Revisiting Stratigraphic Nomenclature for the Three Forks Formation in western North Dakota

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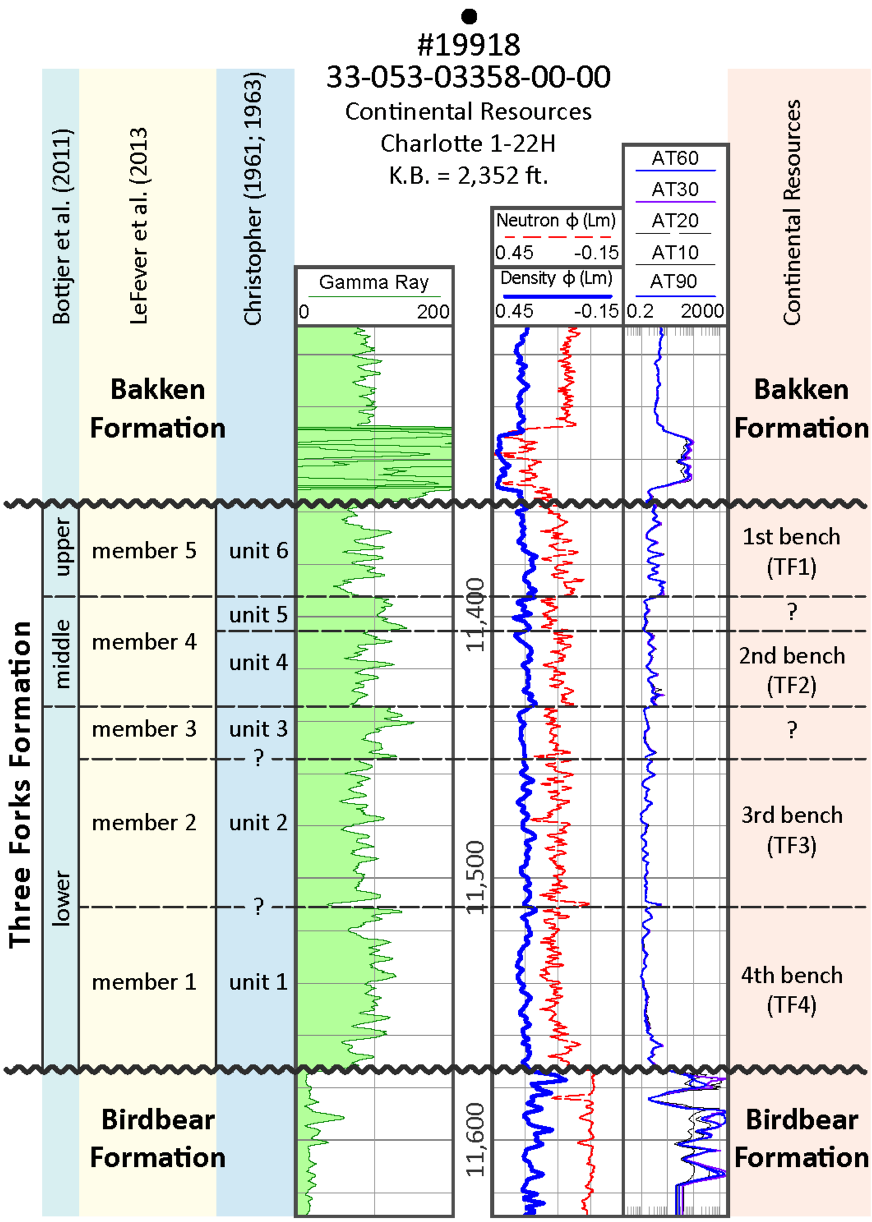

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INTRODUCTION

The Three Forks Formation (Three Forks) was correlated into the Williston Basin of North Dakota at least as early as Sandberg and Hammond (1958) and was defined to include all strata above the Birdbear Formation and below the Bakken Formation. The Three Forks is present in the subsurface of approximately the western half of the state (Fig. 1) (LeFever, 2008). Unconventional exploration and development (horizontal drilling coupled with hydraulic fracturing) initially focused on the upper Three Forks, but later expanded to reservoir targets lower in the section (Nesheim, 2019). Over the past several decades, multiple nomenclature systems have been utilized to stratigraphically subdivide the Three Forks, but a formalized subdivision has yet to be achieved. The purpose of this report is to review previously developed Three Forks stratigraphic nomenclature and work towards an accepted, formalized system.

