Preliminary Middle (2nd bench) and Lower (3rd and 4th bench) Three Forks Horizontal Well Identification

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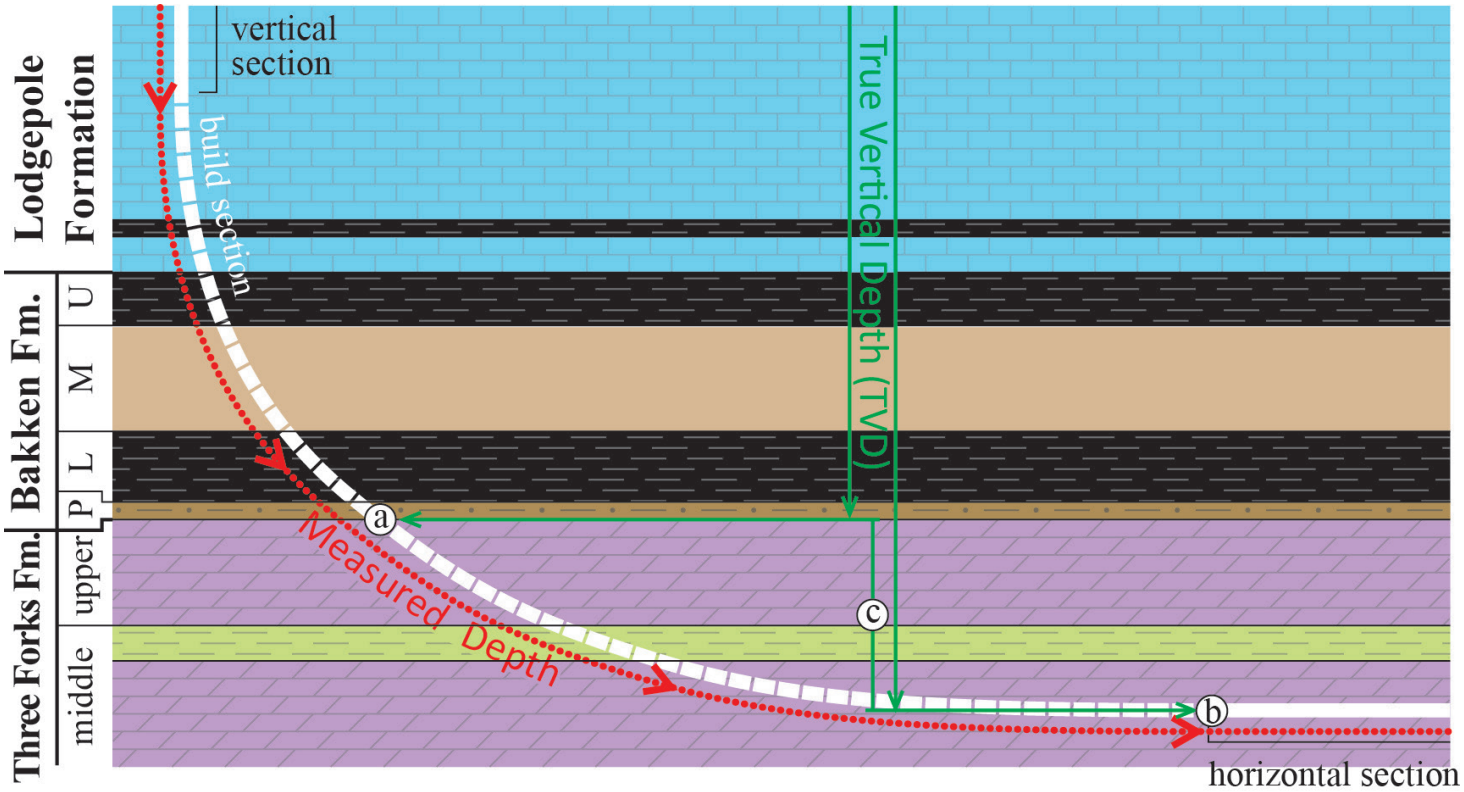

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NORTH DAKOTA GEOLOGICAL SURVEY
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Introduction

More than 15,000 horizontal wells have been drilled and completed within the Bakken and Three Forks Formations in western North Dakota during the past 15 years. While most of these wells have targeted either the Middle Member of the Bakken Formation (Bakken) or the upper member of Three Forks Formation (Three Forks), there are a few hundred horizontal wells that have targeted the middle and lower Three Forks. Since early 2013, more than 250 horizontal wells have been drilled and completed within the middle Three Forks with additional wells within the lower Three Forks (Figs. 1 and 2) (Nesheim, 2020). During 2019, wells drilled and completed in the middle Three Forks accounted for approximately 3% of the total Bakken-Three Forks production in North Dakota. Cumulative production from the middle Three Forks totals more than 57 million barrels of oil and 120 billion cubic feet of gas (Nesheim, 2020).

