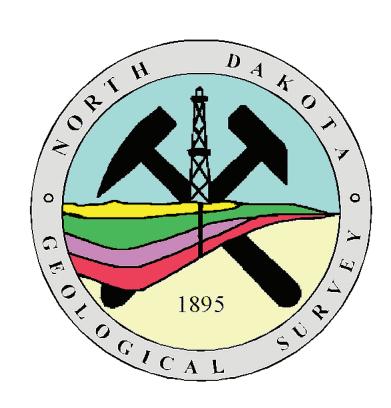
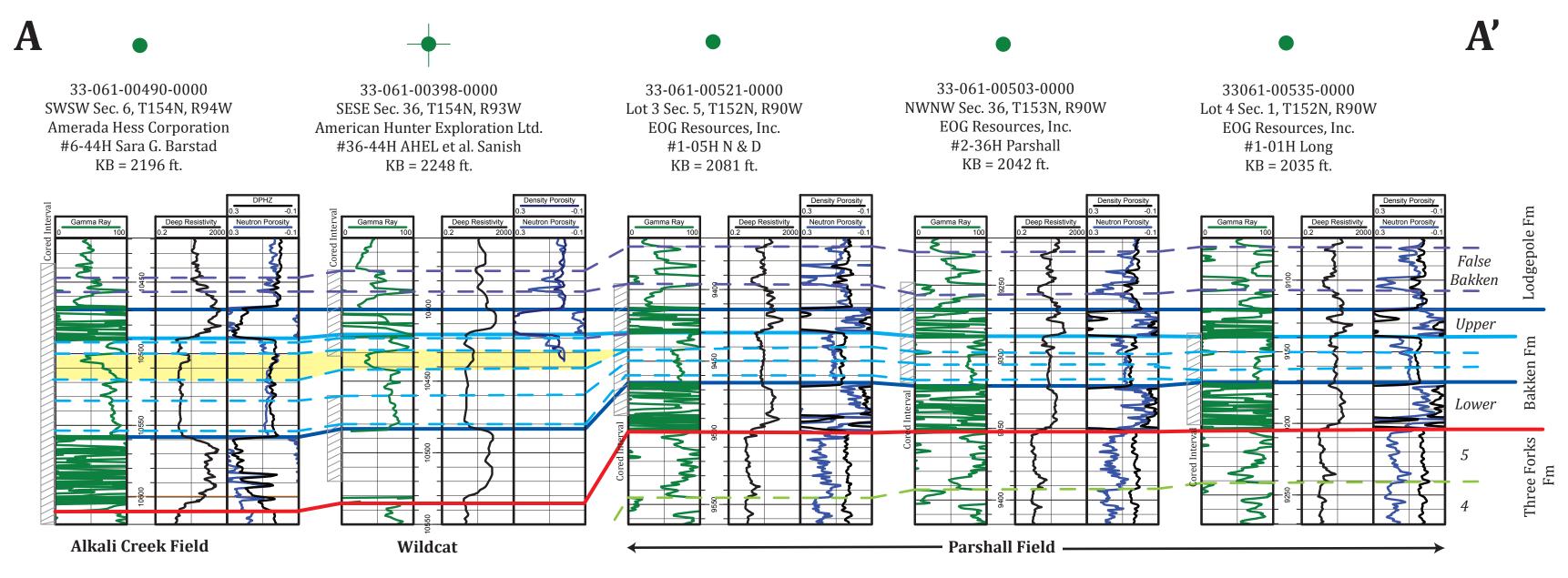
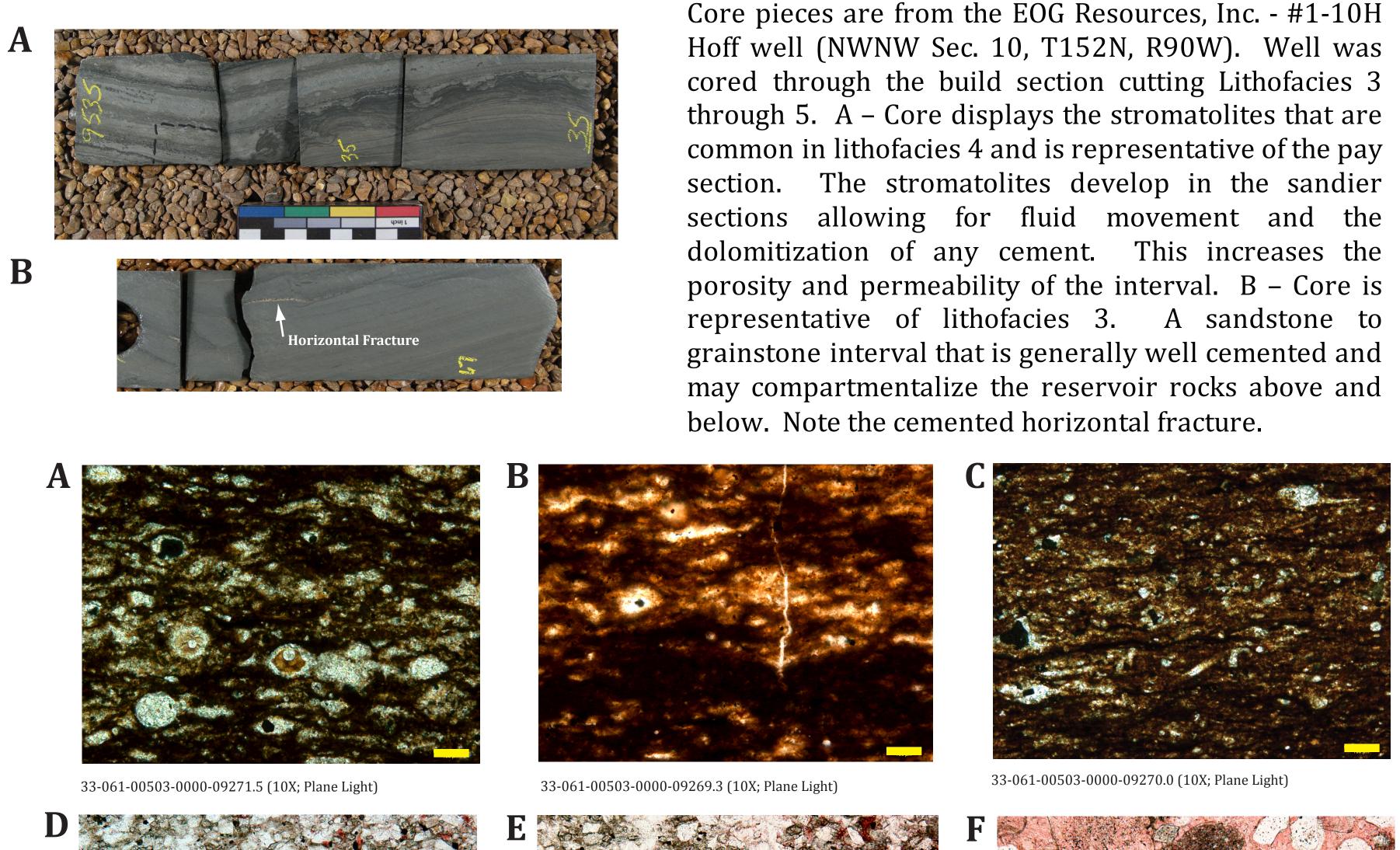
cologic Investigations No. 1



