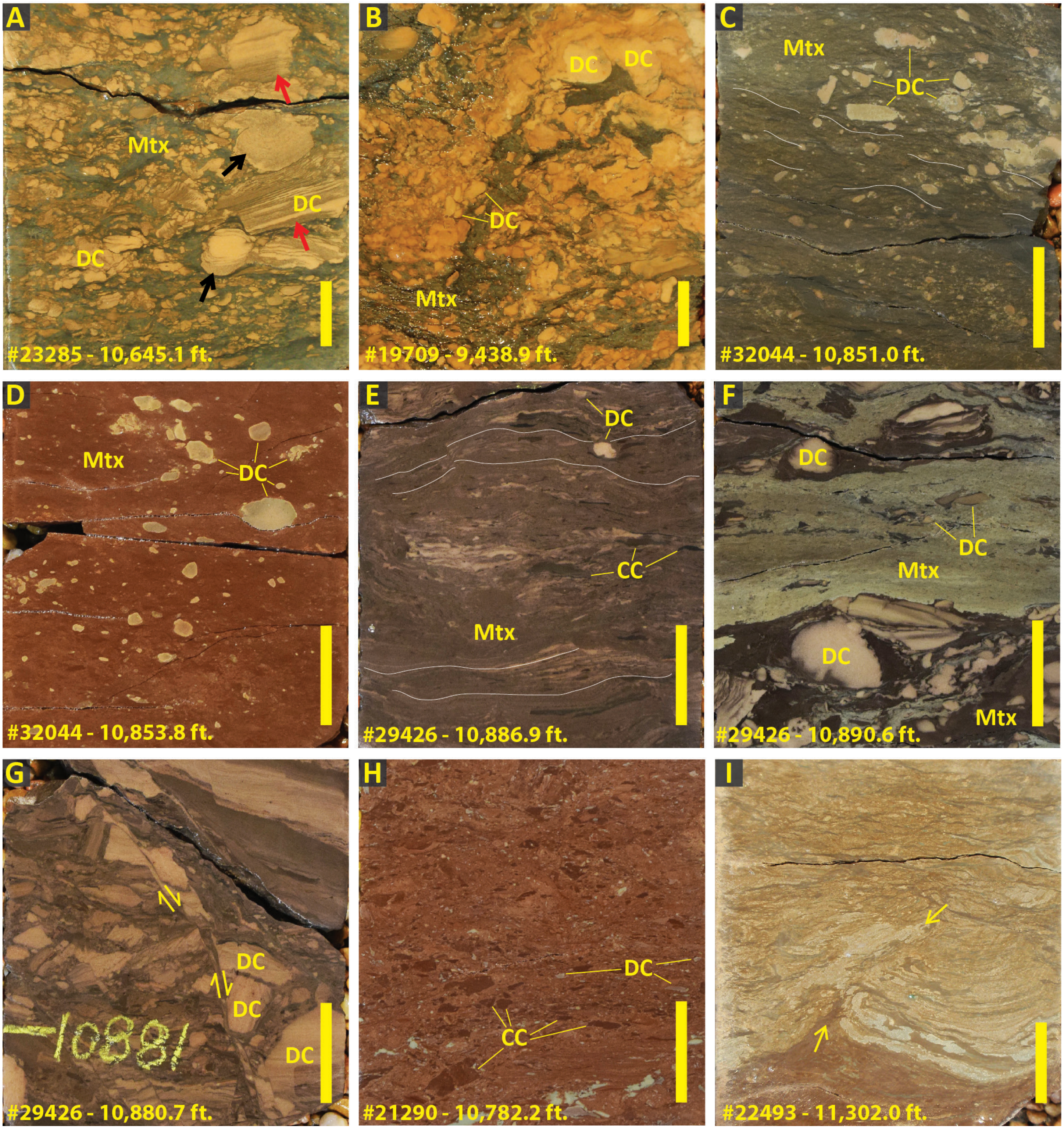


Figure 11. Core photographs of the conglomeratic facies association. A) Matrix- to clast-supported conglomerate with both brittle/non-deformed (red arrows) and plastically deformed (black arrows) dolostone clasts. B) Matrix- to clast-supported conglomerate with abundant plastically deformed dolostone clasts. C) Matrix-supported and laminated conglomerate with green-grey (non-oxidized), clay-rich matrix and granule to pebble-sized dolostone clasts. D) Matrix-supported and very poorly/non-laminated conglomerate with red/maroon (oxidized), clay-rich matrix and granule to pebble-sized dolostone clasts. E) Matrix-supported, wavy laminated conglomerate with dolomitic-rich matrix. F) Matrix-supported conglomerate with variable green, clay-rich and dark brown, dolomite-rich matrix. G) Breccia comprised of angular dolostone clasts and micro-faulting (yellow arrows). H) Red/maroon (oxidized) conglomerate with dolostone and mud/claystone clasts. I) Conglomerate with fluid escape structure (yellow arrows). Bottom left corner of each photograph includes NDIC (North Dakota Industrial Commission) well number and core depth. Thick yellow line in bottom right corner is a 1-inch scale bar. CC = claystone clasts; DC = dolostone clasts; Mtx = matrix

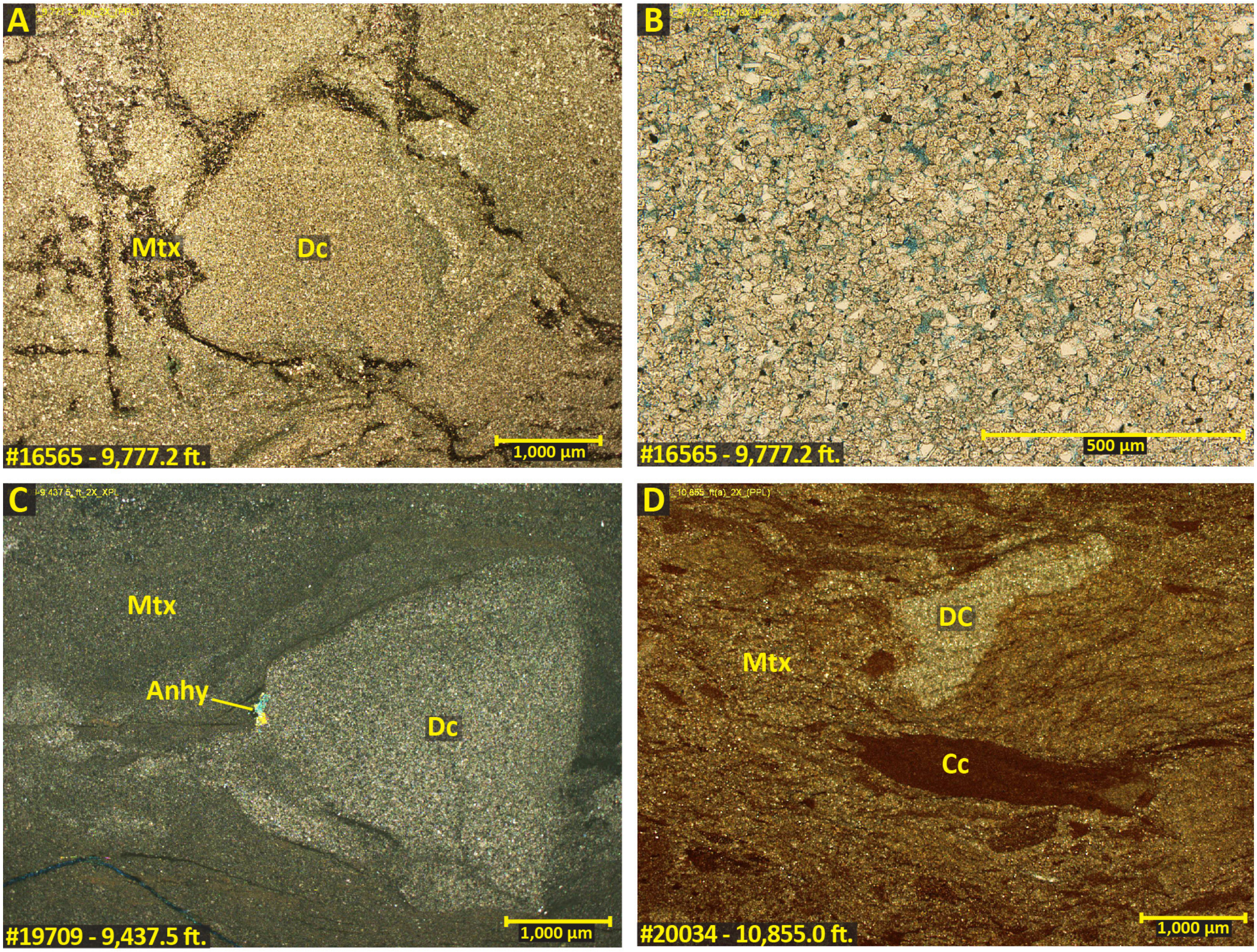


Figure 12. Photomicrographs from thin sections of the middle Three Forks conglomeratic facies association. A-B) Dolostone clast-supported conglomerate with blue stain showing intercrystalline porosity (plane polarized light). C) Matrix-supported conglomerate with dolostone clasts and minor anhydrite (cross polarized light). D) Dolostone and claystone clast-bearing conglomerate (plane polarized light). NDIC (North Dakota Industrial Commission) well number and core depth in the top left corner and 1-inch scale bar in the bottom right corner of each photomicrograph. Anhy = anhydrite; Cc = claystone clast; Dc = Dolostone clast; Mtx = matrix

The silty clay/mud-rich matrix, conversely, indicates that high energy which formed and moved the dolostone clasts was not continuous enough to sort and remove silt to clay/mud. Oxidized and poorly to non-laminated conglomeratic FA interval were deposited within and/or exposed to under arid conditions within a setting that experienced substantial subaerial exposure. The non-oxidized, laminated portions of the conglomeratic FA may represent deposition within/proximal to an aqueous setting that experienced wave and/or current energy. Overall, deposition occurred with one or more episodic high-energy processes within either a relative aqueous (non-oxidized) setting that experience wave and/or current energy to relative non-aqueous setting (negligible wave and/or current energy) in which clay minerals were oxidized.

Bounding Stratigraphic Units

<u>Lower Three Forks (unit 3)</u>

The underlying lower Three Forks (unit 3) is comprised of medium red to dark green-grey, poorly laminated, silty mudstone (Fig. 13A-C). Heterolithic granule to pebble-sized, angular to rounded clasts are present in part, always suspended within the clay/mud-rich matrix. Negligible to moderate reactions to HCl acid indicate variable concentrations of calcite. Minor pyrite is present but rare. Laminae texture, when present, ranges from horizontal to inclined, discontinuous, non-parallel to semi-parallel, and irregularly wavy.

Clay concentrations from compiled XRD data range from 24.0% to 50.8% (34.8% average) with 18.0% to 46.0% (25.1% average) and 22.0% to 50% carbonates (38.4% average) (Fig. 8). Calcite concentrations range from 0% to 42.0% (15.2% average) with sometime minor amount of anhydrite (≤2%) or pyrite (≤1%).

Upper Three Forks (unit 6)

The upper Three Forks is comprised of multiple lithofacies that are comparable to those of the MTF: poorly laminated silty mudstone, laminated silty dolostone, and conglomerates (Fig. 13D-F). Green to grey-green poorly laminated silty mudstone beds may be present, forming beds that are ~1-foot thick or less. Dolostone-clast conglomerate is commonly found within, and sometime limited to, the basal several feet of the upper Three Forks. Overall, conglomerates are less abundant in the upper Three Forks versus the MTF. Laminated silty dolostone commonly comprises more than half of the upper Three Forks section within the observed/logged cores, which is generally more than the underlying MTF section. Some of the laminated dolostone contains minimal to negligible clay/mudstone but more often contains minor to abundant amounts green-grey claystone/mudstone intercalations. Even though comparable lithofacies comprise the upper and MTF, the lithofacies are present in different quantities/ratios. XRD mineralogy of the upper Three Forks is variable but comparable to that of the MTF (Fig. 8).