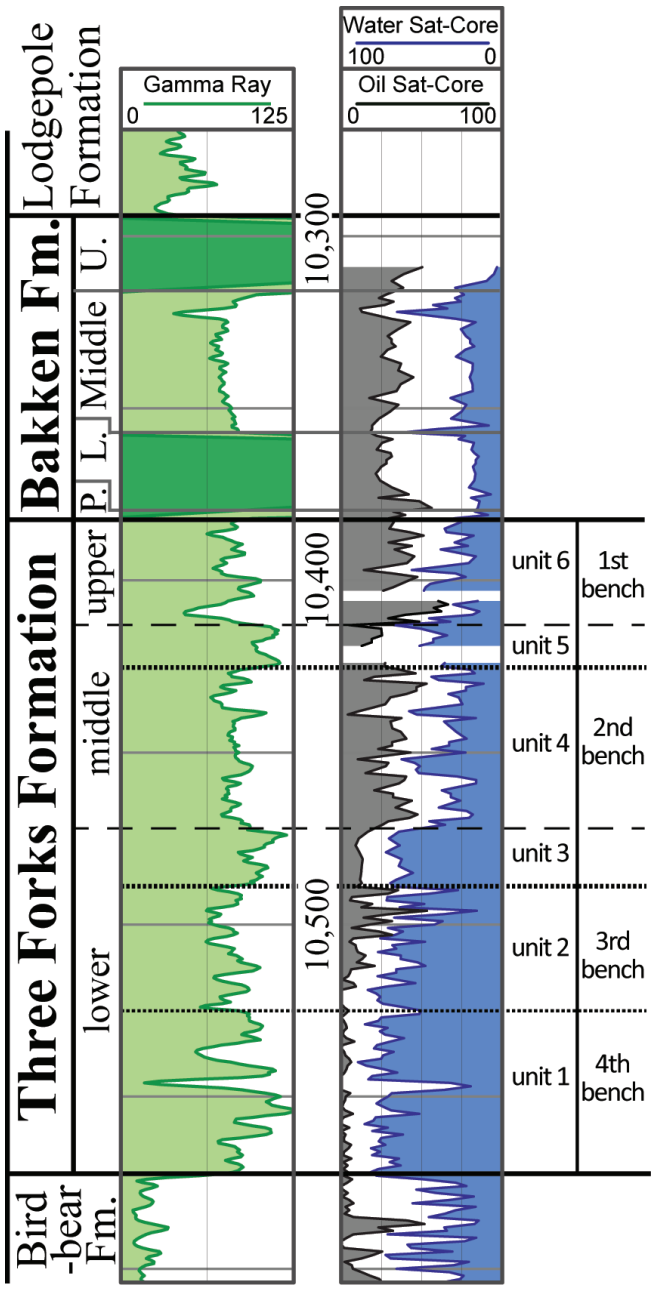

Figure 1. Wireline log example with core-plug fluid saturation data of the Bakken and Three Forks Formation from Enerplus Resource's Hognose 152-94-18B-19H-TF (NDIC: 26990; API: 33-053-05475-00-00). The upper, middle, and lower Three Forks stratigraphic nomenclature is based upon Bottjer and others (2011) while the unit 1-6 system is from Christopher and others (1961, 1963). The informal Three Forks "bench" terminology is from operators. The Pronghorn Member of the Bakken Formation is very thin to absent in this example well. For better examples of the Pronghorn Member on wireline logs, refer to the Figure 3 cross-section. L. = Lower Member P. = Pronghorn Member; U. = Upper Member