## **Parshall & Sanish Fields - Bakken Formation**



Cross-section A - A' across Parshall and Sanish fields (see Map for Line of Section). Parshall field has limited occurrence of lithofacies 3 (shaded yellow) that compartmentalizes the reservoir elsewhere in the basin. Minor structures, access to the entire productive section, overpressuring and related microfractures that end on the east side of the field create the stratigraphic trap that makes Parshall a sweet





33-061-00503-0000-09791.5 (10X: Plane Light)



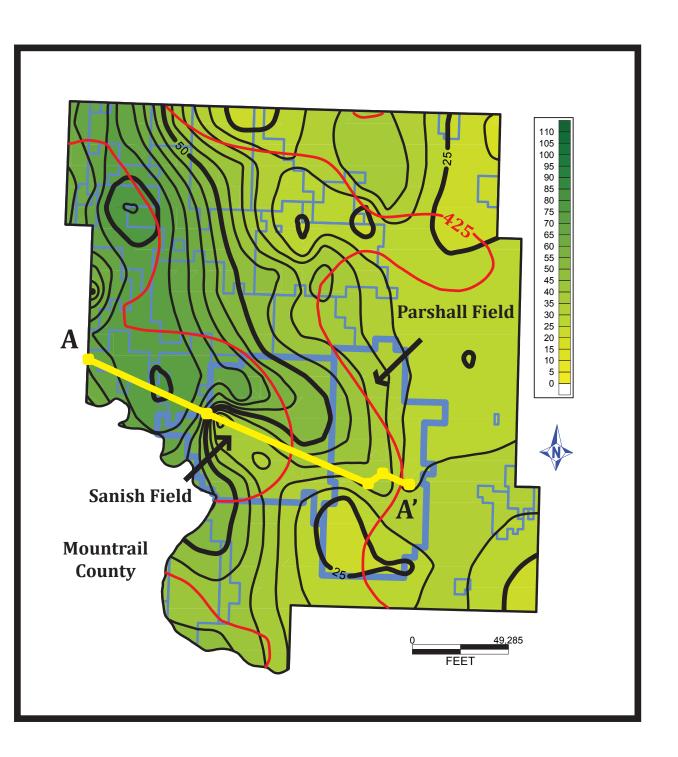
33-061-00503-0000-09270.0 (10X: Plane Light)