MTF FACIES ARCITECTURE

The MTF commonly consists of multiple partial to complete sequences/cycles of the following stacked lithofacies (ascending order): 1) silty mudstone, 2) matrix -supported conglomerate, 3) clast-supported conglomerate, 4) planar to wavy laminated silty dolostone, 5) laminated dolostone intercalated with green-grey claystone, which then reverses order continuing

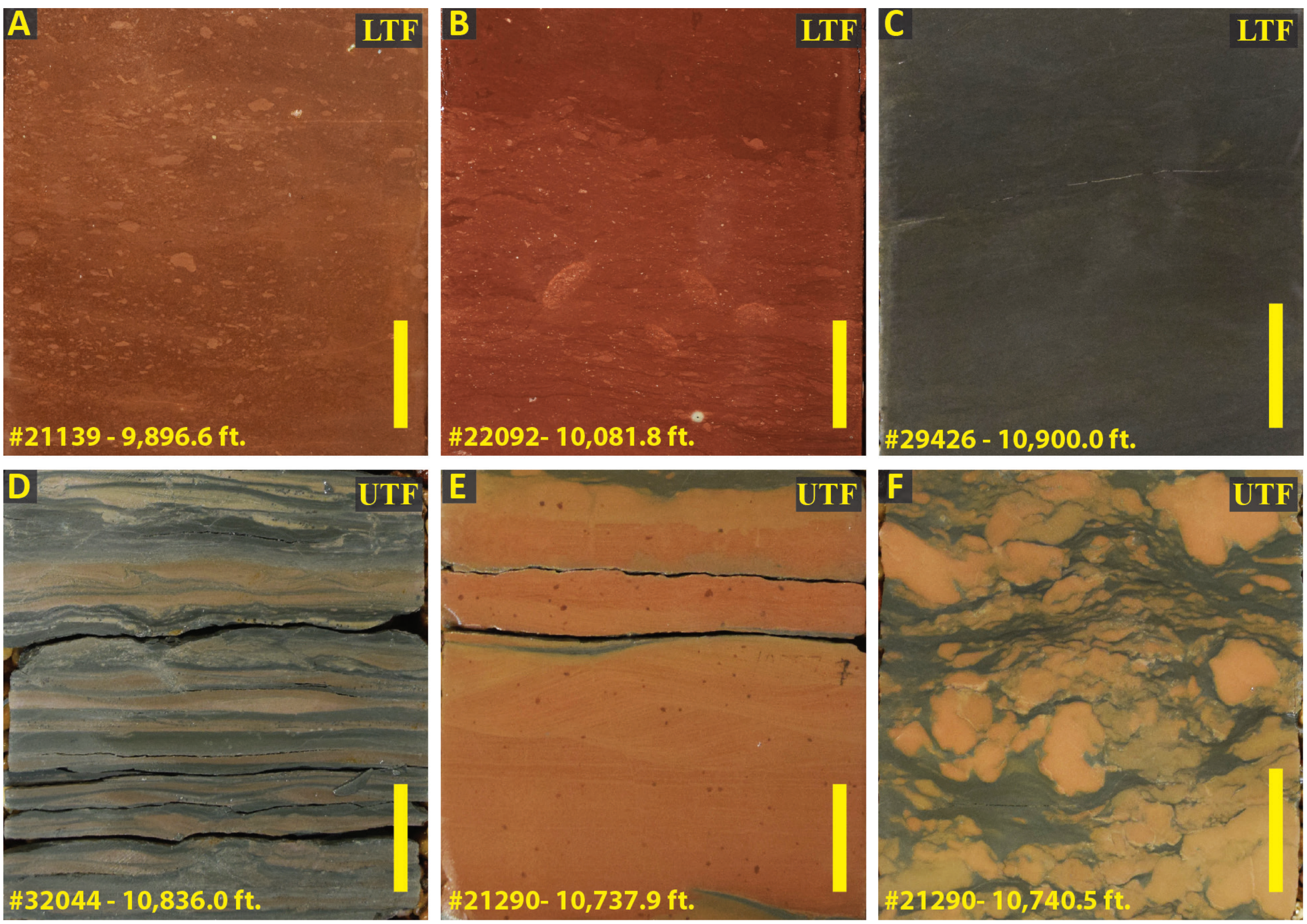


Figure 13. Representative core photographs of the stratigraphic units bounding the middle Three Forks, including the lower Three Forks (Christopher unit 3) (A-C) and the upper Three Forks (Christopher unit 6) (D-F). A) Red/Maroon, matrix-supported conglomerate. B) Red/Maroon, poorly laminated silty mudstone with minor clasts. C) Dark grey-brown, very poorly laminated silty mudstone with negligible clasts. D) Intercalated green claystone and pink-tan silty laminated dolostone. E) Pink-tan, planar laminated to wave-rippled silty dolostone with minor green claystone. F) Green and pink-tan, matrix-supported conglomerate with plastically deformed dolostone clasts and green, clay-rich matrix. Bottom left corner of each photograph includes NDIC (North Dakota Industrial Commission) well number and core depth. Thick yellow lines in bottom right corners are 1-inch scale bars. LFT = lower Three Forks; UTF = upper Three Forks

up in section (Figs. 14 & 15). When the previously described lithofacies are stacked in the described upward order, contacts are generally gradational. Sharp contacts may be present, particularly where one or more intermediate lithofacies are absent. Partial sequences commonly consist of silty mudstone and conglomerates grading into one another, or conglomerates and laminated dolostone. Oxidation is most prevalent in lithofacies near the base and top (silty mudstone) of the composite sequence/stacking pattern display in Figure 14 and become progressively less commonly occurring in lithofacies near the middle of the composite schematic sequence.

Examining lower MTF (unit 4) across the study area, a number of sedimentologic trends occur. The net thickness of laminated dolostone FA comprising the MTF section is highest towards the northern portions of the study area and decreases overall southwards (Fig. 16). Conversely, the net thickness of the silty mudstone FA and oxidization within the section increases towards the southern margins of the study area (Fig. 16). Within the northern portions of the study area, the lower MTF is largely comprised of interbedded laminated dolostone and conglomeratic beds, and transitions to mostly conglomeratic FA southwards. The conglomeratic FA comprises half or more of the lower MTF section in nearly all examined cores. The conglomeratic FA reaches maximum net thicknesses within the central portions of the study area, where more of the facies has a dark brown silty dolostone matrix. Towards the northern portions of the study area, the conglomeratic FA generally has a green clay-rich matrix. Towards the south, claystone clasts increase in abundance and oxidation becomes more prevalent within the conglomeratic FA intervals. Within the central portions of the study area (northeastern McKenzie County), some of the conglomeratic beds commonly contain a dark-brown, dolomitic-rich matrix.

The upper MTF (unit 5) is commonly comprised entirely of interbedded silty mudstone and conglomeratic FA (Fig. 16). A few cores towards the northern portions of the study area contain a thin bed (<1 foot thick) of laminated dolostone within the middle portions of the section. The overall quantity of dolostone clasts and net thickness of the conglomeratic FA increases northwards while decreasing toward the southern margins of the study area. Similar to the lower MTF (unit 4), net thickness of silty mudstone and oxidation increases southwards (Fig. 16).

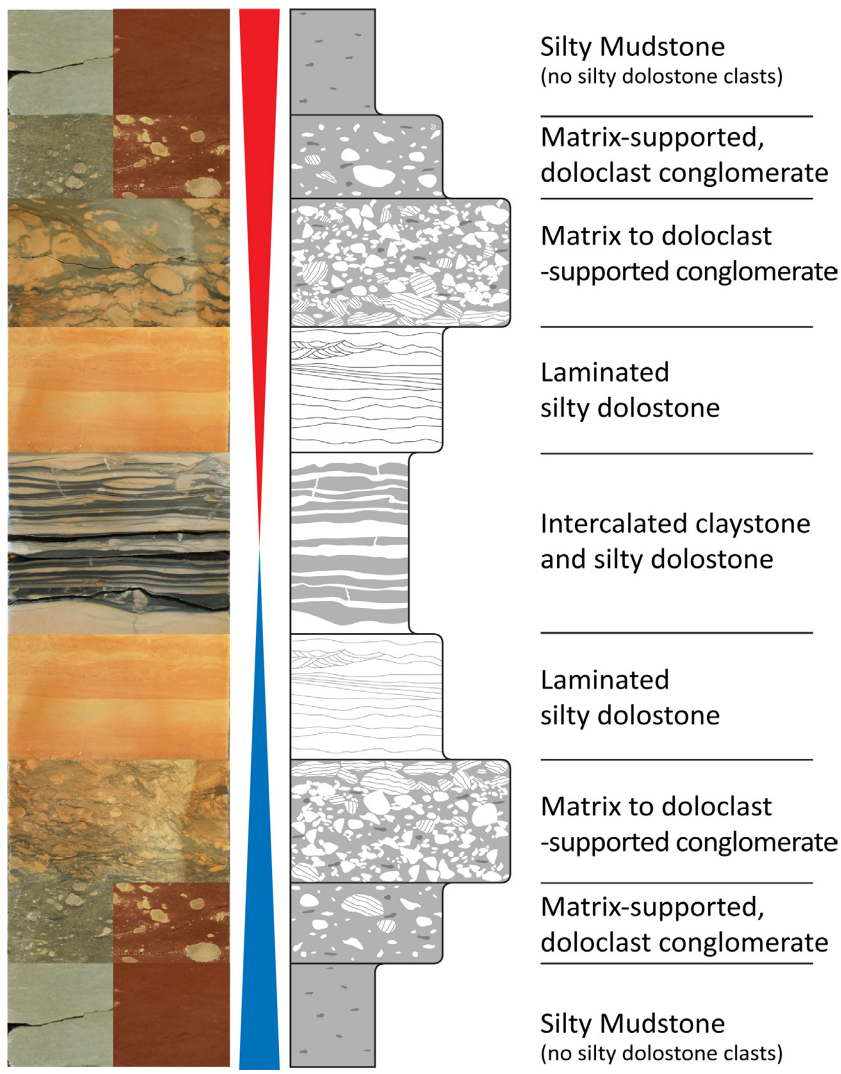


Figure 14. Idealized composite cycle of the middle Three Forks with representative core photographs (left), illustrated core lithologies (middle), and basic rock types (right). Blue upward arrow notes the transgressive portion of the composite core and red arrow depicts regressive.

DEPOSITIONAL MODEL

Deposition of the MTF is interpreted to have occurred along a very low angle, relatively shallow ramp setting which transitioned laterally from a permanently submerged outer-ramp setting into an up-dip, arid coastal plain setting that experienced periodic flooding (Fig. 17). The intercalated grey-green claystone and ripple-laminated silty dolostone reflect deposition in the more distal, outer ramp setting that experienced fluctuating water depth and corresponding energy conditions. Increased water depths above fair-weather wave base (FWWB) allowed suspension deposition of the claystone while periods of decrease water depths below FWWB deposited the higher energy ripple-laminated silty dolostone. Water depth variations could have been influenced by astronomically forced tidal fluctuations and/or meteorological induced water level changes from

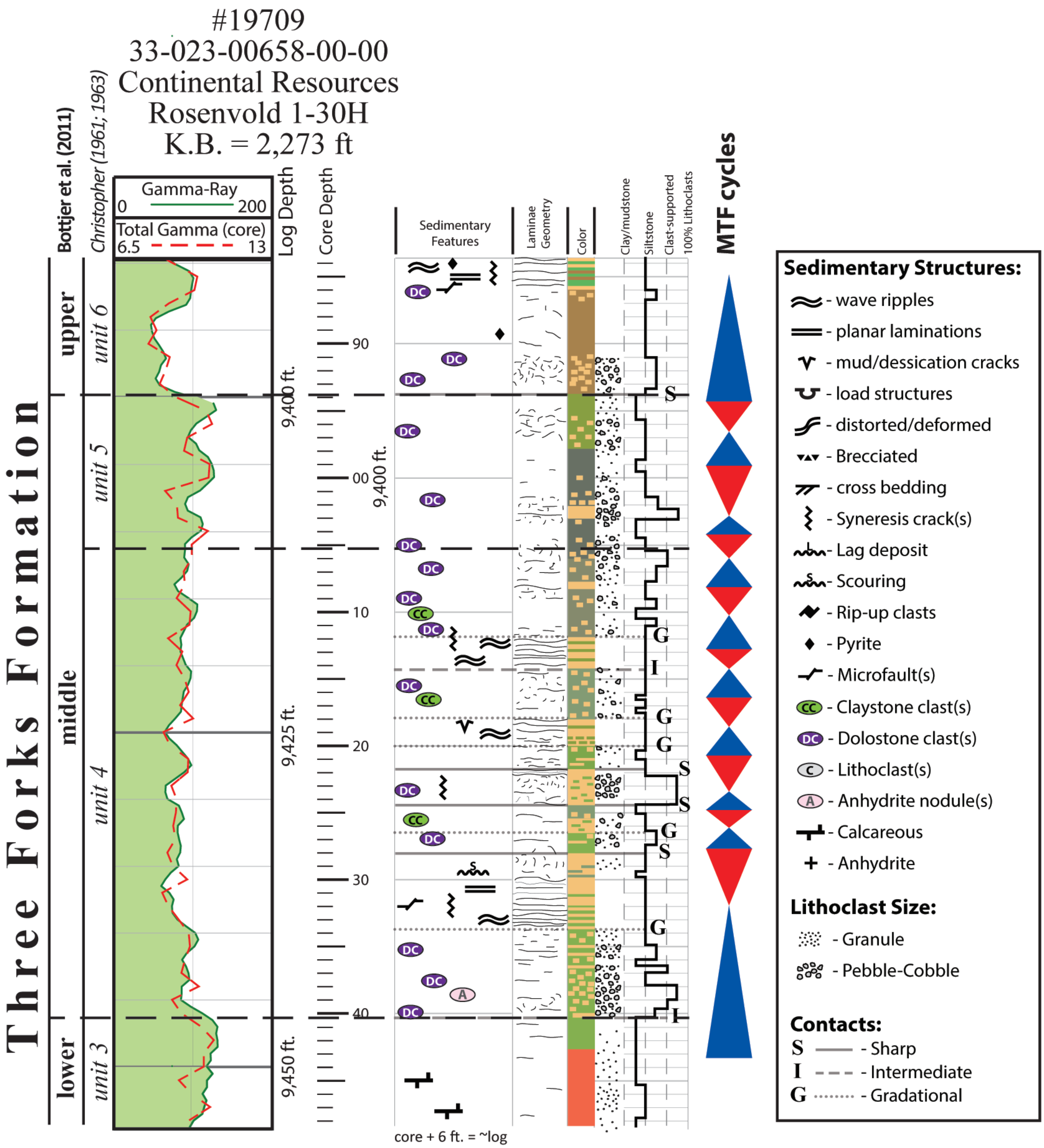


Figure 15. Example core-log illustration of the middle Three Forks section from Continental Resources Rosenvold 1-30H (NDIC: 19709, API: 33-023-00658-00-00). Blue (transgressive) and red (regressive) arrows depict partial to complete middle Three Forks depositional cycles.