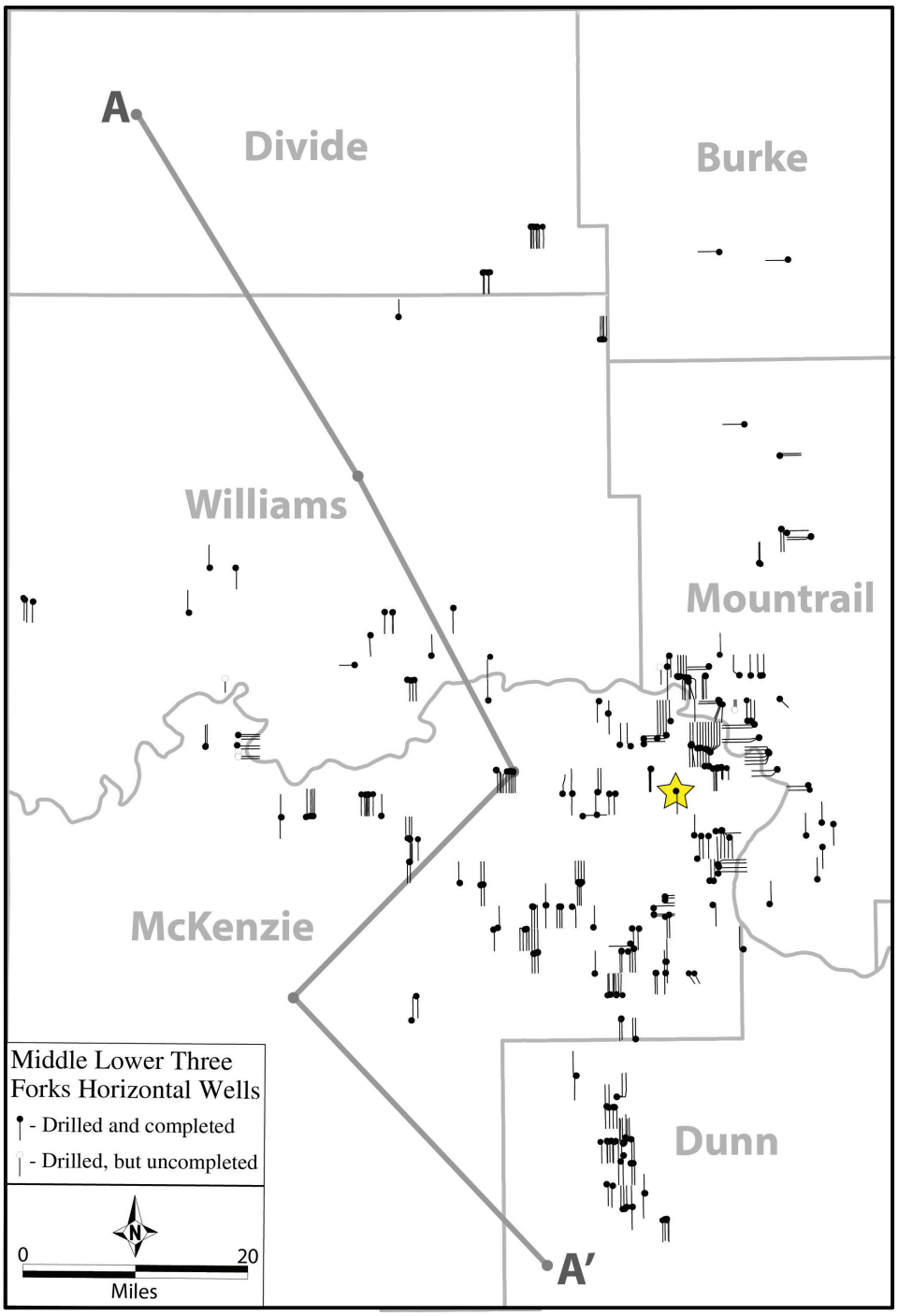

Figure 2. Middle and lower Three Forks horizontal well location map. The yellow star indicates NDIC well #26990 from Figure 1. A-A' represents the location of the Figure 3 cross-section wells.

The North Dakota Oil and Gas Division (NDOGD) began requiring operators to list specific, sub-formational, stratigraphic target intervals on their horizontal Bakken-Three Forks well permits beginning in early 2015. This added requirement allows for the differentiation of upper versus middle or lower Three Forks horizontal wells based upon the initial well permit information. However, pre-2015 horizontal Three Forks well permits do not generally list specific stratigraphic target intervals and, therefore, cannot be readily differentiated within the current NDOGD database. Additionally, initial well permits do not always reflect the final horizontal well target due to various factors (e.g., operators sometimes switch their intended well targets between the phases of initial permitting and final drilling). The purpose of this report is to generate a preliminary published list of validated middle and lower Three Forks horizontal wells which can be used for future production evaluations of both stratigraphic units.