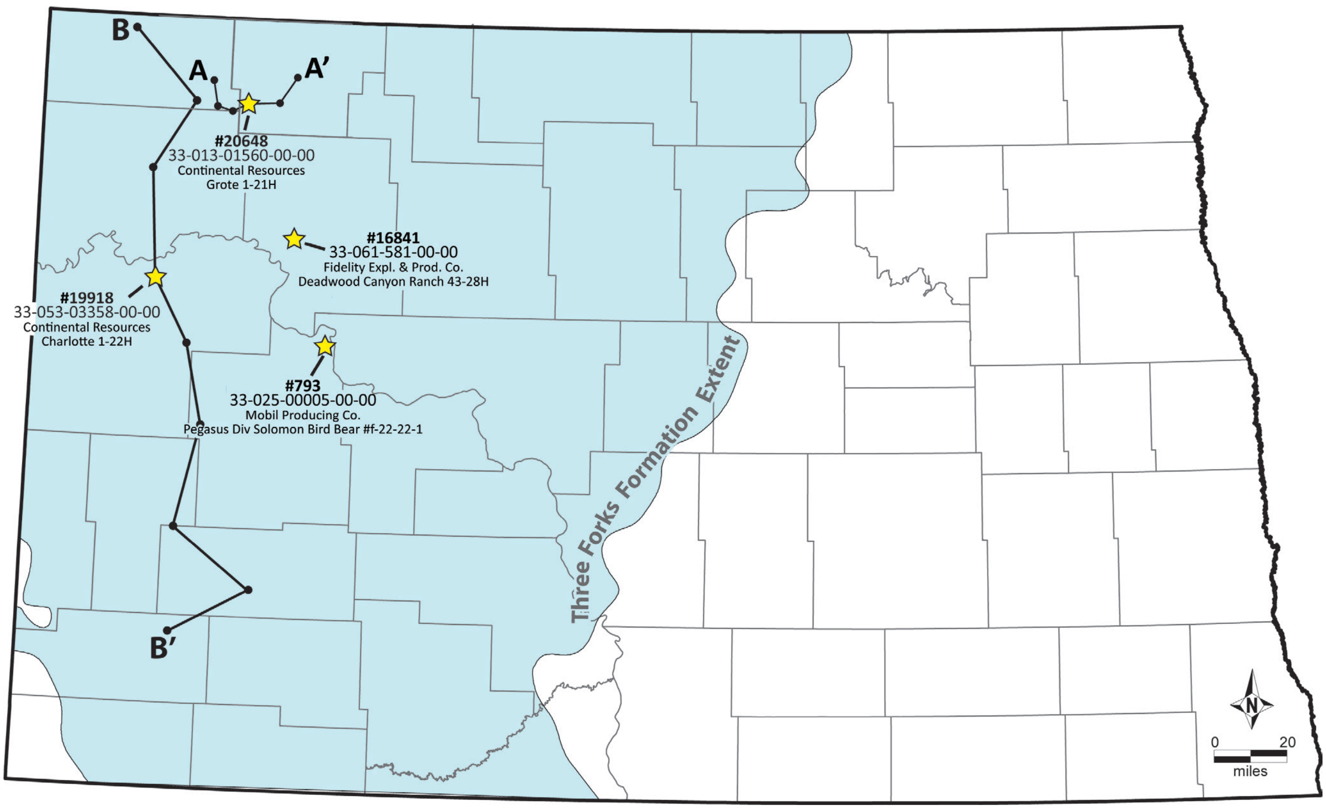

Figure 1. Map of North Dakota showing the extent of the Three Forks Formation (blue) along with the locations of type logs (yellow stars) and cross-sections A-A' and B-B'.