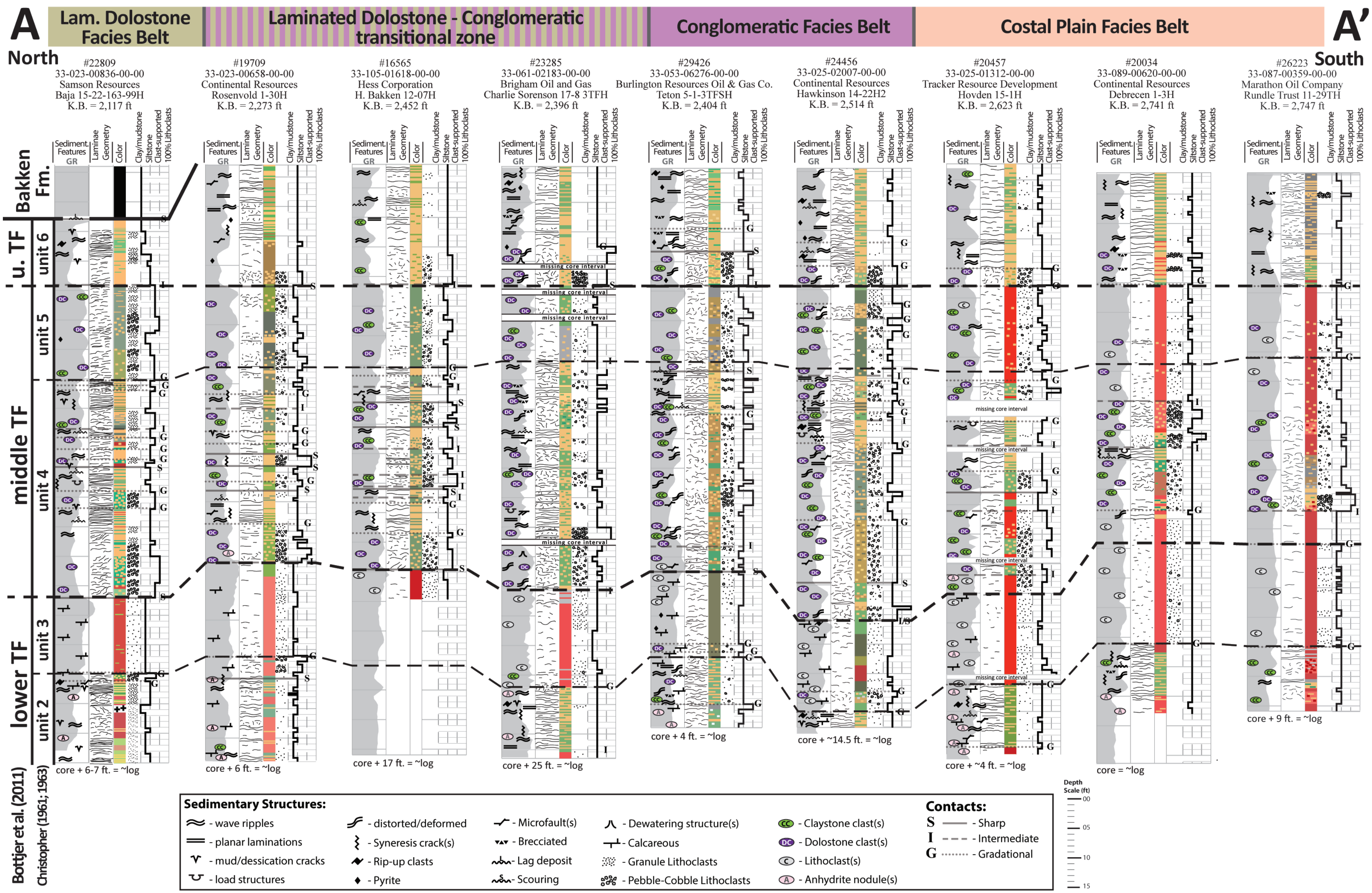
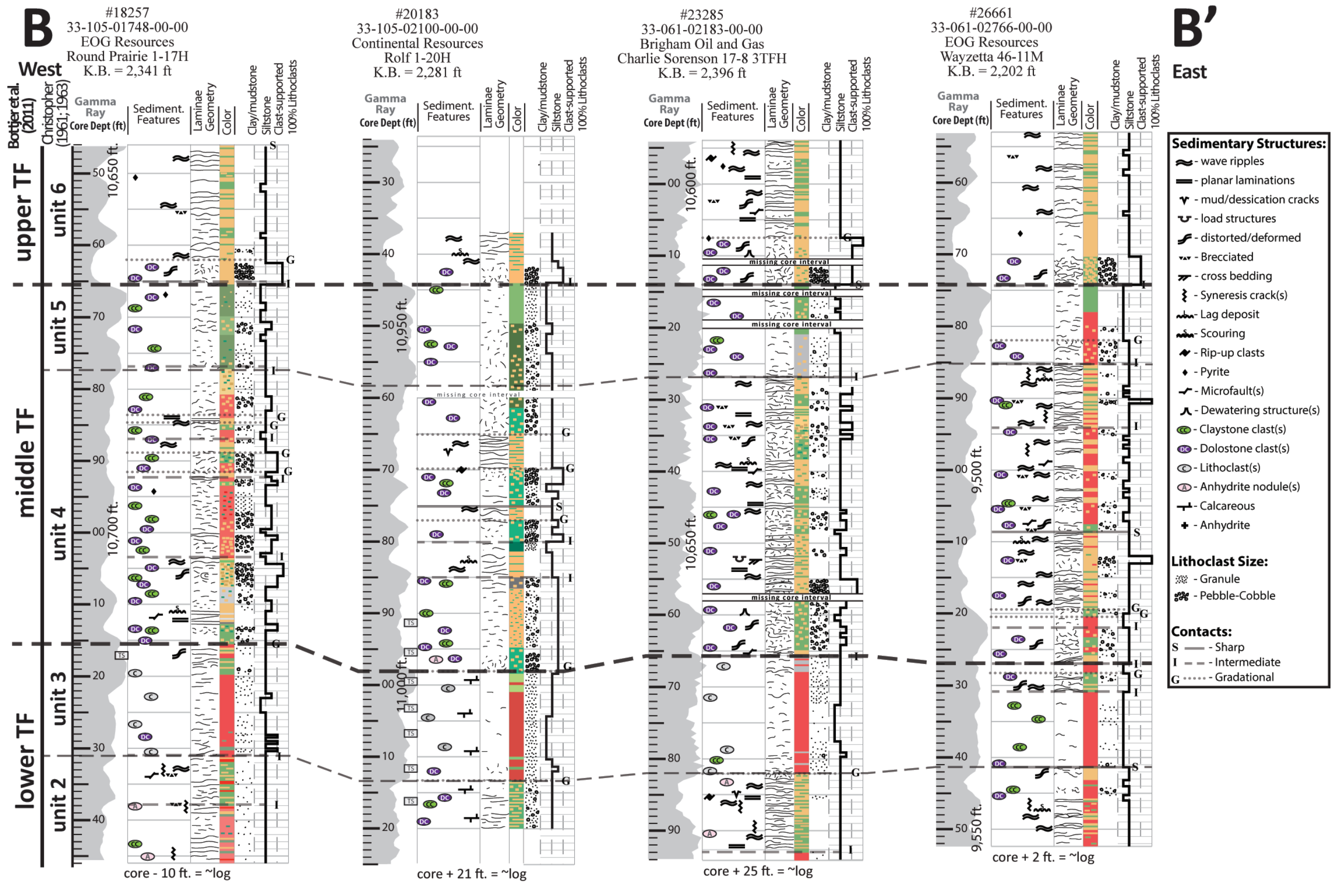


Figure 16. Stratigraphic cross-sections of the middle Three Forks and bounding stratigraphic units (datum: middle Three Forks top). A) A-A' north-south cross-section, B) B-B' east-west cross-section across the northern portions of the study area, and C: C-C' east-west cross-section across the southern margins of the study area.



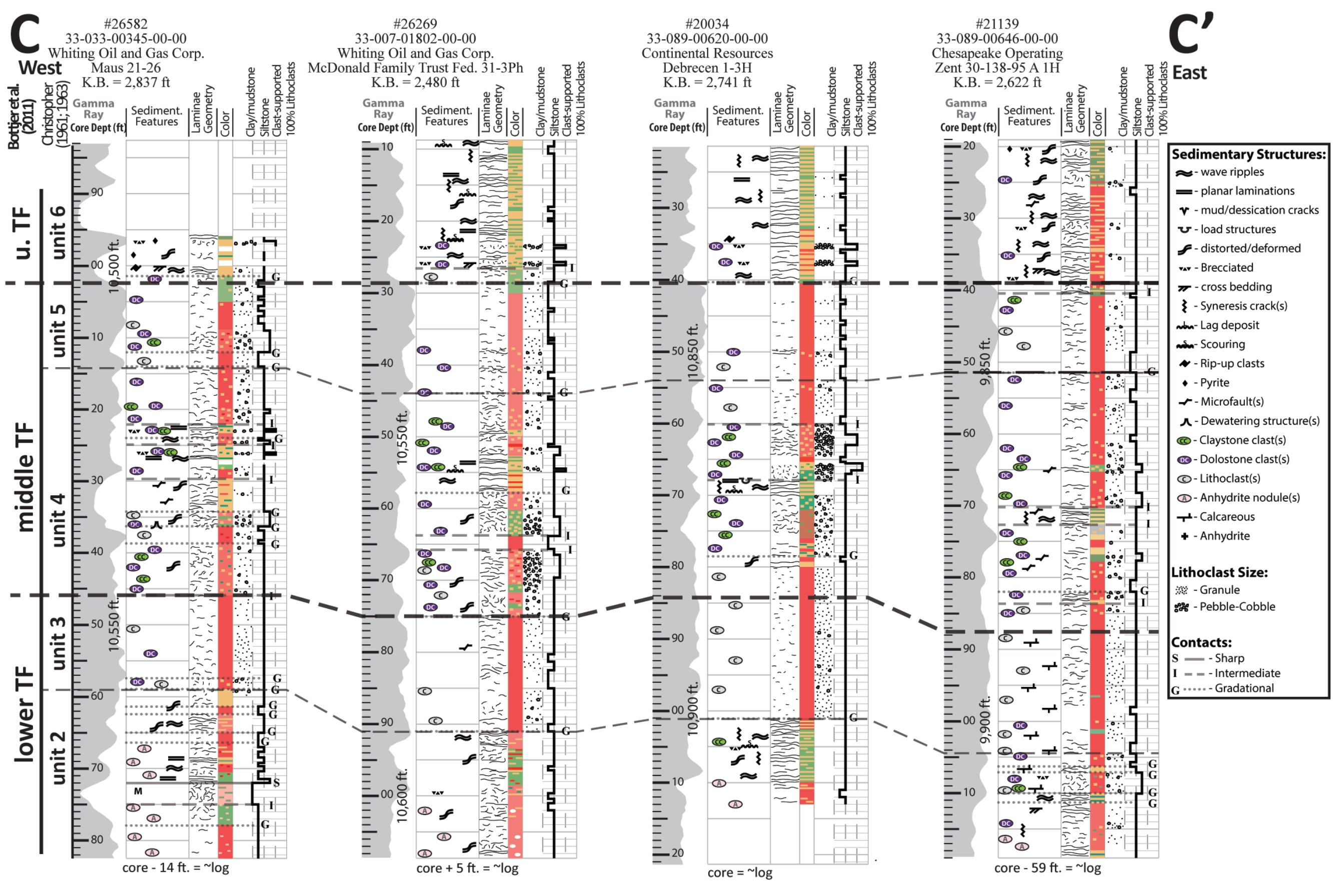


Figure 16. *(continued)* Stratigraphic cross-sections of the middle Three Forks and bounding stratigraphic units (datum: middle Three Forks top). A) A-A' north-south cross-section, B) B-B' east-west cross-section across the northern portions of the study area, and C: C-C' east-west cross-section across the southern margins of the study area.

daily changes in wind direction/velocity and/or seasonal water input variations (Ainsworth et al., 2012).

An interpreted coastal plain setting occurred up-dip of the shallow ramp/tidal flat, where clay to sand to granule/pebble-sized grains/clasts were moved around through a combination of periodic flooding events, fluvial processes, and/or wind transport (Fig. 17). Subaerial exposure within a predominantly arid climatic setting led to sediments often being oxidized.

The dolostone clast-dominated conglomerates primarily formed intermediate of the shallow ramp/tidal flat and coastal plain settings, essentially along the coastline, based upon vertical and lateral facies changes in the MTF across the study area (Fig. 17). In this setting, some conglomeratic deposits were partially to completely hydrated during deposition and initial burial, which led to various forms of soft-sediment deformation (e.g. dewatering structures, plastically deformed dolostone clasts), while other conglomeratic deposits may have been more poorly hydrated and/or subaerially exposed, resulting in oxidized clays. Debris flows along sea cliffs and storm event reworking may have been the dominant processes that contributed to the various types of conglomerate bed deposition. Meanwhile, the oxidized conglomerates that contain more abundant mudstone clasts with minimal to absent laminated dolostone clasts may have developed further inland along the coastal plain, forming as sheet-like mudflows as proposed by Hogancamp et al., (2019).

DISCUSSION AND IMPLICATIONS

Stratigraphic Nomenclature

Previous studies have subdivided the Three Forks using multiple stratigraphic nomenclature systems (Christopher, 1961; 1963; Bottjer et al., 2011; LeFever et al., 2013; 2014; Hogancamp et al., 2019). Most of the stratigraphic nomenclature subdivisions utilize the tops and/or bases of Christopher's units 3 and 5, which on wireline logs have notable elevated gamma-ray signatures that can be correlated regionally across the Williston Basin and beyond (Hogancamp et al., 2019). Additionally, Christopher's units 3 and 5 are distinct stratigraphic units that can be identified in core samples and correlated regionally across western North Dakota using both cores and wireline logs (Fig. 16).