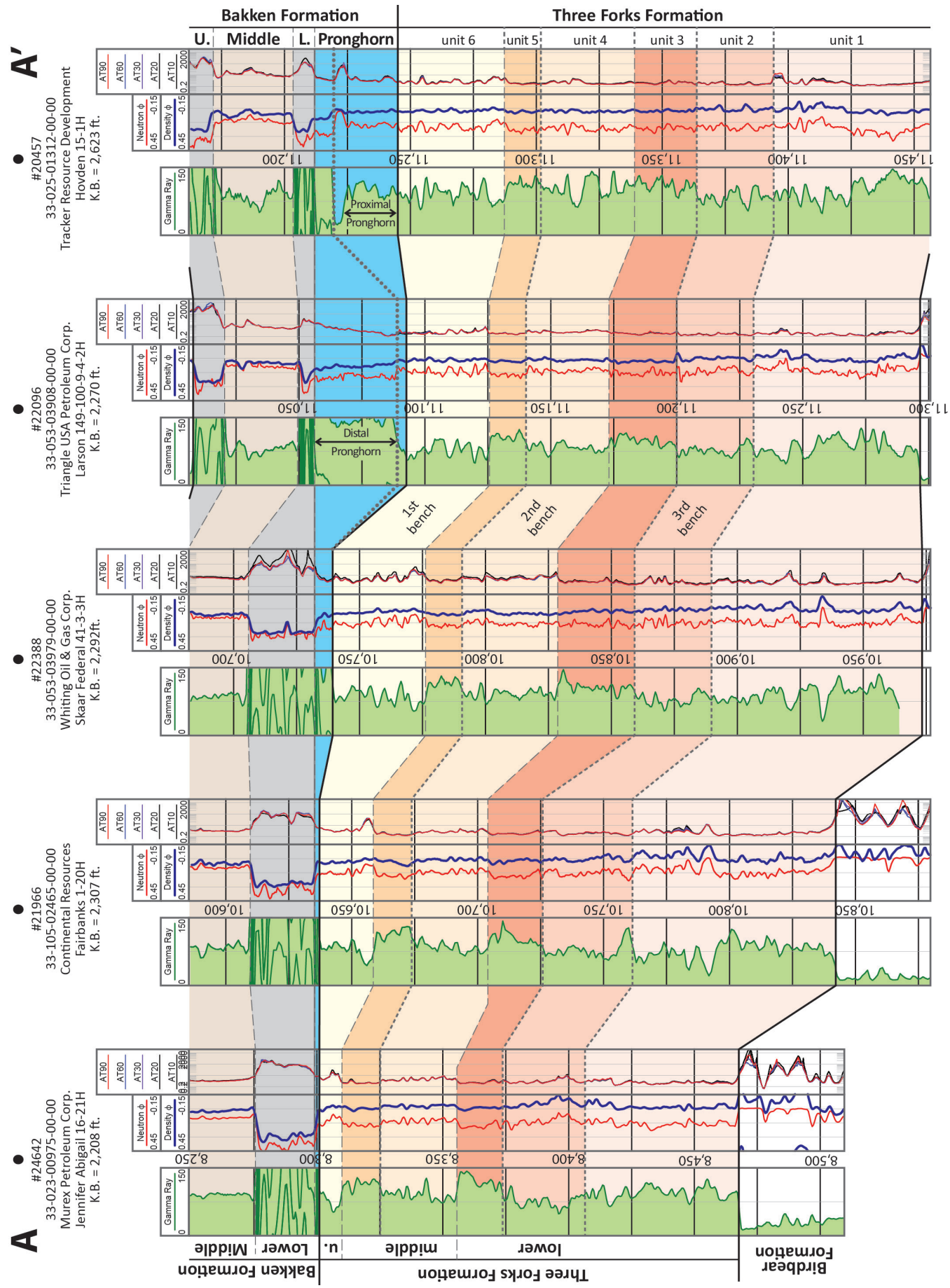

Figure 3. Wireline log cross-section of the Bakken-Three Forks section. The upper, middle, and lower Three Forks stratigraphic nomenclature is based upon Bottjer and others (2011) while the unit 1-6 system is from Christopher and others (1961, 1963). Each cross-section well also has a representative Bakken/Three Forks core that was reviewed to confirm each stratigraphic boundary.

Three Forks Stratigraphy

Several different stratigraphic nomenclature systems have been proposed and utilized for subdividing the Three Forks (Nesheim, 2019). Two of the more commonly referenced systems include a six-unit system proposed by Christopher (1961, 1963) and an upper-middle-lower member system proposed by Bottjer and others (2011) (Fig. 1). Alternatively, several Bakken-Three Forks operating companies have adopted a 4-bench terminology system which approximately corresponds with four generalized stratigraphic target intervals (Fig. 1). While each Three Forks nomenclature system is uniquely relevant, this report utilizes the Bottjer and others (2011) upper-middle-lower member system with references to the 4-bench and 6-unit systems.

Well Identification and Validation

A list of prospective middle and lower Three Forks wells was primarily compiled through a two-stage process. First, operator reported middle and lower Three Forks wells (2015-present) were extracted from the NDOGD internal database. Second, well names were reviewed by operator and used to identify additional prospective middle and lower Three Forks wells, particularly for pre-2015 drilled wells. The basis for the second step is that some operators include a distinction within their well names that specifies the target interval for a given well. A few additional middle and lower Three Forks wells were found through other minor processes. Overall, a list of approximately 440 prospective middle and lower Three Forks wells was compiled for further review.

The base of the Lower Member of the Bakken, also referred to as the lower Bakken shale, was used as the datum for determining the depth of penetration of horizontal wells into the Three Forks section. This datum selection was made due to the consistency and ease at which the Lower Member can be picked on wireline logs. On wireline logs, the base of the Lower Member is marked by abrupt decreases in gamma-ray, neutron-density porosities, and typically an increase in resistivity, a composite wireline log signature that can be readily and consistently picked from well to well (Figs. 1 and 3).

Isopach maps of the stratigraphic intervals separating the middle and lower Three Forks from the Lower Member of the Bakken were created using 73 cores (both partial and complete) of the Bakken-Three Forks section in combination with wireline logs from approximately 1,000 wells. Various publications were reviewed to determine core- and log-based stratigraphic top picks for the Bakken-Three Forks section, including: Bottjer and others (2011), LeFever and others (2011), and Skinner and others (2015). Isopach maps were created for the following intervals: Pronghorn Member of the Bakken and the upper and middle members of the Three Forks Formation. Composite isopach maps were also created for the Pronghorn-upper Three Forks section as well as the Pronghorn-upper Three Forks-middle Three Forks section (Figs. 5 and 6).