Thin-section photomicrographs from two wells in Mountrail County, North Dakota (A-C - 33-061-00503 0000 – EOG Resources, Inc. - #2-36H Parshall; D-E – 33-061-00394-0000 – Marathon Oil Company #26-1 Laredo). A and B are photographs from the Upper Member. Considered to be immature to marginally mature, the shale consists predominantly of clay, silt, organic matter, small carbonate grains that are probably calcispheres, and *Tasmanites*. Intervals appear to alternate between mudrock and shale. Thin-sections also reflect those changes. *Tasmanites*, organic matter, and other grains are unchanged in photographs A and C (mudrock), whereas compression and the organic matter is starting to coalesce in B. D shows the reservoir facies consisting predominantly of quartz sand, dolomite, pyrite, and calcite cement (stained with Alizarin Red). Multiple microfractures can be identified throughout the sample. Photomicrograph E shows the same lithofacies with cross-cutting filled fractures. F shows the dominant marine cement present in the sandstone-grainstone common to lithofacies 3 (shaded yellow on Cross-Section A-A').

# **Reservoirs of the Bakken Petroleum System: A Core-based Perspective** Julie A. LeFever<sup>1</sup>, Richard D. LeFever<sup>2</sup>, and Stephan H. Nordeng<sup>1</sup> <sup>1</sup>North Dakota Geological Survey, <sup>2</sup>University of North Dakota

Sheet 2



Isopach of the Middle Member of the Bakken Formation n Mountrail County, North Dakota. The boundaries of Parshall and Sanish fields are indicated by the heavy blue lines. The Line of Section (A – A') is shown in yellow. Superimposed on the map is the Tmax of the Upper Member based on available data, shown in red (Contour interval of 10° C). The isopach thins to the east moving from Sanish to Parshall field. Also note the swing in the Tmax gradient towards the east over the two fields.