Examining Three Forks core samples, comparable lithofacies, including conglomerates with pebble-sized (to sometimes cobble-sized) dolostone clasts, can be found distributed across the entire Three Forks section, but with uneven stratigraphic distribution. The dolostone clast-bearing conglomerates are most prevalent within the Three Forks section equivalent to the Bottjer et al (2011) MTF, Christopher (1961; 1963) units 4-5, and LeFever et al. (2013; 2014) member 4. The base of the

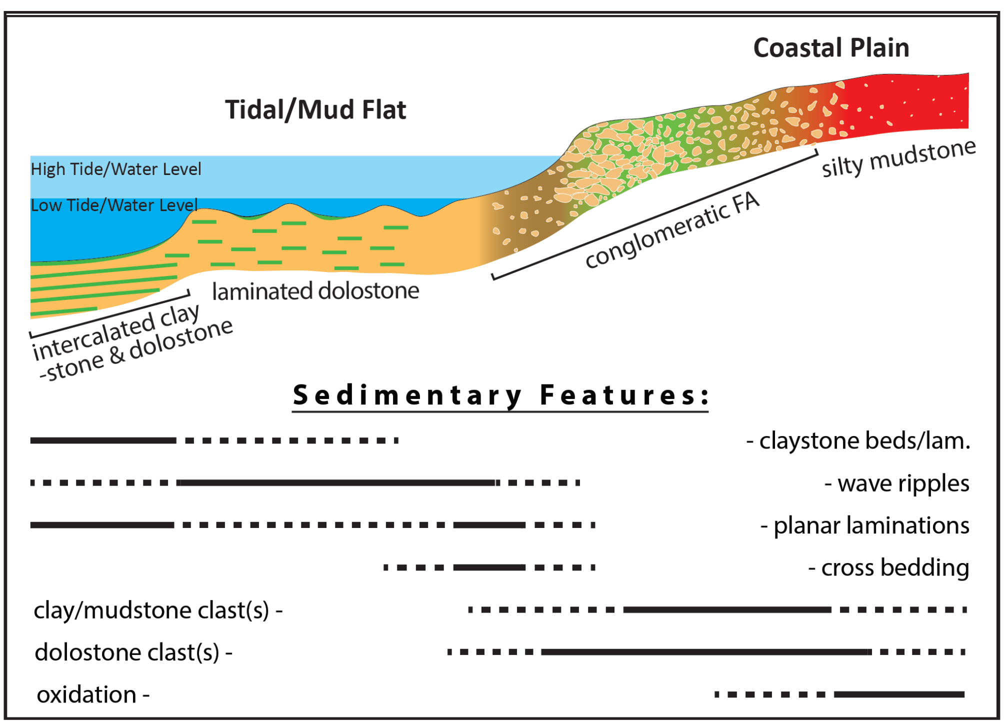


Figure 17. Schematic depositional model for the middle Three Forks depicting the approximate distribution of various sedimentary features (solid black line = commonly present; dotted line = intermittently present).

MTF section, as defined in this study, occurs where pebble- to cobble-sized dolostone clasts begin to appear in core moving upward in section while calcite concentrations become consistently negligible. This core-defined MTF base generally corresponds with a relatively abrupt upward decrease in gamma-ray, either at or near the top of the first of two elevated gamma-ray intervals within the Three Forks section (Christopher 1961; 1963 -> unit 3). However, clay concentrations and corresponding gamma-ray signatures of the basal MTF dolostone clast-bearing conglomerate section can increase both locally as well as regionally towards the south, which inhibits utilizing the gamma-ray log to pick the MTF base as defined above. Additionally, the quantity and vertical distribution of dolostone clasts decreases across the MTF section towards southwestern North Dakota, which also inhibits picking the base of the MTF in both core and wireline logs.

The top of the MTF is defined as top of the second elevated gamma-ray interval within the overall Three Forks section (Christopher 1961; 1963 -> unit 5). A dolostone-clast conglomerate is commonly found at or near the base of the upper Three Forks, which is grouped with the upper Three Forks because that basal conglomeratic bed generally has a sharp lower contact and a relatively gradational upper contact. The basal conglomerate of the upper Three Forks disappears in cores along the southern margins of the study area (Fig. 16A & C). Above the basal conglomerate, minimal dolostone-clast conglomerates are found within the upper Three Forks section and silty laminated dolostone becomes the most prominent lithofacies. Overall, the MTF is primarily defined herein as to where dolostone clast conglomerates are most prevalent in the section.

Defining the base of the MTF has implications in determining the thickness of the unit and isopach mapping. Figure 18 consists of the composite MTF (units 4 and 5) (Fig. 18A) and the lower MTF (unit 4) isopach maps (Fig. 18B), created using the control cores logged for this study defining the top and base of the MTF section as described above (variations in thickness of the upper MTF/unit 5, are minimal). Overall, the thickness of the MTF increases towards the north-northwest while decreasing towards the southwest. Two localized thickening trends occur within the central portions of the study area along with a similarly oriented thin trend in the north-central (Fig. 18). Most of the thinning and thickening trend roughly northwest-southeast, which parallel a number of structures within the study area (most of the structures trend approximately north-south or northwest-southeast) (Fig. 18). Possibly tectonic, basement block movement occurred during deposition of the MTF that aided in developing topographic relief along with debris flows occurred forming, at least in part, some of the dolostone clasts and conglomeratic deposits. Tectonic activity could have induced earthquakes that formed the bed load structures preserved within the laminated dolostone FA beds.

Environmental Conditions during Deposition

Anhydrite is intermittently present within the basal portions of the MTF, indicative of hypersaline water conditions during initial deposition. Syneresis cracks that occur throughout the section are suggestive of highly variable water salinity (Burst, 1965). Furthermore, limited ichnofauna have been described within the middle Three Forks but with no corresponding macro fossils (e.g. bivalves, brachiopods, ostracods) (Franklin and Sarg, 2018; Droege, 2014). The lack of macro fossils and limited ichnofauna are suggestive that physico-chemical stresses may have severely inhibited organic activity within the aqueous portion of MTF deposition (MacEachern et al., 2009). Therefore, the aqueous portion of MTF deposition likely occurred within hypersaline water conditions with highly variable salinity levels that lead to the development of syneresis cracks and severely inhibited organic activity.

Regional Facies Distribution

The lower MTF (unit 4) can be spatially subdivided based upon lateral changes in the lithofacies ratios comprising the unit, including the Laminated Dolostone, Conglomeratic, and Coastal Plain facies belts (Fig. 19A). The Laminated Dolostone facies belt is where more than half of the lower MTF is comprised of the laminated dolostone FA, less than 5% of the section is oxidized, and silty mudstone comprises less than 10% of the overall section (Fig. 16A). The Laminated Dolostone Facies Belt extends along the northern margins of the study area (Fig. 19A).

The Conglomeratic facies belt occurs within the middle portions of the study area (Fig. 19A). Multiple general characteristics define the Conglomeratic Facies Belt for the lower MTF, primarily that the Conglomeratic FA comprises 75% or more of the total net section. Half or more of the Conglomeratic FA is comprised of clast-supported conglomerate and matrix-supported conglomerate with a dolomitic matrix (Fig. 16A). Additionally, silty mudstone net thickness comprises less than 10% of the overall section, with less than 5% of section oxidized (Fig. 16A). Several feet of the laminated dolostone FA is generally present, mostly within the upper half of the section (Fig. 16A).

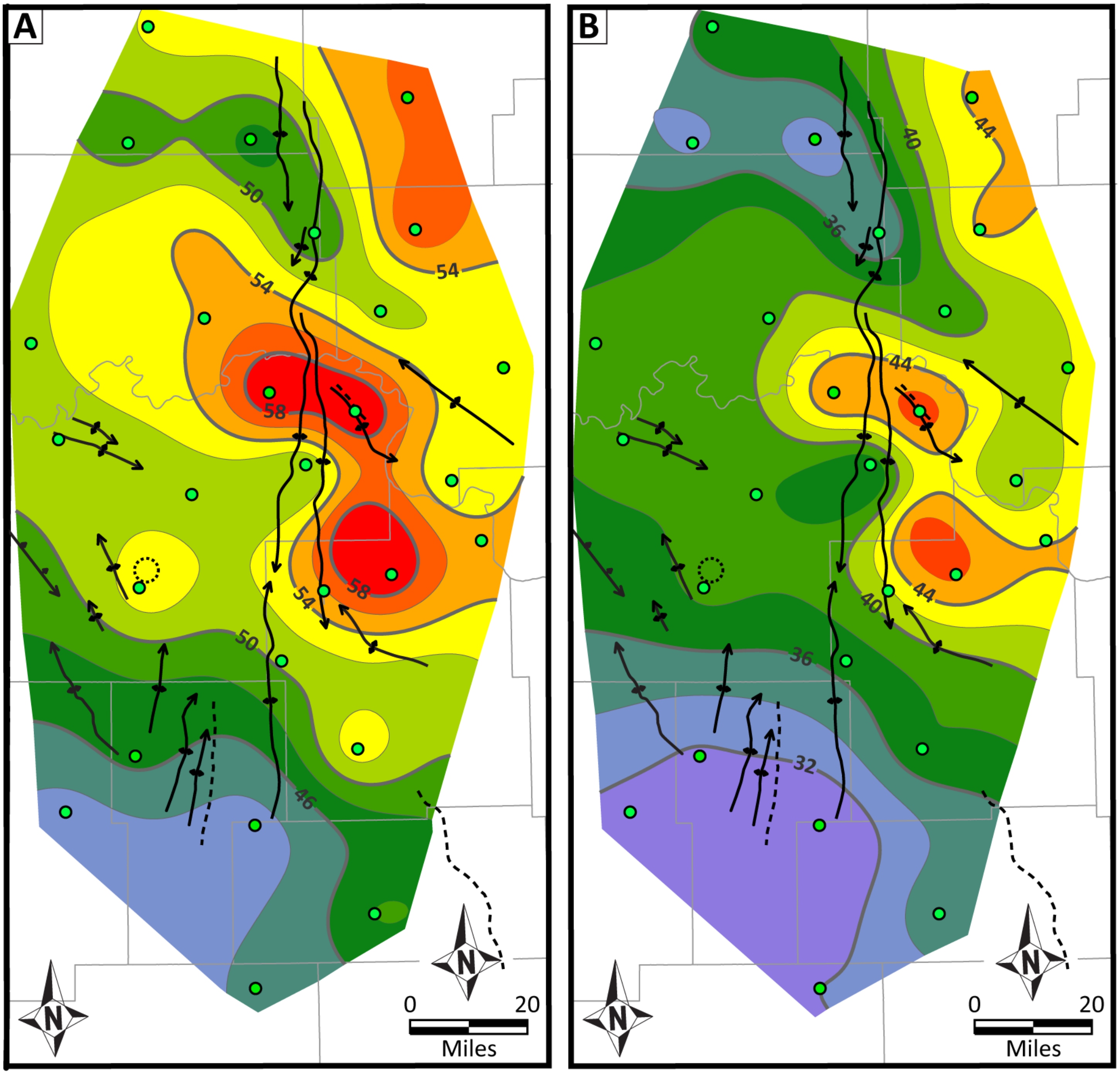


Figure 18. Isopach maps of the middle Three Forks using core control from the 28 cores examined and described from this study (green circles). A) Isopach map of the entire middle Three Forks section (Christopher 1961;1963 -> units 4 and 5). B) Isopach map of the middle Three Forks reservoir (Christopher 1961;1963 -> unit 4 only). Contours are in 5-foot intervals. Solid back lines depict anticlinal and monocline structures while dashed black lines depict faults.

The Coastal Plain Facies Belt covers approximately the southern half of the study area (Fig. 19A) and is primarily defined where silty mudstone comprises >10% of the lower MTF and 20-70% or more of the section has been oxidized (Fig. 16A). Claystone and mudstone clasts as well as clay-rich matrix becomes more common/prevalent within the Conglomeratic FA beds, while the overall amount of dolostone clasts decreases (Fig. 16A). Less than 70% (net) of the section contains pebble to cobble-sized dolostone clasts. Additionally, greater than 20-30% of the net section has been oxidized and most of the conglomeratic FA beds/intervals contain clay-rich matrix and/or have been oxidized (Fig. 16A).

Hydrocarbon Production Trends and Reservoir Quality Implications

Comparing the distribution of productive MTF horizontal wells with the facies belt map, most of the MTF wells are within or proximal to the Conglomeratic facies belt (Fig. 19B). This means that the primary lithology type comprising the reservoir target interval are the Conglomeratic FA beds. The Conglomeratic FA is highly variable in texture and composition and may also vary in reservoir quality.

Studies evaluating reservoir quality of Three Forks lithofacies have so far focused on the upper Three Forks (Peterson, 2013; Brinkerhoff et al., 2016; Adeyilola et al., 2020), which is largely comprised of laminated dolostone FA equivalent rock but also consists, to a lesser amount, of Conglomeratic FA equivalent rock. Peterson (2013) analyzed core samples from the upper Three Forks (unit 6) as well as the underlying upper MTF (unit 5) using nuclear magnetic resonance (NMR) to evaluate pore-size distributions and reservoir quality of various lithofacies (Fig. 20). Lithofacies with larger and better-connected pore throats are more prone to take on hydrocarbon charge and yield hydrocarbon production in completed wells.