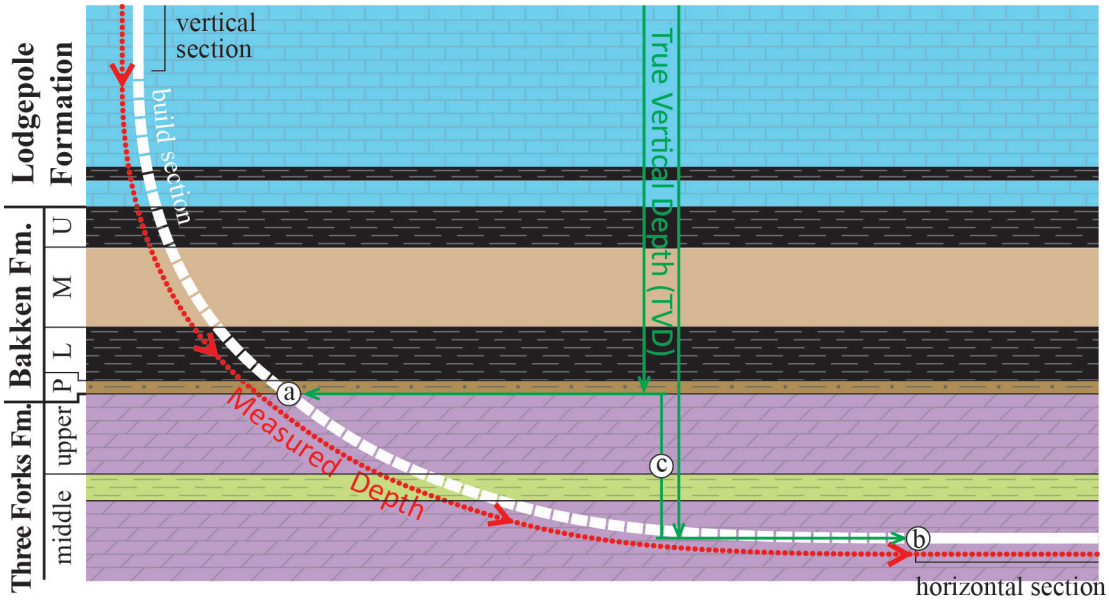

Figure 4. Schematic diagram depicting a middle Three Forks horizontal well labeling the vertical, build, and horizontal portions of the borehole. L = Lower Member; M = Middle Member; P = Pronghorn Member; U = Upper Member