REVIEW OF THREE FORKS STRATIGRAPHIC NOMENCLATURE SYSTEMS

Subdividing the Three Forks within the Williston Basin began as early as Fuller (1956), in which the Three Forks section (referred to as the Qu`Appelle Group in Fuller's report) was described to consist primarily of three sedimentary cycles (1-3 in ascending order) (Figs. 1 and 2). Fuller (1956) noted the three cycles were easily observed on gamma-ray well logs and each consisted of iron-stained dolomitic siltstones (base) with increasing upward argillaceous content that terminates into radioactive red shales. Fuller (1956) did not assign a sedimentary cycle number to an uppermost set of beds in the Three Forks equivalent section that was iron sulfide rich and non-red stained (Fig. 2).

Christopher (1961; 1963) developed a six-unit subdivision system (Fig. 3) for the Three Forks equivalent Torquay Formation in southern Saskatchewan. Christopher (1961; 1963) described his six units to reflect broadly alternatively dolomite-anhydrite versus more argillaceous horizons. He correlated the units primarily using gamma ray and neutron wireline logs for several hundred wells, but noted the units were not readily evident in core. Christopher's (1961) regional cross-section correlations included several wells that extended south of the Canadian border, including two wells within the Williston Basin of North Dakota.

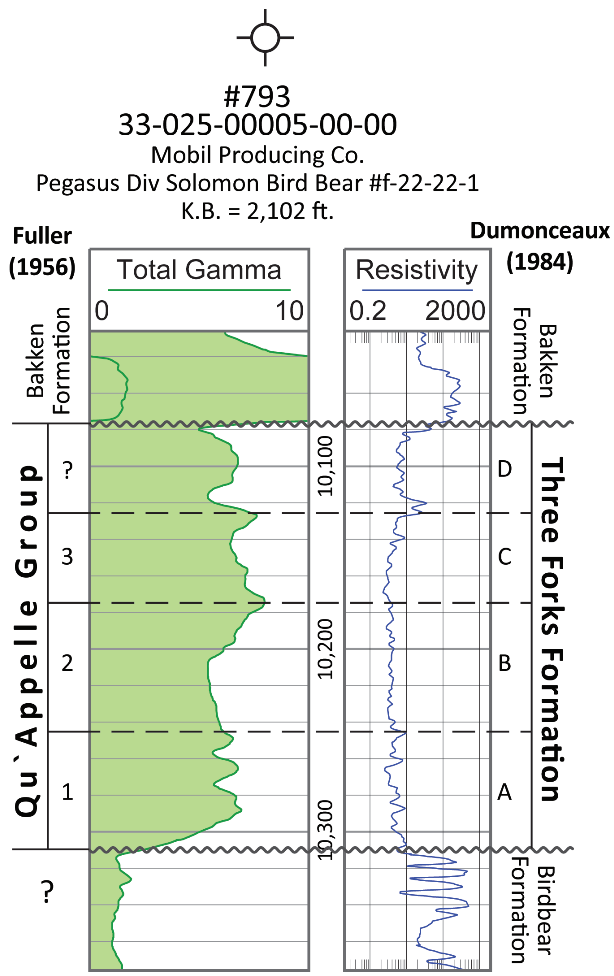

Figure 2. Wireline logs through the Three Forks Formation and adjacent strata from Mobil Producing's Pegasus Division Solomon Bird Bear #f-22-22-1 with the proposed stratigraphic nomenclature of Dumonceaux (1984) and Fuller (1956).