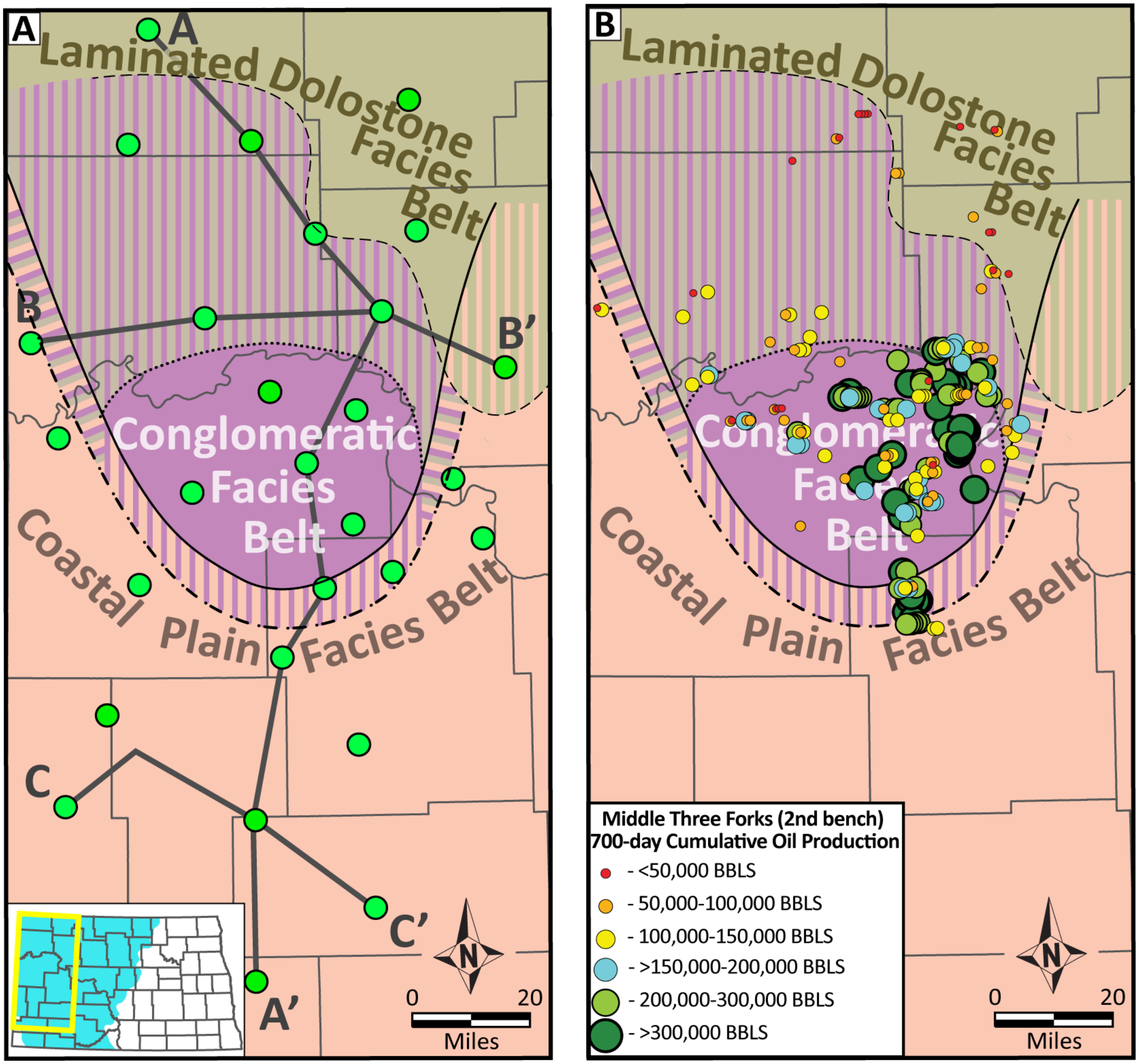


Figure 19. General facies belt map of the lower middle Three Forks (Christopher 1961; 1963 -> unit 4). A) Facies belt map with core control (green circles), Figure 16 cross-section locations, and North Dakota reference map in bottom left corner (yellow outline is study area, blue coloring is extent of Three Forks Formation, grey lines are county outlines). B) Facies belt map with middle Three Forks horizontal wells depicted as bubbles that are sized and colored to reflect 700-day cumulative oil production. Laminated Dolostone Facies Belt (brown area) = ≥50% of section comprised of laminated dolostone FA, <10% is silty mudstone FA, and <5% of overall section is oxidized. Conglomeratic Facies Belt (purple area) = ≥75% of net section is Conglomeratic FA containing dolostone clasts and/or dolomitic matrix, <10% is silty mudstone FA, and <5% of overall section is oxidized. Coastal Plain Facies Belt (red area) = >10% of net section is silty mudstone FA, and >5% (usually 20-70%) of the section has been oxidized. The multi-colored areas of each map depict intermediate transition zones between the various facies belts.

The four lithofacies identified and evaluated by Peterson (2013) (which can be approximately correlated to lithofacies described in this study) consisted of 1) Laminated (intercalated dolostone and claystone), 2) Clean Dolomite-Laminated (laminated dolostone FA), 3) Clean Dolomite-Mottled (conglomeratic FA), and 4) Massive Green Mudstone (conglomeratic and silty mudstone FA) (Fig. 20). The Clean Dolomite-Laminated facies (Laminated Dolostone FA with minimal clay/mudstone intercalations of this study) was noted to have the lowest overall total porosity but was interpreted as the best reservoir facies because it contained the largest pore-size distributions as well as the highest overall core-plug oil saturations (Fig. 20). The Massive Green Mudstone facies (~Silty Mudstone FA) was noted to have the highest overall total porosity but was interpreted as the poorest reservoir facies because of containing the smallest pore-size distributions and overall lowest core-plug oil saturations (Fig. 20). The additional two lithofacies of Laminated (Intercalated dolostone-claystone: laminated dolostone FA) and Clean Dolomite-Mottled (Conglomeratic FA) facies yielded variable, intermediate pore-size distributions of the previous two lithofacies reviewed above (Fig. 20). The Laminated facies equivalent within the MTF section is limited while the Clean Dolomite-Mottle equivalent Conglomeratic facies, as stated above, makes up most of the reservoir facies in the primary area of development for MTF horizontal wells.

Continental Resources Hawkinson core (Fig. 21) is an example of a MTF core located within the area of MTF production that contains variable conglomeratic FA beds and has corresponding core-plug fluid saturation data. Core interval 11,224-11,235 ft. is comprised of conglomeratic facies with a dark brown, dolomitic matrix with a relatively low gamma-ray signature which contains elevated core-plug oil saturations of near ~50% and reduced water saturations of ~25% (Fig. 21). The immediate overlying core interval of 12,212-12,224 ft. is also comprised of dolostone clast-bearing conglomeratic facies but with a green, clay-rich matrix that corresponds with a relatively elevated gamma-ray signature (Fig. 21). This conglomeratic interval has increased water (≥60%) and reduced oil (≤25%) saturations. The changes in fluid saturation levels between the two types of conglomeratic FA may be linked to variations in pore throats sizes and/or connectivity, where larger and/or more connected pores in the dolomitic conglomeratic FA is better able to take on hydrocarbon charge and the more clay-rich conglomeratic FA has smaller and/or less connected pores that are less able to take on hydrocarbon charge. Similar core-plug fluid saturation versus conglomeratic bed type vertical and lateral changes in the conglomeratic FA of the MTF reservoir (unit 4) should be a future area of investigation across the MTF productive area (Fig. 19B).

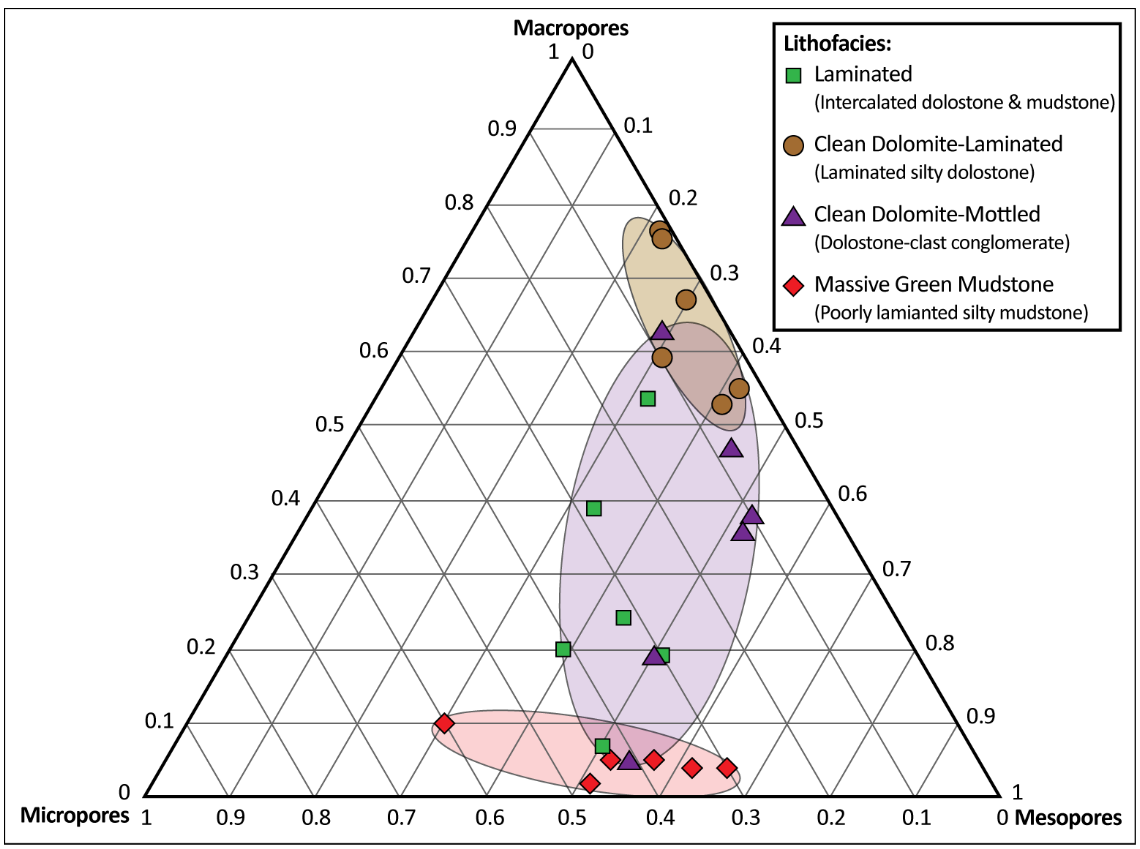


Figure 20. Ternary diagram of Micropores (<0.5 microns) versus Mesopores (0.5-5.0) microns and Macropores (>5 microns) using T2 cutoff values of 1 ms and 10 ms. Figure modified from Peterson (2017). Primary lithofacies listed are from Peterson (2017) while lithofacies in parentheses are the approximate correlative lithofacies of this study.

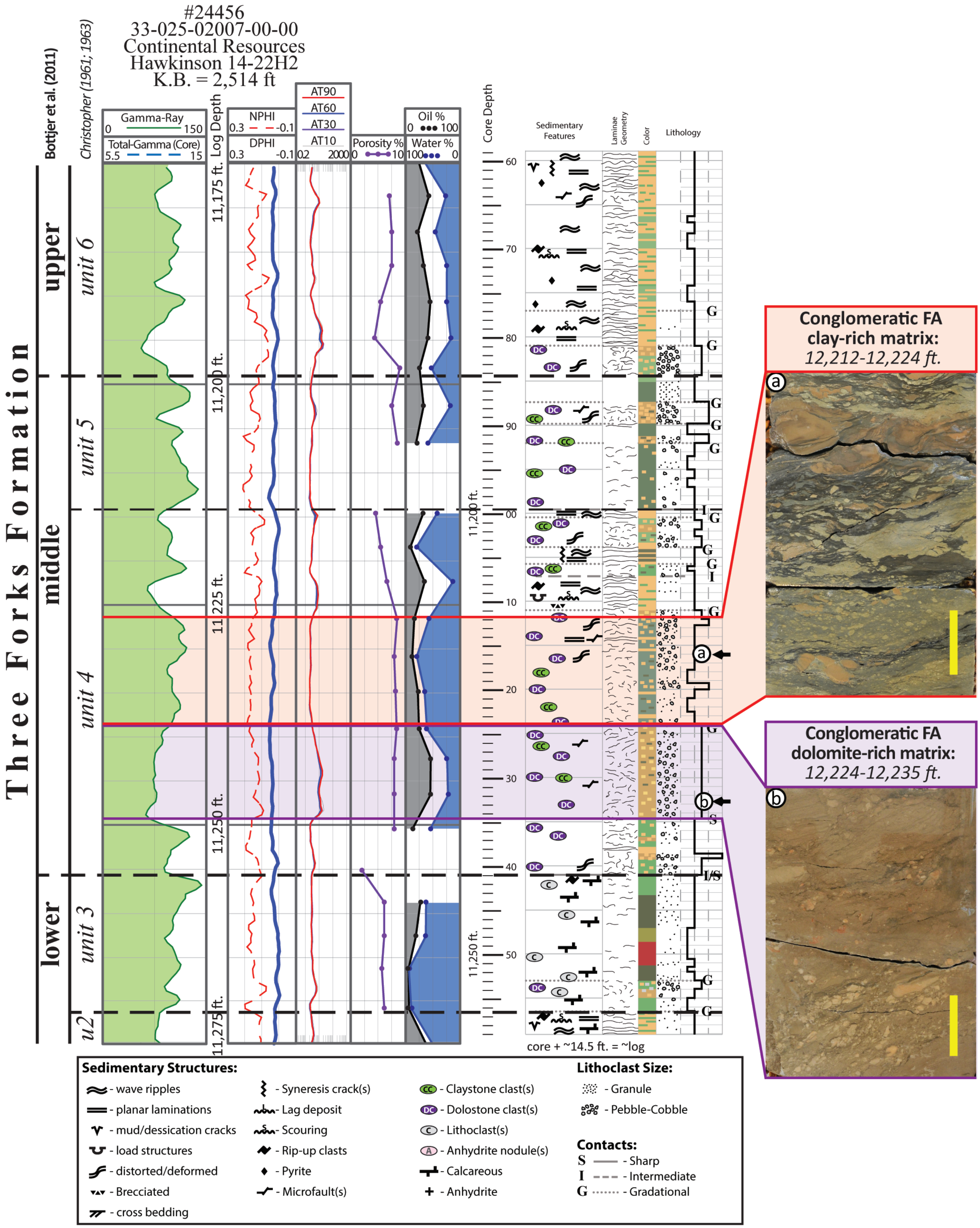


Figure 21. Wireline log (left) with standard core-plug analysis data (middle) and core-log illustration (right) of the middle Three Forks section from Continental Resources Hawkinson 14-22H2 (NDIC: 24456; API: 33-025-02007-00-00). Core photograph (a) depicts a conglomerate bed with a green-grey, clay-rich matrix that corresponds with overall lower oil and higher water core-plug saturations. Meanwhile, core photograph (b) depicts a conglomerate bed with a medium tan-brown, dolomite-rich matrix that corresponds with overall higher oil and lower water core-plug saturations.