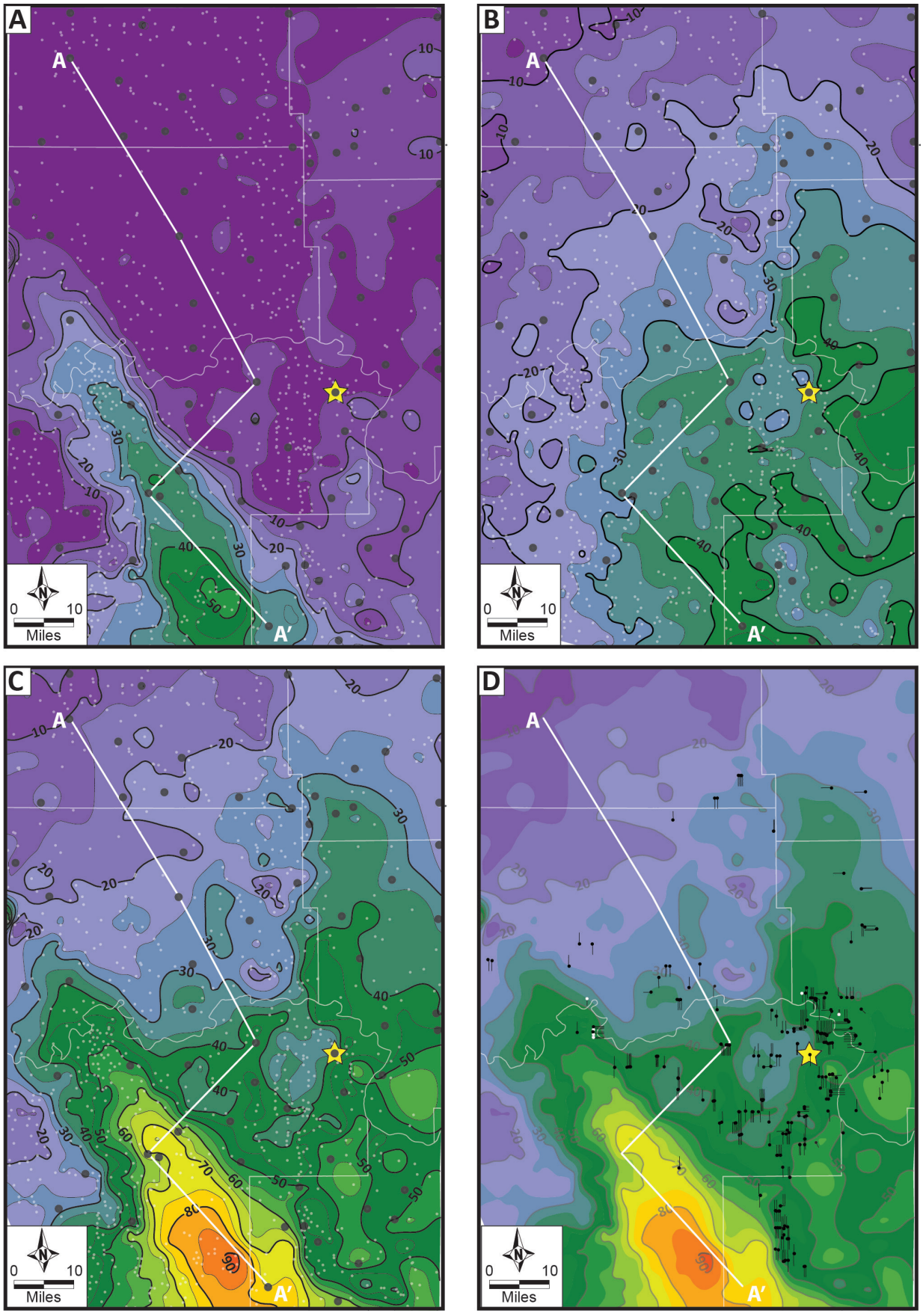

Figure 5. Isopach maps of the Pronghorn Member of the Bakken Formation and upper member of the Three Forks Formation. A) Isopach of the Pronghorn Member. B) Isopach of the upper member of the Three Forks Formation. C) Combined isopach of the Pronghorn Member and upper Three Forks. D) Combined isopach of the Pronghorn Member and upper Three Forks with the horizontal middle Three Forks wells depicted. Thin white lines are county borders. Small white dots indicate wireline log control wells, larger dark grey circles depict core control wells, and A-A' is the Figure 3 cross-section wells. Contours are in 5-foot intervals.

For each prospective middle and lower Three Forks well, the MWD (measured while drilling) gamma-ray log was used to pick the measured depth (MD) base of the Lower Member of the Bakken, which was in turn converted to the true vertical depth (TVD) using the well's directional survey data (Fig. 4). Next, the MD landing point of each horizontal well was picked and converted to TVD at the approximate point where the well's borehole inclination reached approximately 90 degrees. This picked point was compared to the casing point and/or the beginning depth of the well's perforated interval (Fig. 4). The TVD of penetration below the base of the Lower Member of the Bakken was calculated using the two points outlined above as illustrated in Figure 4. The calculated depth of penetration was then compared with the composite Pronghorn-upper Three Forks isopach to identify middle Three Forks wells as well as with the composite Pronghorn-upper Three Fork-middle Three Forks isopach to identify lower Three Forks wells (Figs. 5 and 6). Lastly, the directional survey data of each horizontal lateral was compared to structure contour maps of the middle or lower Three Forks tops to determine if the horizontal borehole stayed within the middle/lower Three Forks for most of the lateral (Fig. 7).

Results

The combined net thickness of the Pronghorn + upper Three Forks section in the study ranged from 6 ft. to 91 ft. (Fig. 5c). A total of 288 horizontal wells were identified that have been drilled within the middle Three Forks (industry: 2nd bench and ~unit 4 – Christopher 1961, 1963). For each validated middle Three Forks well, the horizontal portion of the well both penetrated and generally stayed more than 10 feet below the top of the middle Three Forks (Fig. 5d). A handful of horizontal wells were identified that landed a few feet into the uppermost portion of the middle Three Forks but did not penetrate more than 10 ft. (TVD) into the unit and therefore were not included in the final middle Three Forks well list.