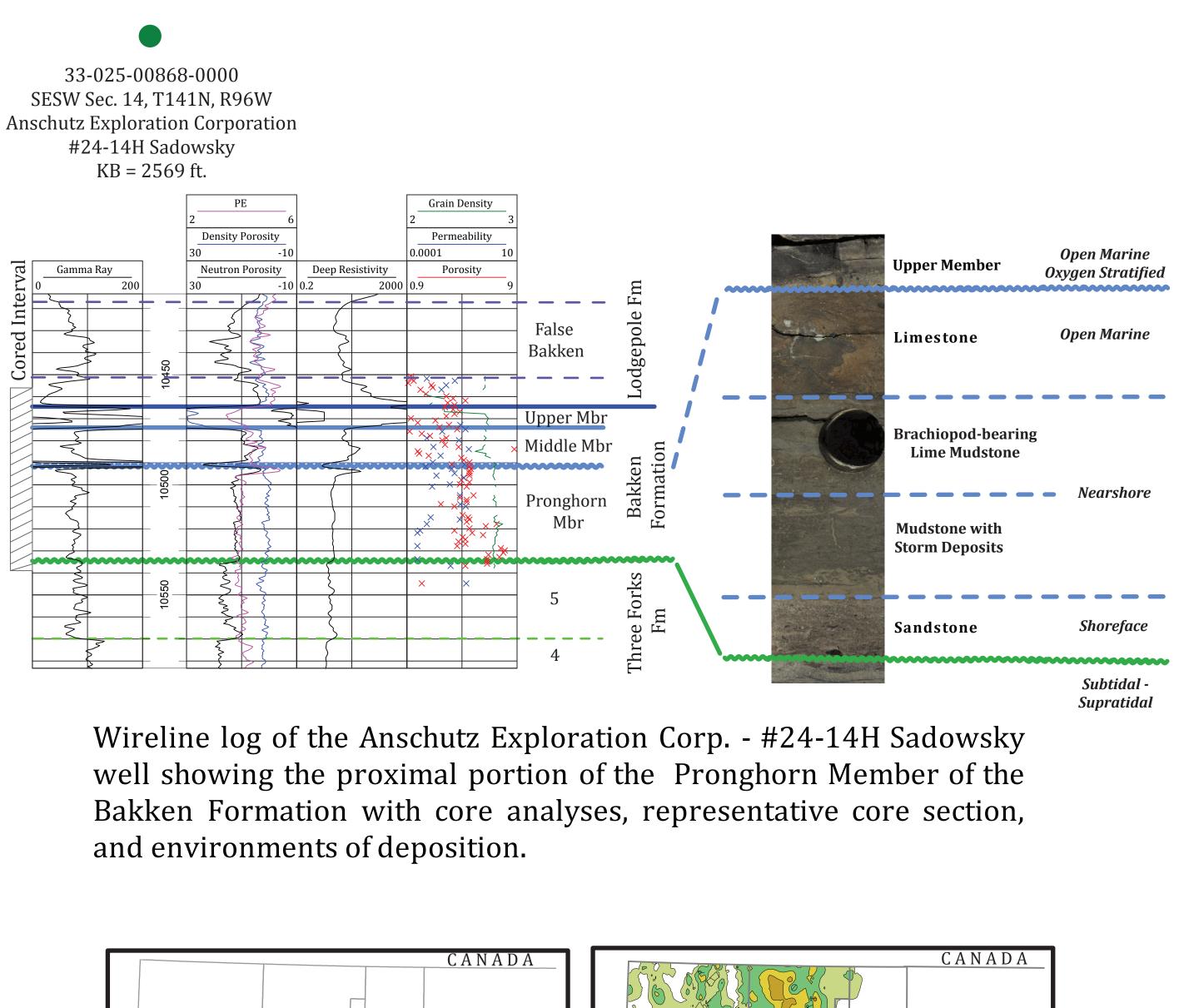
#### Reservoir

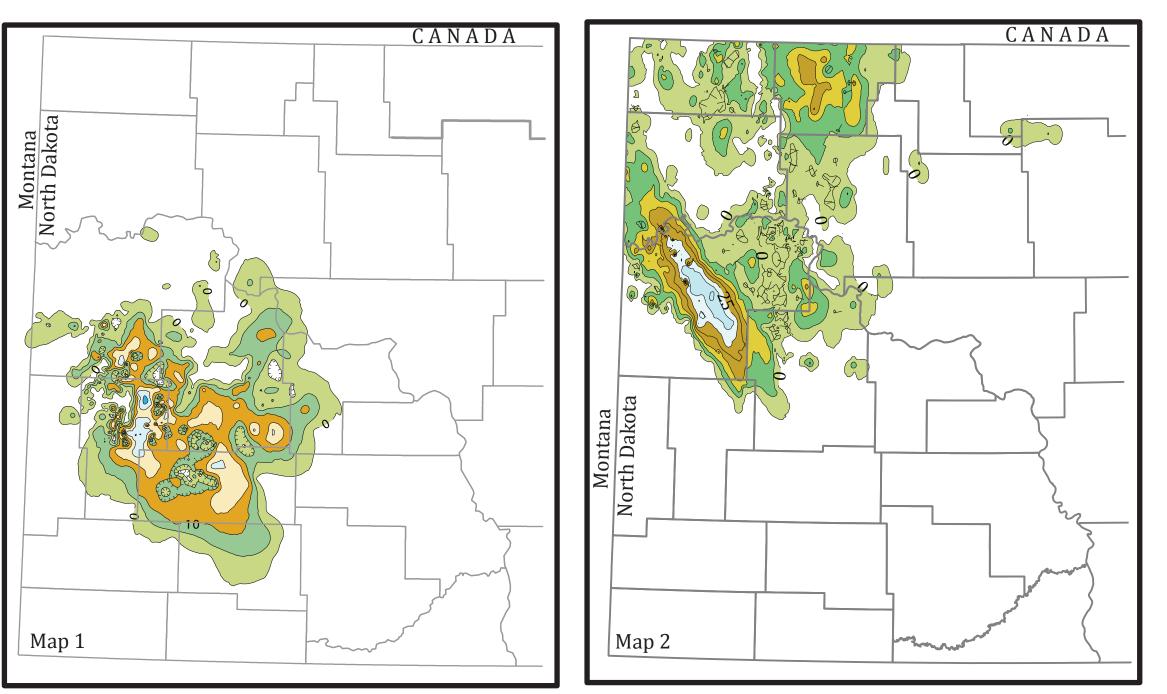
The reservoir at Parshall Field is located within lithofacies 4 of the Middle Member and consists of an algal-rich dolomitic siltstone to very fine-grained sandstone probably lagoonal in origin. Porosity ranges from 5 to 9% with an average permeability of .02 mD. The reservoir section is overpressured which is probably responsible for creating a well-developed microfractures enhancing the network of transmissibilitv