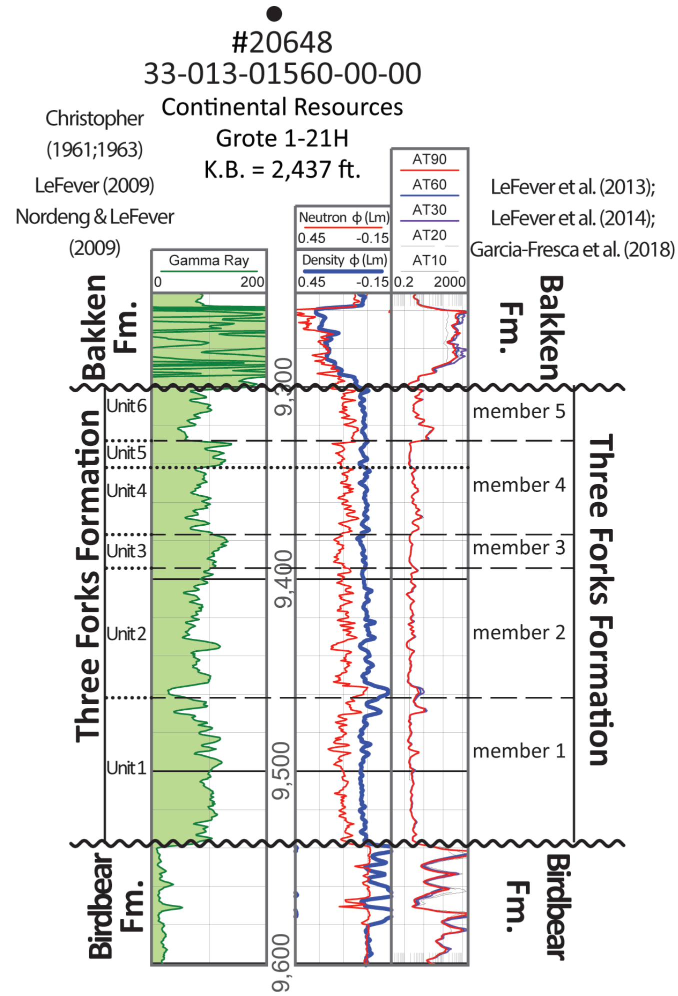

Figure 3. Wireline logs through the Three Forks Formation and adjacent strata from Continental Resource's Grote 1-21H with the proposed stratigraphic nomenclature of Christopher (1961; 1963) and LeFever et al. (2013; 2014).

Dumonceaux (1984) correlated Fuller's (1956) three cycles on wireline logs from southern Saskatchewan into western North Dakota. Dumonceaux labeled the three Fuller cycles as A-C in ascending stratigraphic order within North Dakota and referred to the uppermost interval as the D cycle (Fig. 2). However, Dumonceaux noted the four cycles are not evident in the rock record as different or alternating rock types, but instead primarily reflect wireline log characteristics.

As exploration and development in the Bakken Petroleum System expanded to include the upper Three Forks section, the six-unit Three Forks subdivision from Christopher (1961; 1963) was initially utilized by the North Dakota Geological Survey (NDGS) and further correlated across western North Dakota (LeFever and Nordeng, 2008; LeFever et al., 2009; LeFever et al., 2011) (Figs. 3 and 4). While the six-unit system was primarily correlated using wireline logs, Three Forks log to core correlations and core facies were also examined by the NDGS (Nordeng and LeFever, 2009).

After the NDGS initially correlated the six-unit system into North Dakota, Bottjer et al. (2011) adopted a more simplified, informal, three-member stratigraphic nomenclature system (upper, middle, and lower members) for the Three Forks section (Fig. 5). Bottjer et al. (2011) documented with well logs how the upper, middle, and lower members correlated with the six-unit system of Christopher (1961; 1963), which corresponds as follows: upper member = unit 6, middle member = units 4 and 5, and the lower member = units 1-3 (Fig. 5). While Bottjer et al.