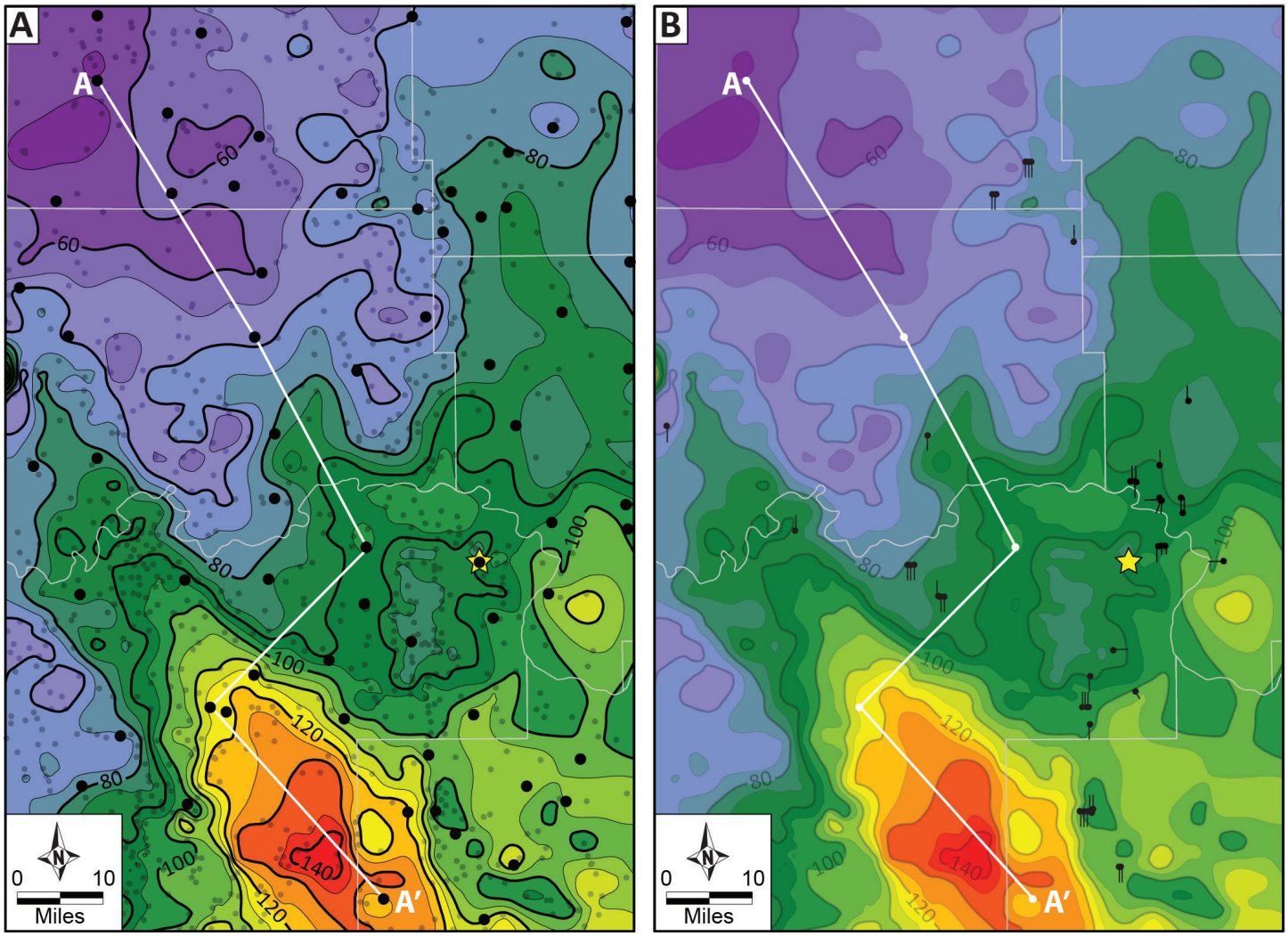

Figure 6. Composite isopach maps of the Pronghorn Member (Bakken Formation) and the upper and middle members of the Three Forks Formation. A) Combined isopach map showing well (small grey circles) and core (large black circles) control points. B) Combined isopach map with lower Three Forks horizontal wells. Contours are in 5-foot intervals.