In addition to the microfractures, a network of macrofractures and larger regional scale fractures exist. Macrofractures present in lithofacies 3 tend to be calcite-filled and v-shaped. The existence of natural horizontal fracturing is confirmed visually in the EOG Resource Inc. - #1-10H Hoff. Regional fractures in the area are probably related to combination of basement tectonics, basin tectonics, and dissolution of the Devonian Prairie salt and subsequent collapse.

Questions remain concerning the sourcing of the reservoir. Core and thin-section work suggest that the shales are marginally mature and probably are responsible for at least some oil being generated in place. Additional oil may result from the algal material that is available in the Middle Member. Measured TOCs of up to 10% have been reported in the Parshall area (Dan Jarvie, pers. comm.). Oil has also migrated updip into the field from the deeper portions of the basin immediately west of Parshall Field. The shale becomes immature immediately east of the field.

### **Pronghorn Member**



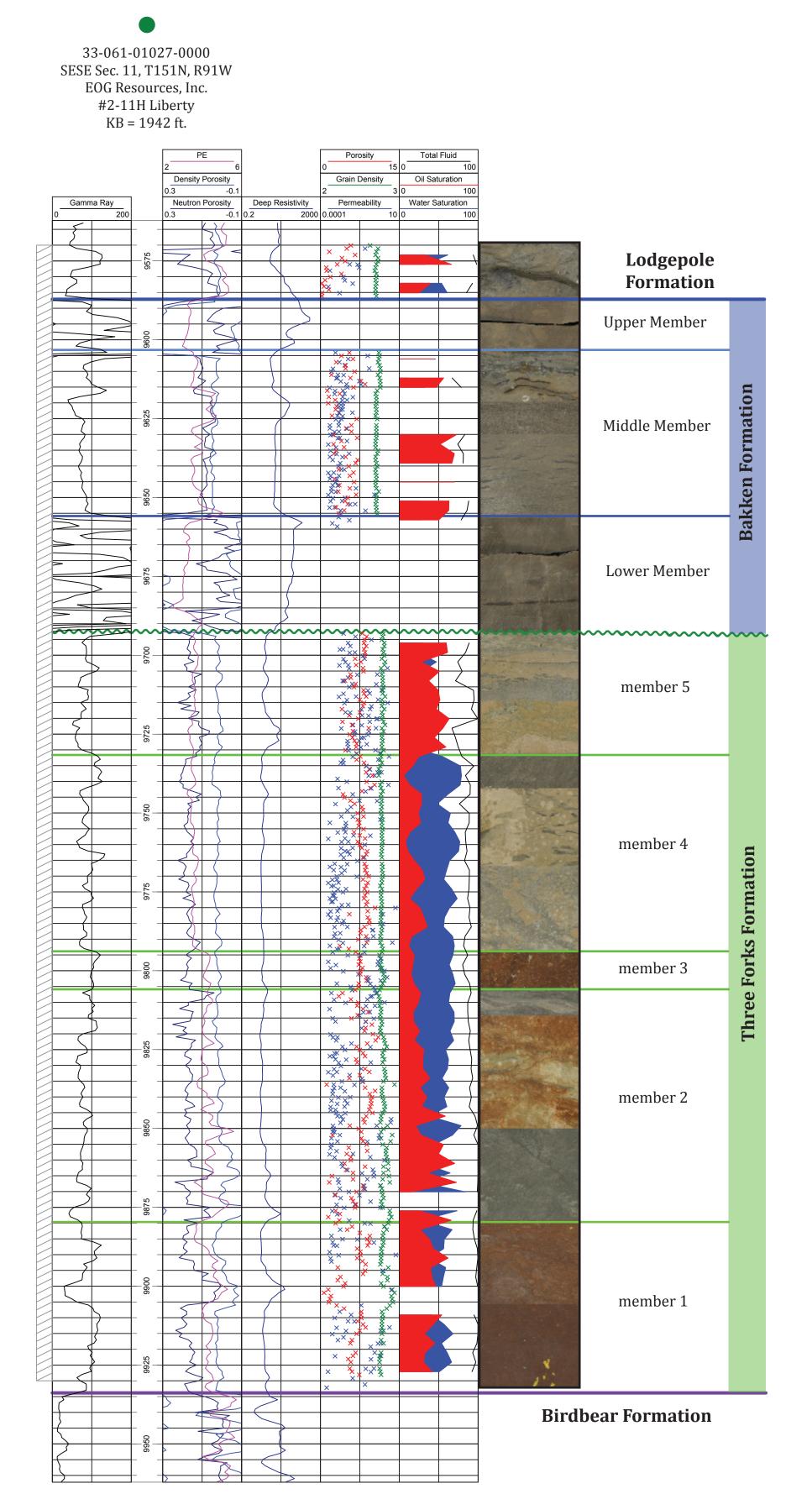


The Pronghorn Member was named in 2011 as a result of new core data. Map 1 shows the distribution of the proximal beds and is represented in the log and core section shown above. Consisting of a sequence of mixed siliciclastics and carbonates it is restricted to the southwest. It is unconformably overlain by the Lower Member and unconformably overlies the Three Forks Formation. It reaches a maximum thickness of 52

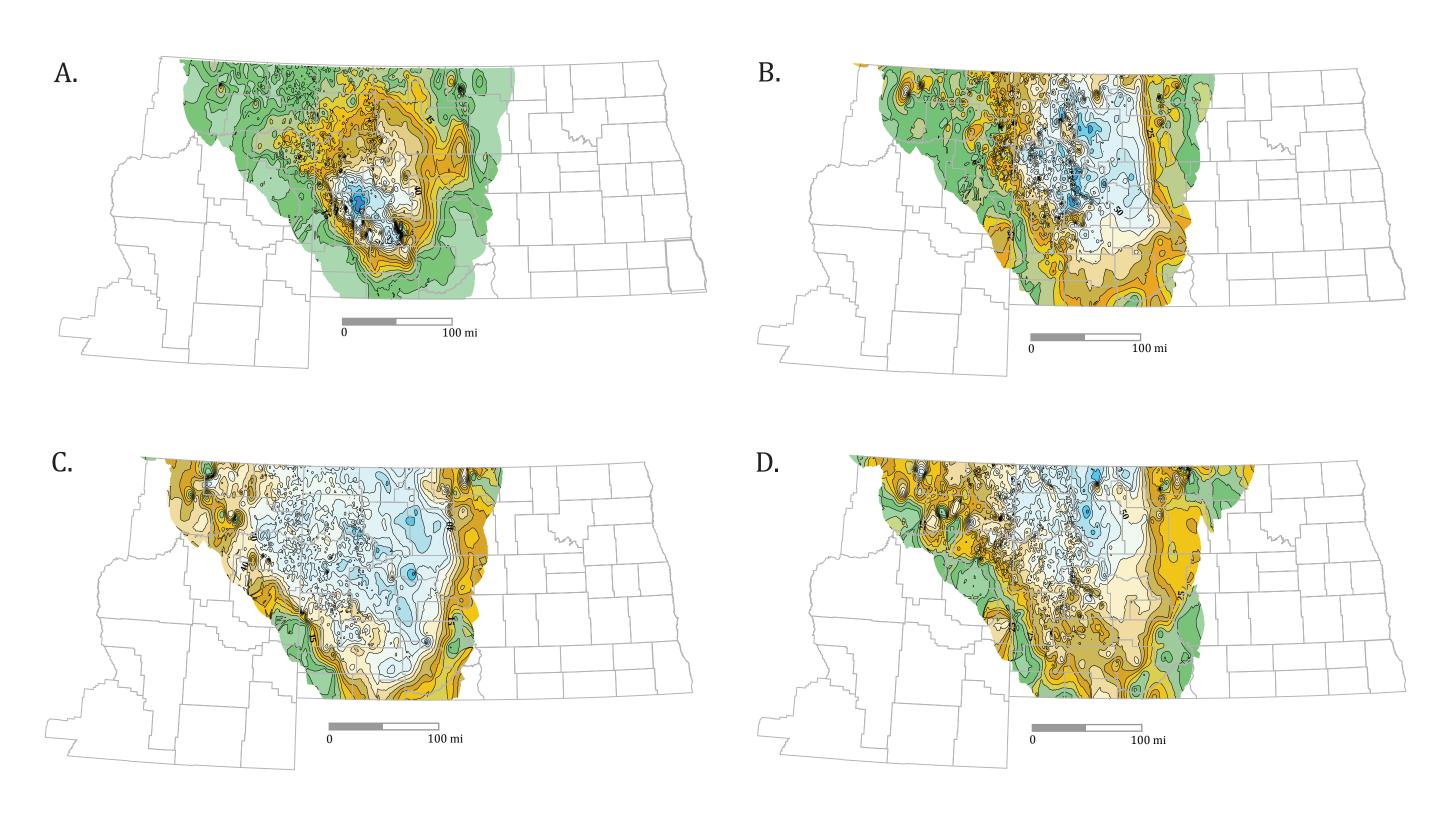
Map 2 shows the distribution of the distal beds to the Pronghorn Member. Beds resemble the Lower Member but have less organic matter and a higher carbonate and silt component. It reaches a maximum thickness of 58 ft in the linear trough-like feature.