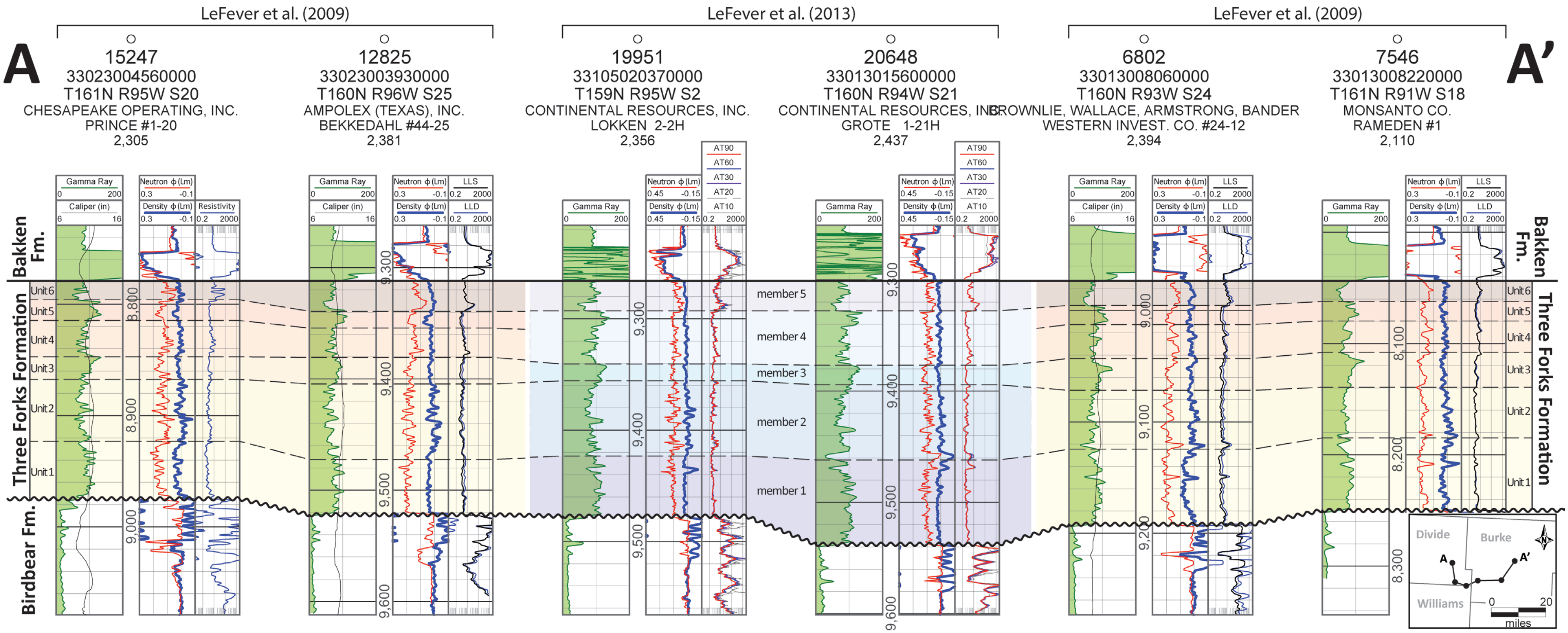

Figure 4. Cross-section combining well logs from LeFever et al. (2009) and LeFever et al. (2013) that correlate their six-unit and five-member stratigraphic nomenclatures of the Three Forks Formation.