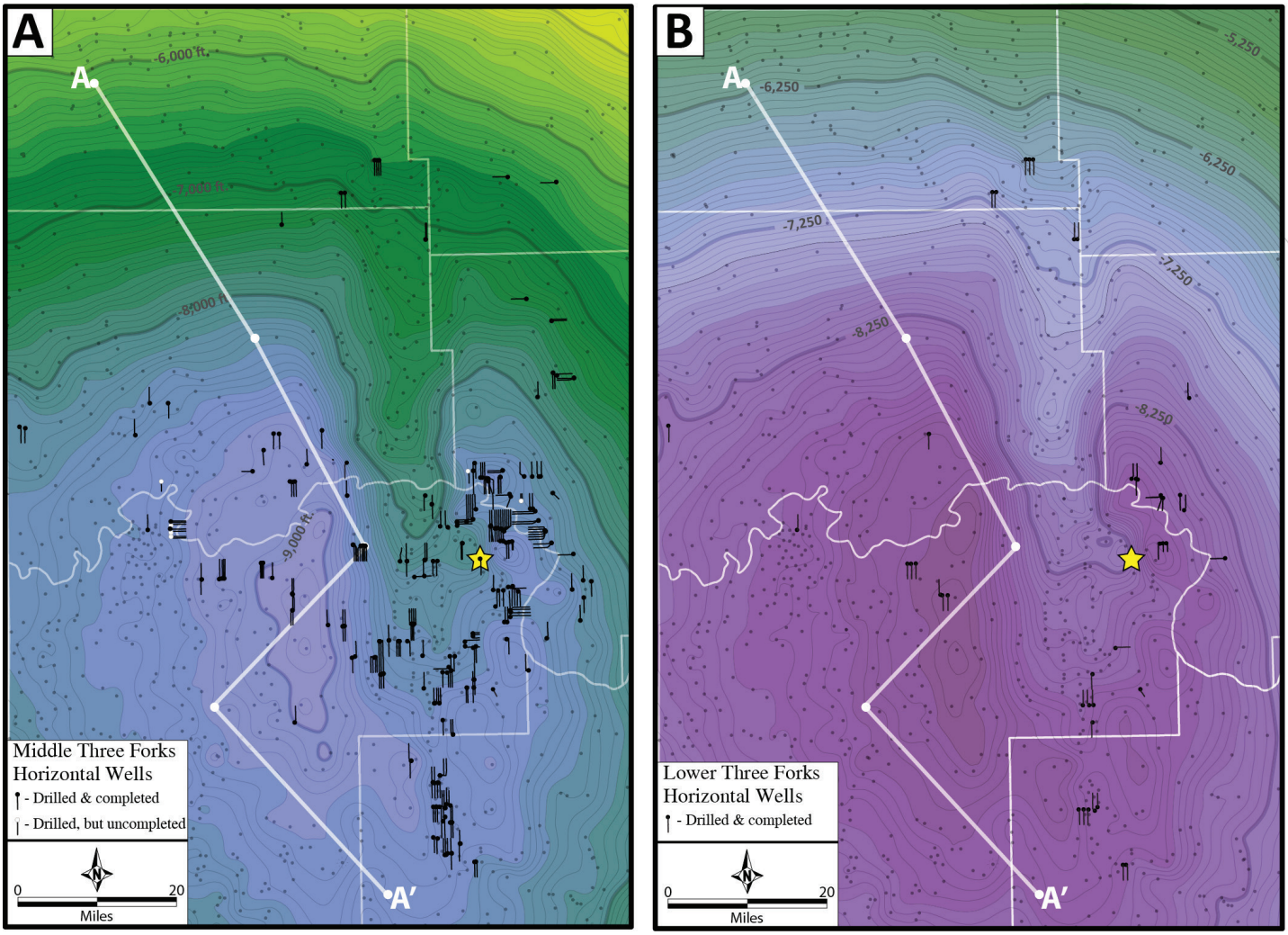

Figure 7. Structure contour maps of the tops of the A) middle and B) lower Three Forks Formation. Light grey circles depict the wireline log control wells used to create the map. Thin white lines depict county borders. Contours are in 5-foot intervals.

The combined net thickness of the Pronghorn + upper and middle Three Forks section ranged from 51 ft. to 143 ft. within the study area (Fig. 6a). A total of 43 horizontal wells were identified that penetrated and stayed within the lower Three Forks section for most of the horizontal lateral portion of the well (Fig. 6b). Most of the lower Three Forks horizontal wells (41) penetrated between 18 and 62 feet into the unit (industry: 3rd bench and ~unit 2 – Christopher 1961, 1963). However, two of the horizontals penetrated more than 90 ft. into the lower Three Forks section (industry: 4th bench and ~unit 1 – Christopher 1961, 1963).

Additional Discussion

Even though the Pronghorn Member is stratigraphically positioned below the Lower Member of the Bakken and directly overlies the Three Forks, the Pronghorn was not used as the datum to determine depth of Three Forks penetration primarily because of variable gamma-ray wireline log signatures related to changes in Pronghorn lithology. LeFever and others (2011) subdivided the Pronghorn into distal versus proximal facies. The distal facies contains relatively high clay concentrations that correspond with elevated gamma-ray wireline log signatures which are moderately distinguishable from the Lower Member of the Bakken and upper Three Forks (e.g. well #22096 - Fig. 3). However, the proximal facies contains relatively low clay concentrations and exhibits a relatively low gamma-ray wireline log signature which is difficult to distinguish from the upper Three Forks without core control (e.g. well #20457 - Fig. 3). Since gamma-ray is the primary means to pick formation-stratigraphic tops for the majority of horizontal wells and the proximal Pronghorn is nearly indistinguishable from the upper Three Forks using gamma-ray logs, the Pronghorn-base/Three Forks-top was not used as the datum in this study.

The well list included in this report is unlikely to be an all-inclusive list of middle and lower Three Forks horizontal wells for several reason. Continued drilling in the play with lead to additional, future middle and lower Three Forks horizontal wells. Additionally, the NDOGD provides a 6-month confidentially period for newly drilled and/or completed wells, and therefore additional middle and/or lower Three Forks wells could exist at the time of this report but are on confidential status and unavailable to review/include in this report. Finally, while some Bakken-Three Forks operators provide well name distinctions based upon stratigraphic target intervals, other operators do not. This suggests that additional, pre-2015 horizontal middle and/or lower Three Forks wells exist that are not on the published well list. Overall, the published list of middle and lower Three Forks wells included in this report should be viewed as a preliminary starting point for compiling and evaluating production results for both units.

This study focused on identifying and validating middle and lower Three Forks wells. Due primarily to time constraints, a list of validated upper Three Forks or Pronghorn horizontal wells was not generated. Over 5,000 total horizontal wells have been drilled within the Three Forks Formation according to the present NDOGD database. Given that this study identified and validated 331 horizontal wells drilled in the middle and lower Three Forks Formation versus 5,000+ total Three Forks wells, it can be assumed that the majority of remaining Three Forks horizontal wells were drilled in the upper Three Forks. In addition, the Pronghorn Member of the Bakken has been a target of horizontal drilling, particularly towards the southern margins of the play (Skinner et al., 2015). While the Pronghorn Member is a distinct stratigraphic unit, it occupies the same approximate stratigraphic position as the upper Three Forks. While the Pronghorn locally thickens to upwards of 40-50 ft. along the southern margins of the Bakken-Three Forks Play, where it can be considered a distinct reservoir target, in other areas it is less than 10 ft. thick and is simultaneously targeted along with the upper Three Forks. The 2013 USGS assessment included the Pronghorn Member within the Three Forks assessment unit (Gaswirth and Marra, 2015).

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