CONCLUDING REMARKS:

- The MTF is comprised of three generalized lithofacies associations: 1) planar to ripple-laminated silty dolostone, 2) poorly laminated silty mudstone (roughly comprised of equal concentrations of quartz + feldspars, total clays, and dolomite), and 3) conglomerates that are highly variable in texture as well as composition.
- Vertical and lateral lithofacies distributions in cores and sedimentary structures indicate that deposition occurred along a low-angle ramp, in which the laminated dolostones formed primarily within a subaqueous tidal/mudflat setting that graded up dip/landward into oxidized, poorly laminated silty mudstone (coastal plain) with conglomerates mostly forming between the two end-member settings. Water conditions were likely hypersaline with highly variable salinity levels.
- The prominence of pebble-sized dolostone clast-bearing conglomerates and the absence calcite can be used to determine the MTF interval in core, which can generally be correlated to gamma-ray wireline log signatures.
- The primary area of drilling and production activity for the MTF occurs where the reservoir interval is primarily comprised of dolostone clast-bearing conglomerates (>75%), which are variable in texture and likely reservoir quality.
- The dolostone clast-bearing conglomerates with relative low clay concentrations (either clast-supported with limited matrix and/or a dolomite-rich/clay-poor matrix) appear to be the most prominent, best reservoir rock of the MTF reservoir.

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Sandberg, C.A., and Hammond, C.R., 1958, Devonian system in Williston Basin and central Montana: American Association of Petroleum Geologists Bulleting, v. 42, no. 10, p. 2293-2334.

Sesack, S. A., 2011, Sequence stratigraphy, depositional Environments, and regional mapping of the Late Devonian interval, upper Three Forks Formation, Sanish Member, and Lower Bakken Shale, U.S. Portion of the Williston Basin: West Virginia University M. S. Thesis, 212 pp.

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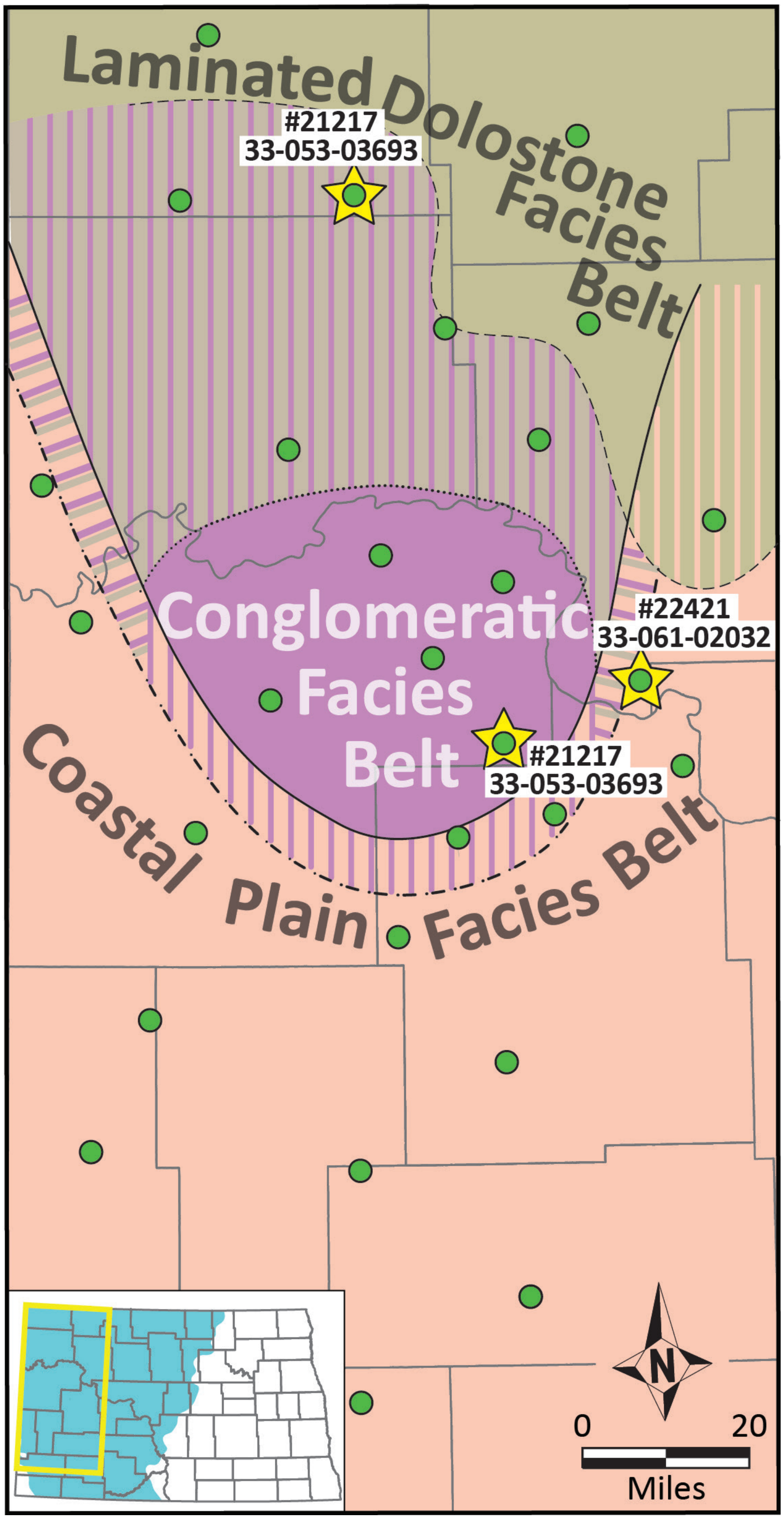
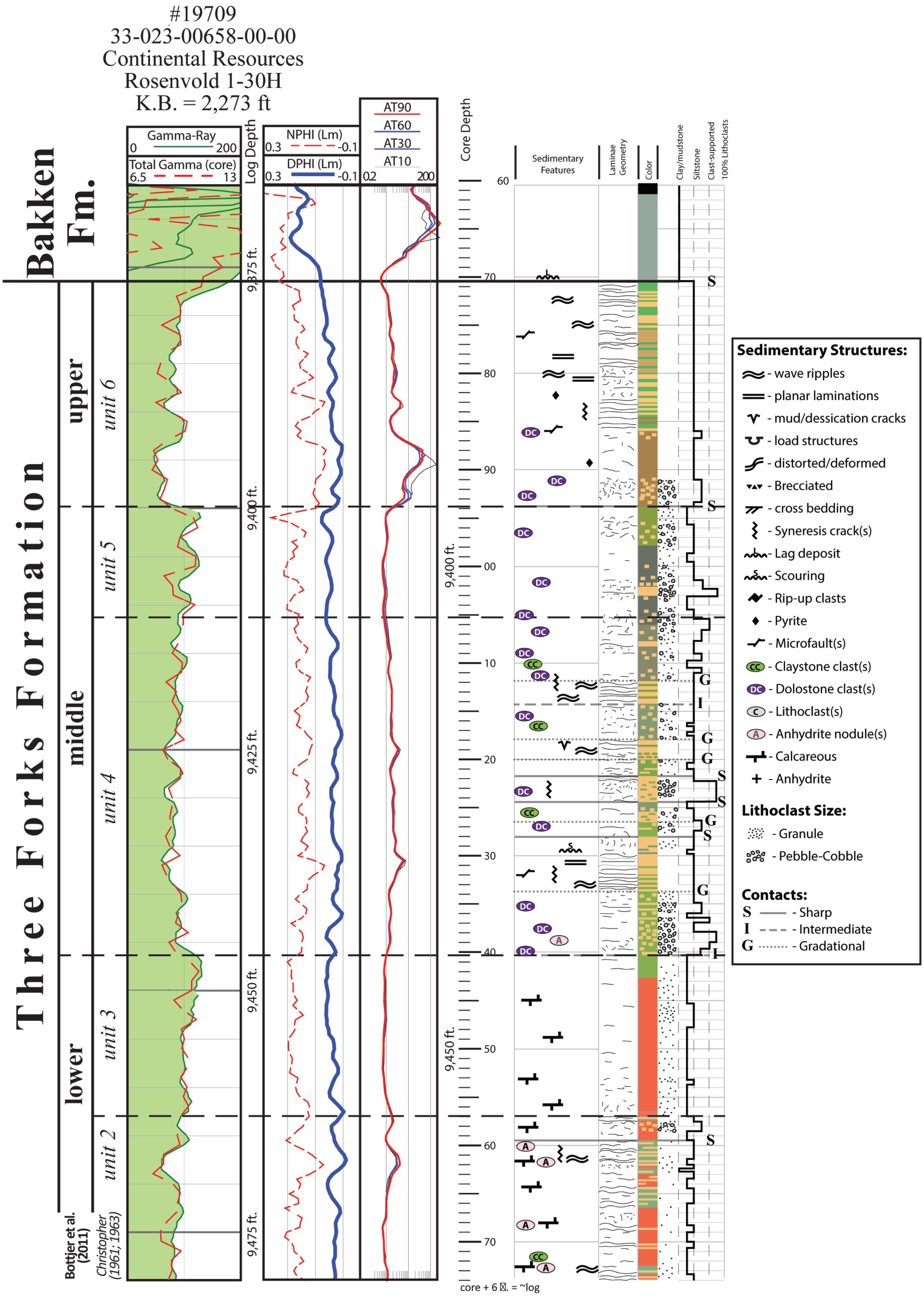
APPENDIX

Three cores spanning the middle Three Forks and adjacent bounding units were selected as representative visual examples of how the middle Three Forks changes across the study area. In part, these three cores were selected both on their spatial locations (one from each of the three generalized proposed facies belt: Laminated Dolostone, Conglomeratic, and Coastal Plain, their stratigraphic completeness of extending through the entire middle Three Forks section as well as 20+ feet into the bounding stratigraphic units (upper and lower Three Forks), and high-quality tripod (multi-core box) photograph sets. The appendix facies belt map shows the core locations as yellow stars.

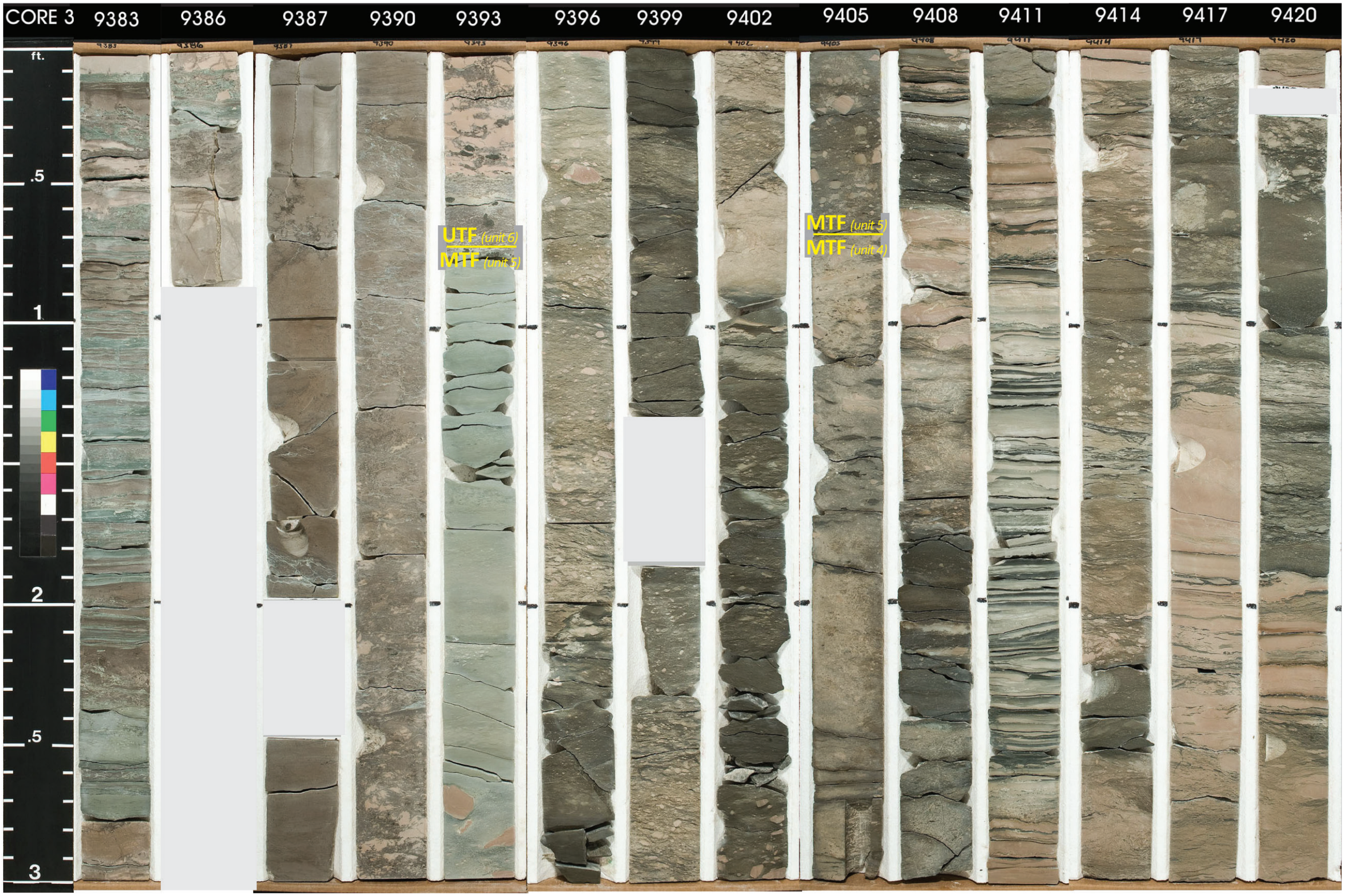


APPENDIX


#19709
33-023-00658-00-00
Continental Resources
Rosenvold 1-30H
K.B. = 2,273 ft
Bakken Fm.
Three Forks Formation
upper
middle
lower
unit 6
unit 5
unit 4
unit 3
unit 2
Bottjer et al. (2011)
Christopher (1961; 1963)
Gamma-Ray
0
200
Total Gamma (core)
6.5
13
Log Depth
9,375 ft.
9,400 ft.
9,425 ft.
9,450 ft.
9,475 ft.
NPHI (Lm)
0.3
-0.1
DPHI (Lm)
0.3
-0.1
AT90
AT60
AT30
AT10
0.2
200
Core Depth
60
70
80
90
9,400 ft.
00
10
20
30
40
9,450 ft.
50
60
70
core + 6 ft. = ~log
Sedimentary Features
Laminae Geometry
Color
Clay/mudstone
Siltstone
Clast-supported
100% Lithoclasts
DC
CC
A
S
I
G
Sedimentary Structures:
- wave ripples
- planar laminations
- mud/dessication cracks
- load structures
- distorted/deformed
- Brecciated
- cross bedding
- Syneresis crack(s)
- Lag deposit
- Scouring
- Rip-up clasts
- Pyrite
- Microfault(s)
CC - Claystone clast(s)
DC - Dolostone clast(s)
C - Lithoclast(s)
A - Anhydrite nodule(s)
- Calcareous
- Anhydrite
Lithoclast Size:
- Granule
- Pebble-Cobble
Contacts:
S - Sharp
I - Intermediate
G - Gradational

NWNE Sec. 30-T160N-R96W
CONTINENTAL RESOURCES, INC.
ROSENVOLD 1-30H

NDIC File No: 19709
API No: 33-023-00658-00-00
Core Interval: 9,387-9,423 ft.