Production in the Pronghorn Member is currently restricted to the proximal beds shown in Map 1. The reservoir consists of a series of dolomitic mudstones with HCS beds with intercrystalline porosities ranging from 6 to 9%. As clay content increases, the distal beds' production decreases. Total fluids also decrease with the presence of lithofacies 3.





The wireline log of the EOG Resources, Inc. - #2-11H Liberty well is displayed with core analyses, fluid saturations, nomenclature, and a representative core section. The Liberty well shows high oil saturations throughout the lower portion of the Three Forks section suggesting potential for oil.



All maps have a contour interval 5 ft ("Bench 4").

The Three Forks Formation overlies the anhydrites of the Birdbear Formation and underlies the Bakken Formation. Recent cores provide a view of the entire stratigraphic succession (see wireline log). Member 1 is a redbed sequence consisting of a tan to grey-green to red interbedded mudstones mixed with siltstones and sandstones. Anhydrite is present as nodules and layers. The member is representative of a sabkha environment of deposition. Member 2 is an interbedded sequence of grey-green and dark red mudstones with occasional anhydrite nodules and beds. Member 2 represents environments ranging from sabkha to tidal mudflat. Member 3 is a red to grey-green slightly dolomitic mudstone mixed with poorly sorted clasts representing a mudflat. Basal member 4 consists of grey-green, tan and orange-red interbedded mudstone to sandy dolostone that is brecciated probably due to dewatering. This is overlain by an interbedded sequence of apple-green dolomitic mudstone and tan dolostone with desiccation breccia at the base and structures that include ripples, flaser beds, syneresis cracks, and mudcracks. Capping the sequence is a massive dark brown to dark red dolomitic mudstone. Member 4 represents a finingupward sequence indicative of tidal mudflat to intertidal to shallow offshore environments. Member 5 repeats the sequence with basal tan dolomitic, brecciated dolostone that is overlain by the applegreen claystone and tan dolostone with ripples, flaser beds, syneresis cracks, and mudcracks. This also represents a progression from tidal mudflat to intertidal to supratidal environments. At the top of the Three Forks is a significant unconformity.

Current industry terminology refers to the member 5, 4, 2, and 1 as benches (i.e. member 5 is referred to as the "First Bench"). Careful attention to the stratigraphy is necessary when discussing producing intervals. The wireline log for the Liberty well also plots the fluid saturations. It is interesting to compare the oil saturations (red) against the water saturations (blue). Oil saturations are consistent through the Bakken, but tend to taper off below member 5 of the Three Forks Formation.