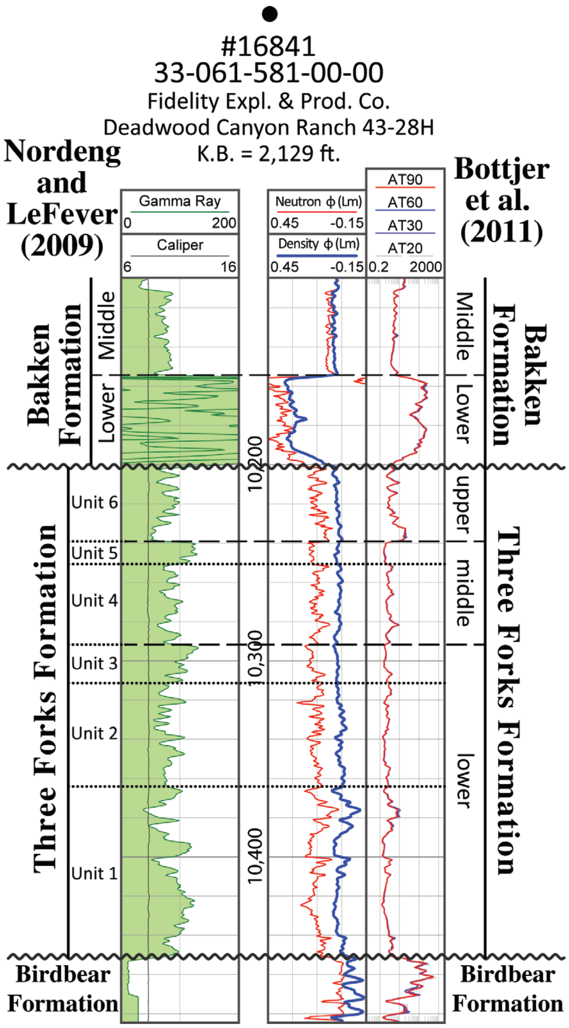

Figure 5. Wireline logs through the Three Forks Formation and adjacent strata from Fidelity's Deadwood Canyon Ranch 43-28H with the six-unit system from Nordeng and LeFever (2009) (borrowed from Christopher, 1961;1963) and the upper-middle-lower system from Bottjer et al. (2011).

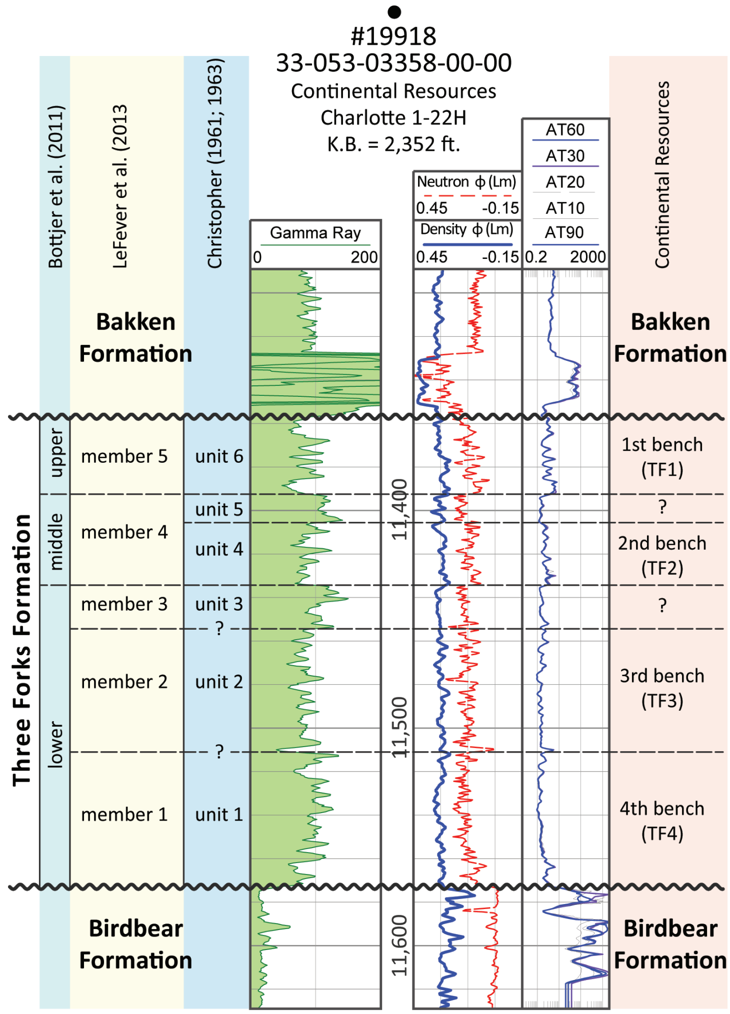

Figure 6. Wireline logs through the Three Forks Formation and adjacent strata from Continental Resource's Charlotte 1-22H comparing the four-bench/reservoir terminology system with the proposed stratigraphic nomenclature from Christopher (1961; 1963), Bottjer et al. (2011), and LeFever et al. (2013; 2014).