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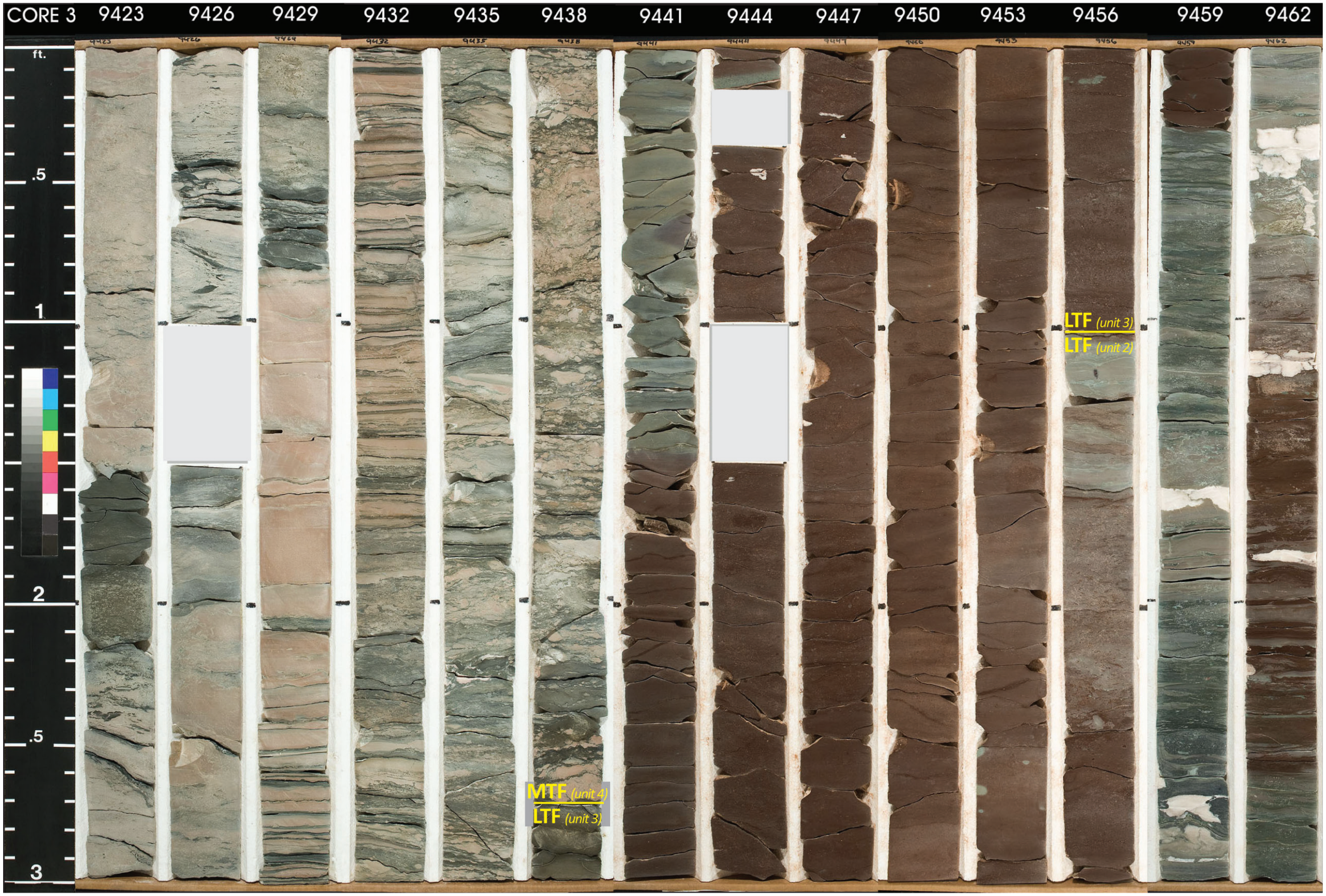
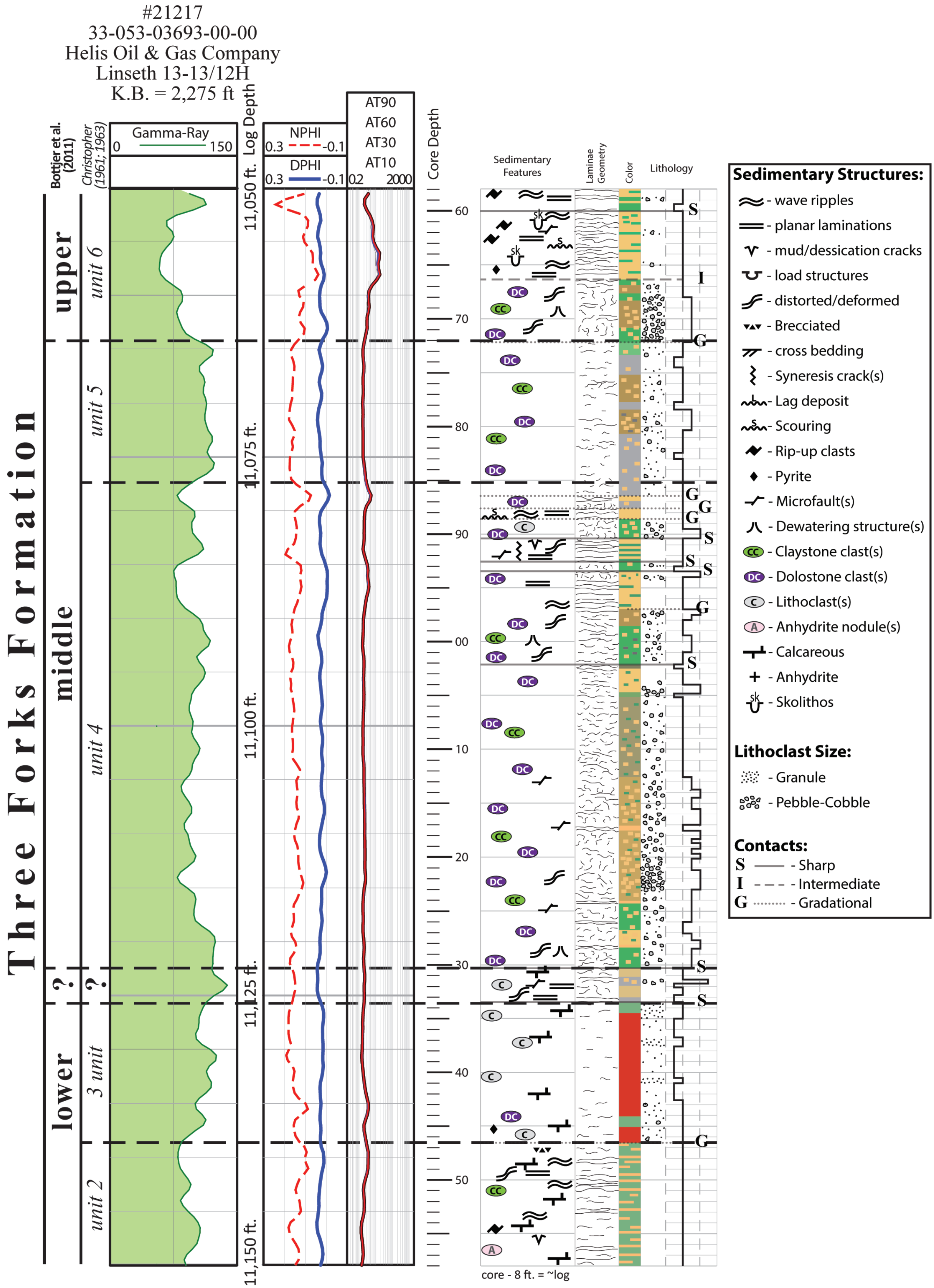
NWNE Sec. 30-T160N-R96W
CONTINENTAL RESOURCES, INC.
ROSENVOLD 1-30H

NDIC File No: 19709
API No: 33-023-00658-00-00
Core Interval: 9,423-9,465 ft.



APPENDIX

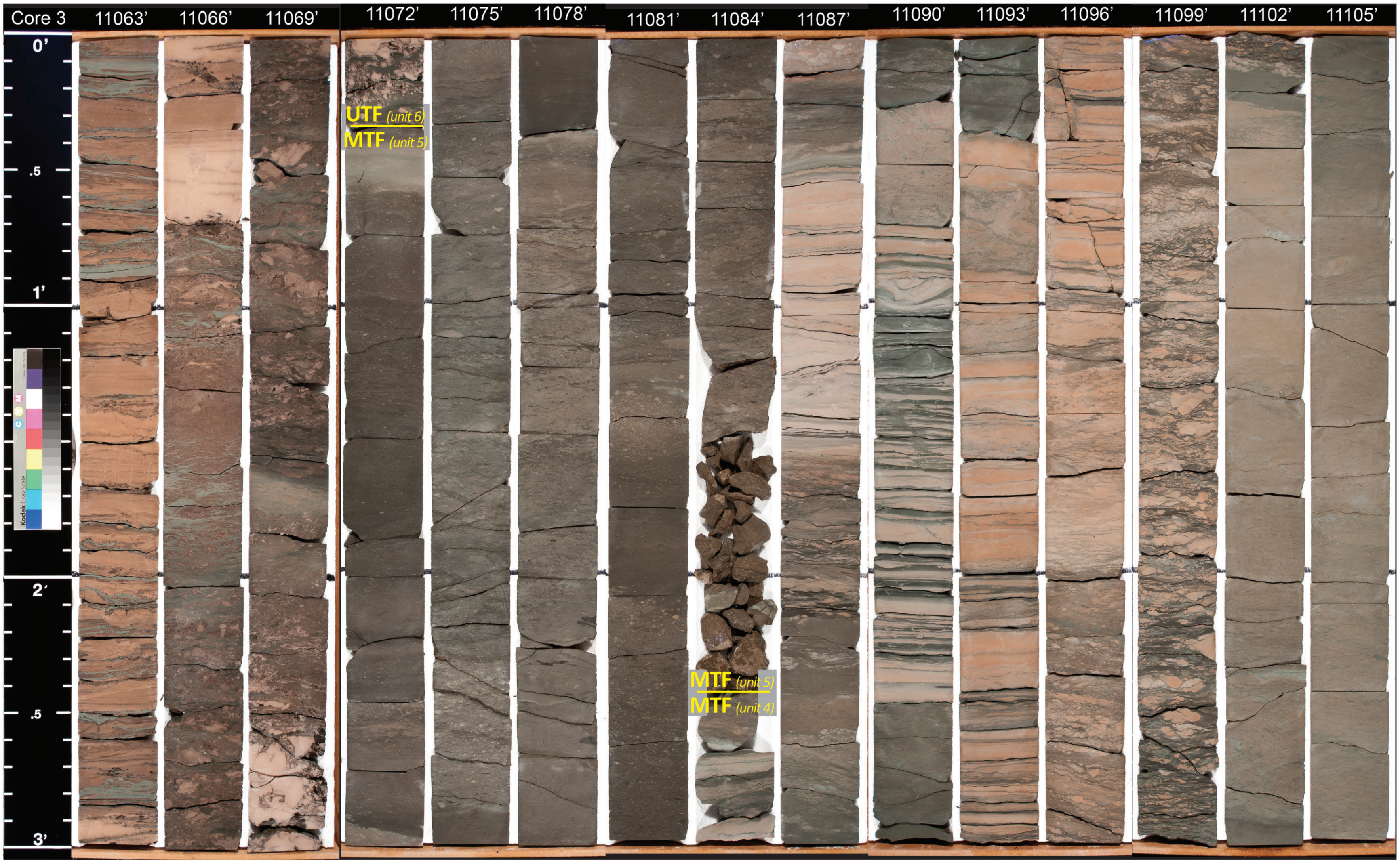


#21217
33-053-03693-00-00
Helis Oil & Gas Company
Linseth 13-13/12H
K.B. = 2,275 ft
Bottjer et al. (2011)
Christopher (1961; 1963)
Gamma-Ray
0 150
Log Depth
NPHI
0.3 -0.1
DPHI
0.3 -0.1
AT90
AT60
AT30
AT10
0.2 2000
Core Depth
Sedimentary Features
Laminae Geometry
Color
Lithology
Three Forks Formation
upper
middle
lower
unit 6
unit 5
unit 4
3 unit
unit 2
?
11,050 ft.
11,075 ft.
11,100 ft.
11,125 ft.
11,150 ft.
60
70
80
90
00
10
20
30
40
50
core - 8 ft. = ~log
Sedimentary Structures:
- wave ripples
- planar laminations
- mud/dessication cracks
- load structures
- distorted/deformed
- Brecciated
- cross bedding
- Syneresis crack(s)
- Lag deposit
- Scouring
- Rip-up clasts
- Pyrite
- Microfault(s)
- Dewatering structure(s)
- Claystone clast(s)
- Dolostone clast(s)
- Lithoclast(s)
- Anhydrite nodule(s)
- Calcareous
- Anhydrite
- Skolithos
Lithoclast Size:
- Granule
- Pebble-Cobble
Contacts:
S - Sharp
I - Intermediate
G - Gradational