#### Summary

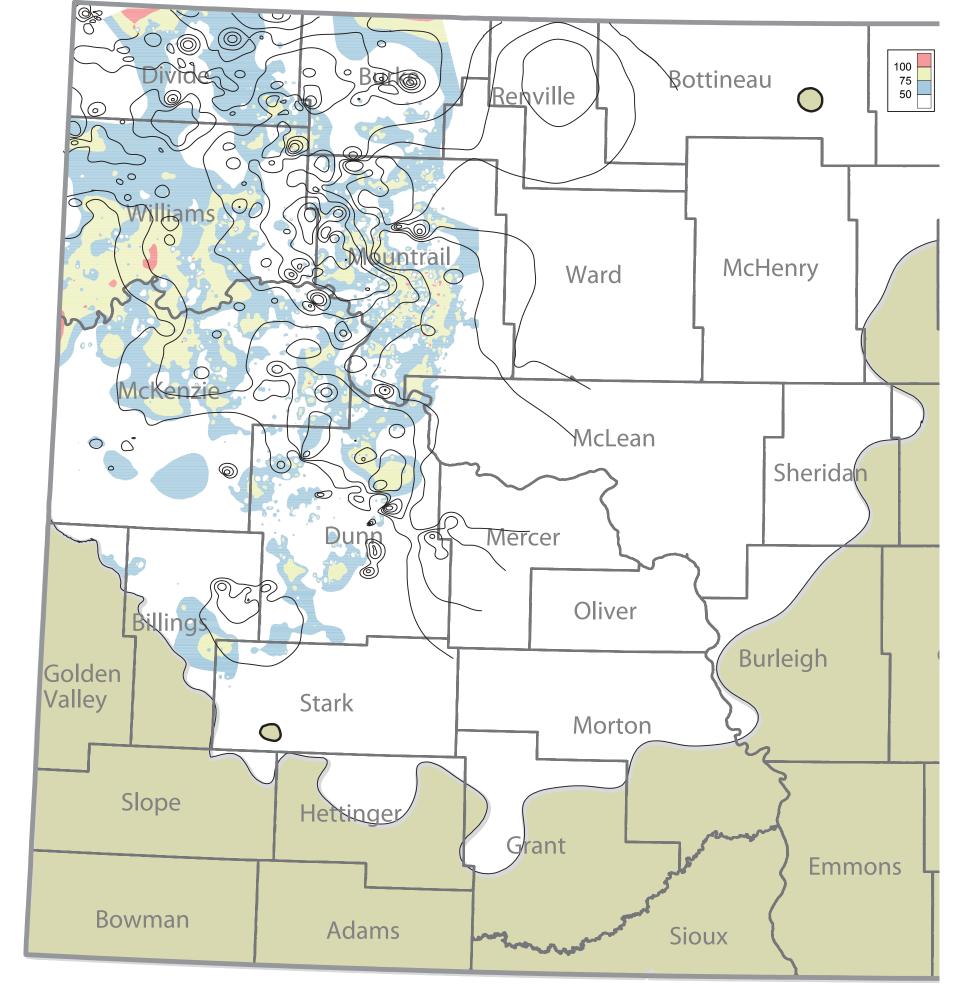
A variety of unconventional reservoirs exist within the Bakken Petroleum System. Each of these reservoirs has been the focus of severeal episodes of drilling throughout the history of the Williston Basin.

Six reservoirs have been discussed. Variations in rock composition have resulted in continued use of available cores and the continued acquisition of additional cores. I becomes readily apparent that each area within the source system requires examination of cores with possible adjustment to drilling and completion methods. Data obtained from cores and samples are strategic in making those adjustments.

The additional data also generate additional questions. Uncertainty exists as to what is actually producing in both Bakken and Three Forks reservoirs. Are the current



Isopach maps of the individual members, in descending orders, of the Three Forks Formation in North Dakota and Montana. A – Three Forks member 5 ("Bench 1") reaches maximum thickness of 85 ft. B – Three Forks member 4 reaches a maximum thickness of 67 ft ("Bench 2"). C – Three Forks member 2 ("Bench 3"). D – Three Forks member 1 reaches a maximum thickness of 77 ft.



#### **Total Produced Fluid vs Lithofacies**

The colored filled contours represent regions in which the daily total fluid production for existing wells lies above the 50th percentile. Regions in white represent portions of the basin in which total fluid production is below the 50th percentile. Solid contours are isopach lines of the lithofacies 3. Thickness of the lithofacies appears to affect total fluid production suggesting that the fracture stimulation treatments may not be penetrating the entire section for wells that have a horizontal leg in the upper lithofacies.

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- Gaswirth, S.B., Marra, K.R., Cook, T.A., Charpentier, R.R., Gautier, D.L., Higley, D.K., Klett, T.R., Lewan, M.D., Lillis, P.D., Schenk, C. J., Tennyson, M.E., and K.J. Whidden, 2013, Assessment of undiscovered oil resources in the Bakken and Three Forks Formations, Williston Basin Province, Montana, North Dakota, and South Dakota: USGS Fact Sheet 2013-3013.
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wellbores draining the Middle Member, the Upper Member or both? What portion of the Three Forks is actually producing or are the fracture stimulations for the lower units? Saturations exist in some wells within the Three Forks and are absent in others. The discontinuous nature of these saturations requires further work.

The ability to extract oil from the Bakken has increase with each technological advance. Reserves estimates of 7.4 billion barrels of technically recoverable oil drive the activity (Gaswirth et al., 2011).