(2011) focused their work on the Bakken and upper Three Forks Formations, their cross-sections correlated the upper, middle and lower Three Forks members across several dozen well logs with a green mudstone consistently noted at the top of the middle Three Forks.

As petroleum companies (operators) began to expand their exploration and development efforts deeper into the Three Fork section, ensuing NDGS publications switched to a five-member system (LeFever et al., 2013; 2014). The five-member system only partially corresponds to the six unnamed members identified by Christopher (1961; 1963) (Figs. 3 and 4). Most recently, the five-member system was incorporated by Garcia-Fresca et al. (2018), a notable regional sedimentological and stratigraphic study of the Three Forks. Some operators, however, started to subdivide the Three Forks stratigraphy at that time into zones or benches using primarily wireline log characteristics specific to reservoir targets. These informal zone/bench subdivision systems have been described as inconsistent from operator to operator (Garcia-Fresca et al., 2018). A four-bench system, referred to as benches 1 to 4 in descending order, has been used most prevalently amongst operators (Fig. 6) (e.g. Gaswirth and Marra, 2015; Garcia-Fresca et al., 2018). The four-bench system is primarily tied to four specific reservoir targets for horizontal, unconventional-style wells, and does not address the entire Three Forks stratigraphic section.

More recently, Franklin and Sarg (2018) identified and correlated seven regional shallowing upward cycles. The seven cycles were described in cores and correlated with wireline logs but were not proposed as a nomenclature system. While Franklin and Sarg (2018) did consist of very insightful and detailed sedimentological information, they did not attempt to correlate their seven cycles with any of the previously suggested stratigraphic nomenclature.

CURRENT INVESTIGATION

The North Dakota Geological Survey is currently reviewing previously proposed and/or utilized stratigraphic nomenclature systems for the Three Forks Formation with plans to endorse and/or modify an existing nomenclature system or propose a new system. The primary reason for this investigative effort is to endorse or create a nomenclature that can be formalized for the purpose of better defining changes in Three Forks stratigraphy.

A total of 43 complete to near complete North Dakota cores of the Three Forks Formation have been identified for study (Plate I). To date, 12 of those cores have been logged (described) for the current investigation. The stratigraphic cross-section (A-A') includes nine of those core descriptions along with the corresponding gamma-ray wireline logs (Plate I). The cross-section displays the three-member (upper, middle, and lower) system from Bottjer et al. (2011), in part because it is the simplest and easiest system to correlate between both cores and wireline logs. Below is a preliminary list of potential key characteristics that were recently observed in the complete and near-complete Three Forks cores which may, in part, be used to formally subdivide the Three Forks section.

Potential Key Sedimentological/Lithological Characteristics of the Three Forks Formation:

- Calcite and anhydrite are most abundant in the lower Three Forks section.
- The lower Three Forks is mostly massive to mottled with an overall poorly developed/preserved laminated to bedded texture.
- Red coloration (oxidation) is limited to the lower Three Forks section in northwestern North Dakota but extends upwards into the middle Three Forks towards the south.
- Lithoclast bearing/supported facies are common to abundant in the middle and lower Three Forks but are absent to minimal in the upper Three Forks.
- Middle Three Forks stratigraphy ranges from well-developed/preserved (approximately horizontal) laminated to bedded texture to a more massive-mottled texture.
- Two distinct red to green argillaceous/shale intervals, that can be correlated regionally in core and wireline logs (increased gamma-ray signatures), are positioned in the middle to upper portions of the Three Forks section. The tops of these argillaceous/shale intervals display a consistent, sharp contact with overlying dolostone while the bases vary from moderately sharp to intermediate-gradational.
- The interlaminated/bedded dolostone and shale texture is primarily found in the upper Three Forks and secondarily in the middle Three Forks.
- The upper Three Forks is primarily green and tan in color with minimal to negligible red (oxidation) coloration.
- Distinctive trace fossils (burrowing) appear to be primarily restricted to the upper Three Forks and are only present within select cores.
- Climbing and oscillatory ripples are most commonly present in the upper Three Forks but can also extend intermittently through the middle and/or lower Three Forks section.

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