APPENDIX

Sec. 13-T149N-R95W
HELIS OIL & GAS COMPANY, L.L.C.
LINSETH 13-13/12H

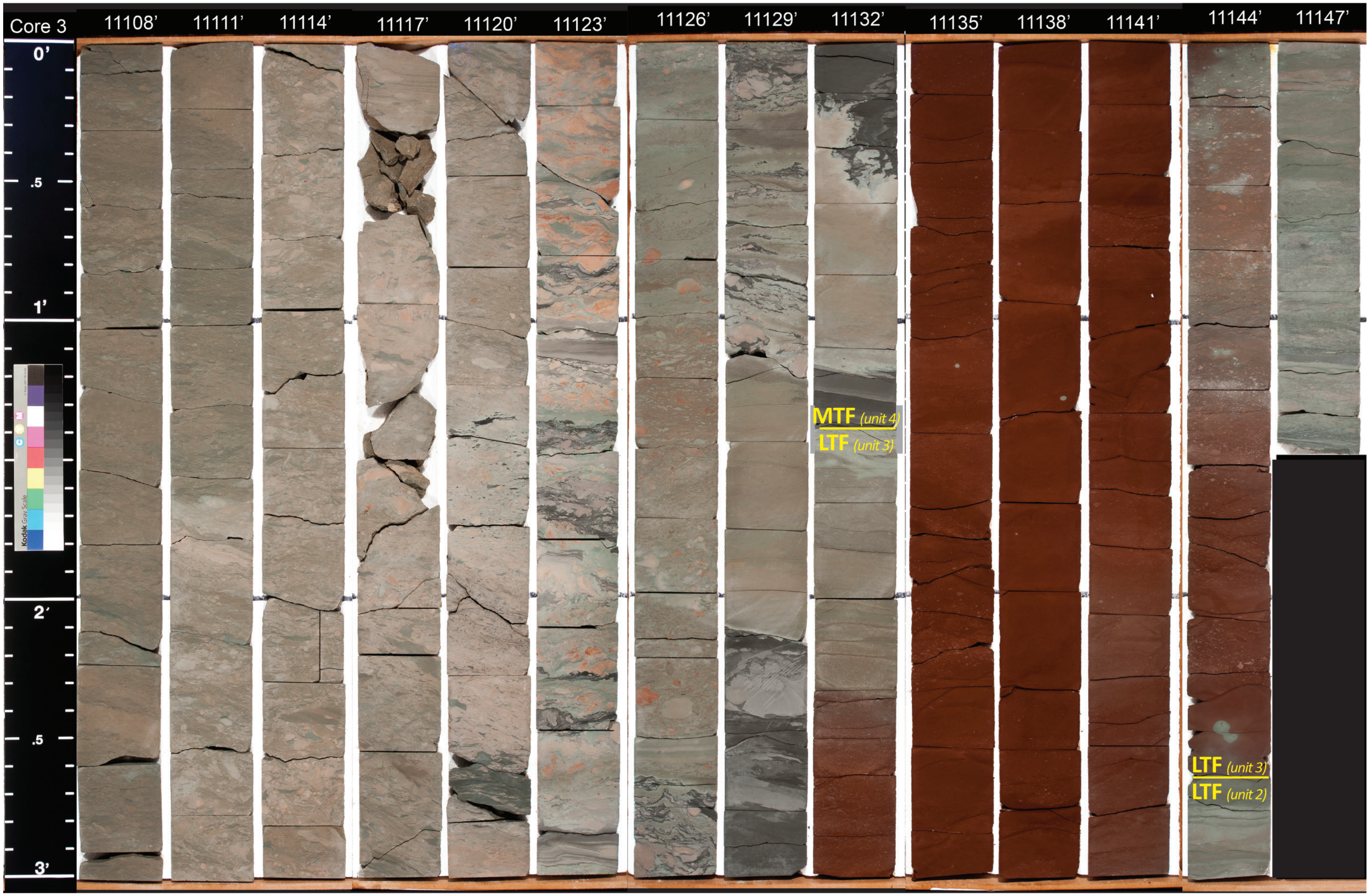
NDIC File No: 21217
API No: 33-053-03693-00-00
Core Interval: 11,063-11,108 ft.



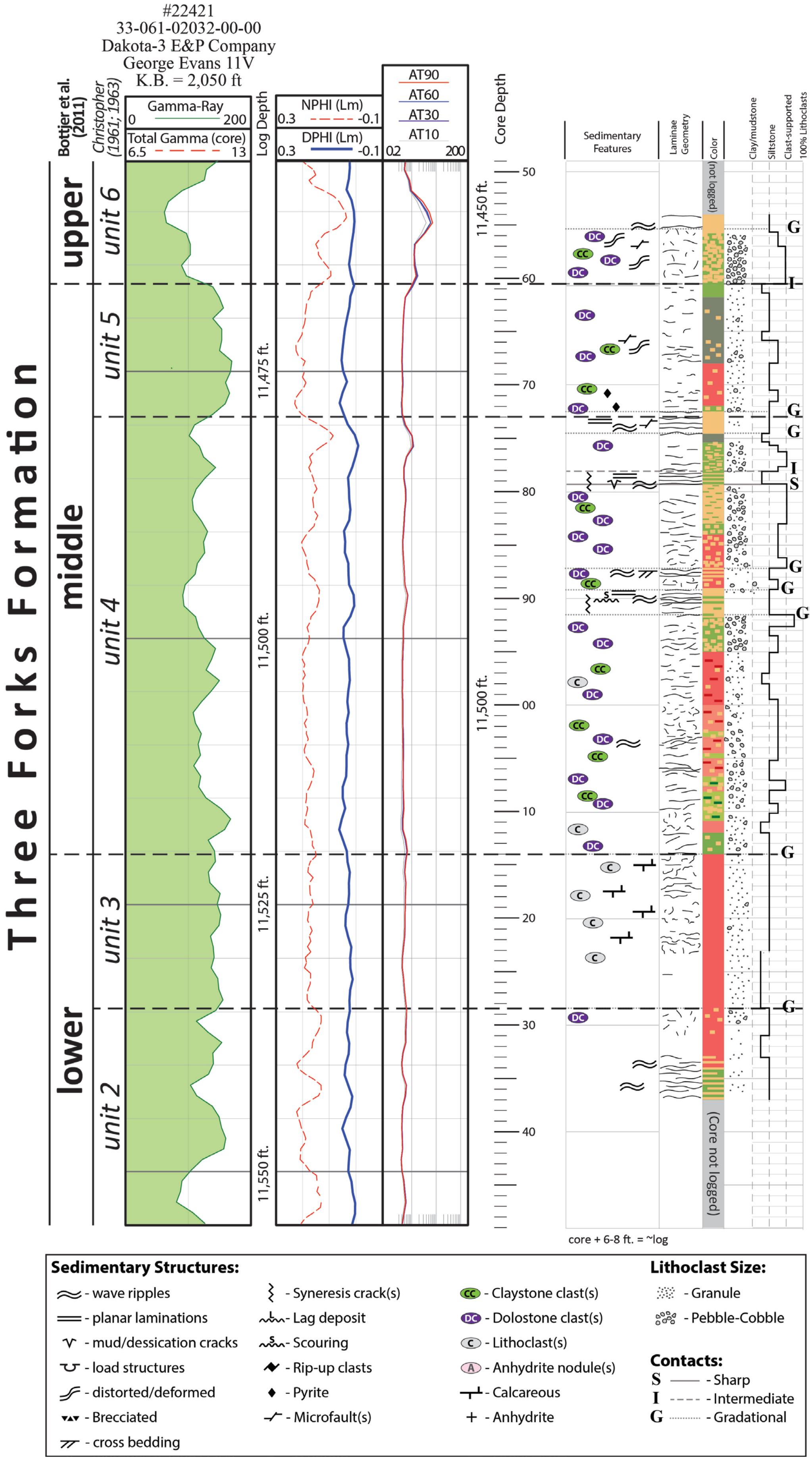
APPENDIX

Sec. 13-T149N-R95W
HELIS OIL & GAS COMPANY, L.L.C.
LINSETH 13-13/12H

NDIC File No: 21217
API No: 33-053-03693-00-00
Core Interval: 11,108-11,148.5 ft.



APPENDIX

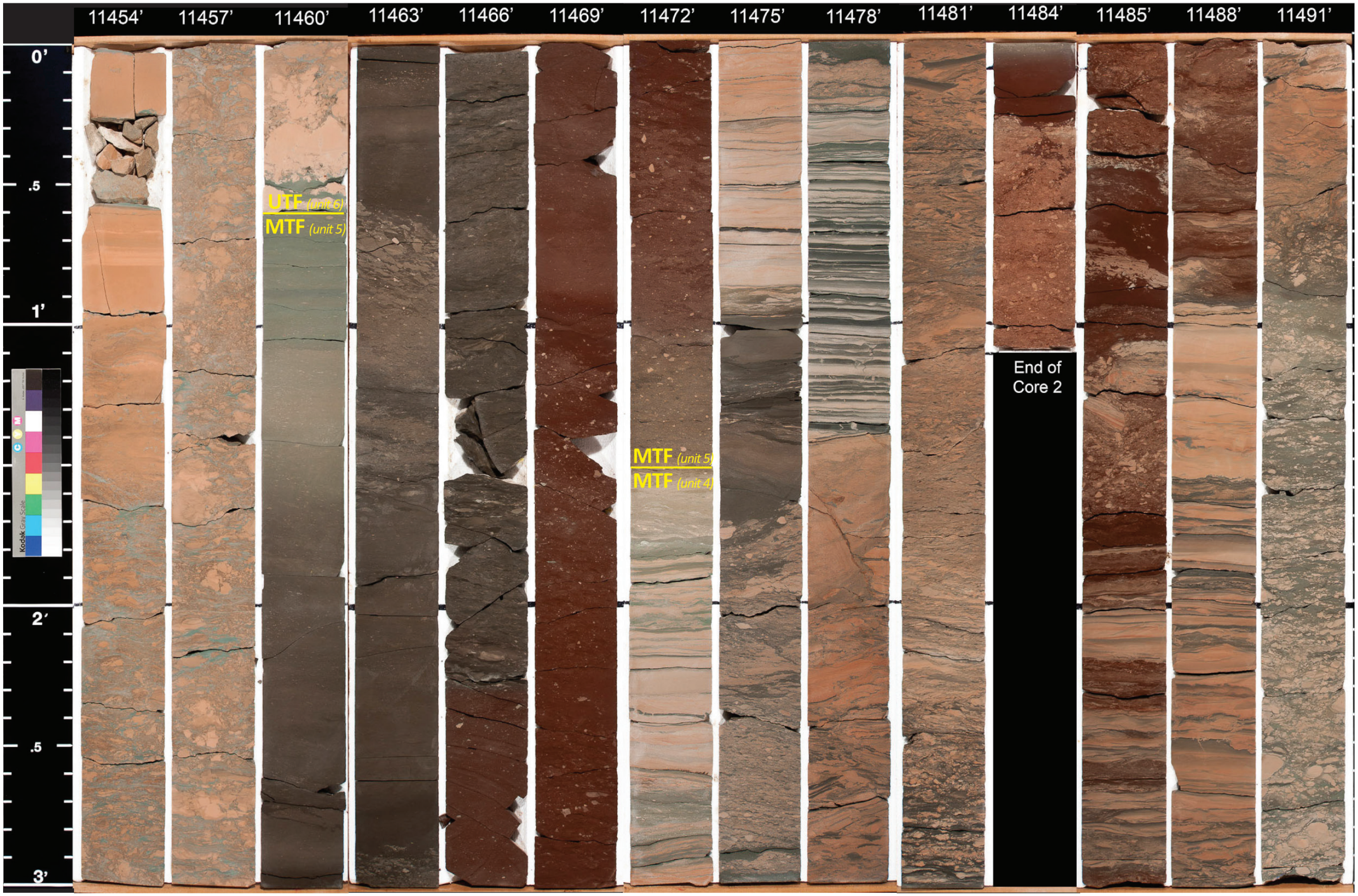


#22421
33-061-02032-00-00
Dakota-3 E&P Company
George Evans 11V
K.B. = 2,050 ft
Bottjer et al. (2011)
Christopher (1961; 1963)
Gamma-Ray
0 200
Total Gamma (core)
6.5 13
Log Depth
NPHI (Lm)
0.3 -0.1
DPHI (Lm)
0.3 -0.1
AT90
AT60
AT30
AT10
02 200
Core Depth
Sedimentary Features
Laminae Geometry
Color
Clay/mudstone
Siltstone
Clast-supported
100% Lithoclasts
Three Forks Formation
upper
middle
lower
unit 6
unit 5
unit 4
unit 3
unit 2
11,450 ft.
11,475 ft.
11,500 ft.
11,525 ft.
11,550 ft.
(not logged)
(Core not logged)
core + 6-8 ft. = ~log
Sedimentary Structures:
- wave ripples
- planar laminations
- mud/dessication cracks
- load structures
- distorted/deformed
- Brecciated
- cross bedding
- Syneresis crack(s)
- Lag deposit
- Scouring
- Rip-up clasts
- Pyrite
- Microfault(s)
- Claystone clast(s)
- Dolostone clast(s)
- Lithoclast(s)
- Anhydrite nodule(s)
- Calcareous
- Anhydrite
Lithoclast Size:
- Granule
- Pebble-Cobble
Contacts:
S - Sharp
I - Intermediate
G - Gradational

APPENDIX

SWSE Sec. 11-T150N-R92W
DAKOTA-3 E&P COMPANY, LLC
GEORGE EVANS 11V

NDIC File No: 22421
API No: 33-061-02032-00-00
Core Interval: 11,454-11,494 ft.



APPENDIX

SWSE Sec. 11-T150N-R92W
DAKOTA-3 E&P COMPANY, LLC
GEORGE EVANS 11V

NDIC File No: 22421
API No: 33-061-02032-00-00
Core Interval: 11,494-11,540 ft.