Continued Petroleum Exploration of the Birdbear/Duperow Formations (Devonian), North Dakota

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Introduction

The Upper Devonian Birdbear and Duperow Formations of western North Dakota have historically produced nearly 174 million barrels of oil (MMBO) from 671 wells. These carbonate-evaporite units were deposited in the shallow Elk Point epeiric seaway during the Late Devonian (figs. 1 and 2) (Pilatzke et al., 1987; Wilson and Pilatzke, 1987; Burke and Sperr, 2006; LeFever, 2009). This shallow seaway extended from northern Alberta to South Dakota and from western Montana to eastern North Dakota (Pilatzke et al., 1987; Martiniuk et al., 1995). Deposits consist of several upward shallowing/shoaling packages that were deposited in two transgressive-regressive marine cycles (fig. 3) (Switzer et al., 1994; Martiniuk et al., 1995).

Stratigraphy

The Duperow Formation consists of a regionally extensive cyclic package of marine carbonates and evaporites that were deposited in a broad back-reef portion of the Elk Point seaway (fig. 1). The formation consists of informal upper and lower members representing subtidal, intertidal, and supratidal conditions (fig. 3) (Wilson, 1967). Within each cycle, the lowermost subtidal package is generally a brachiopod-crinoid wackestone or a stromatoporoid boundstone that is overlain by a middle intertidal facies that consists of laminated lime mudstone characterized by ostracods and calcispheres interbedded with minimally fossiliferous pelloidal beds or laminated lime mudstone. An upper supratidal unit composed of bedded anhydrite and very fine-grained dolostone caps the sequence (Pilatzke et al., 1987). The cycles of the lower member consist of thicker subtidal and intertidal deposits; whereas the upper member generally has thinner, predominantly intertidal and supratidal deposits (fig. 2).

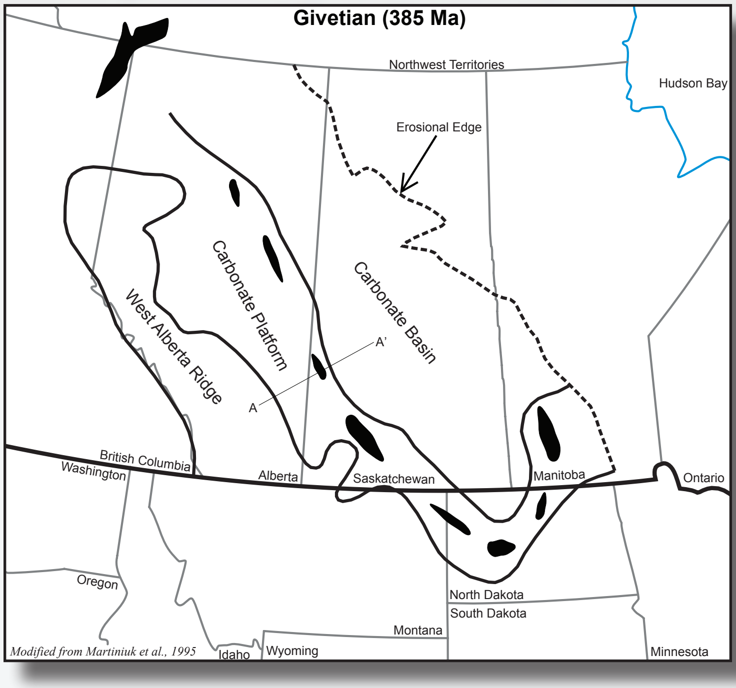

Figure 1. Map of Elk Point Basin circa 385 Ma (Givetian). See figure 2 for cross-section A-A'. Modified from Martiniuk et al., 1995.

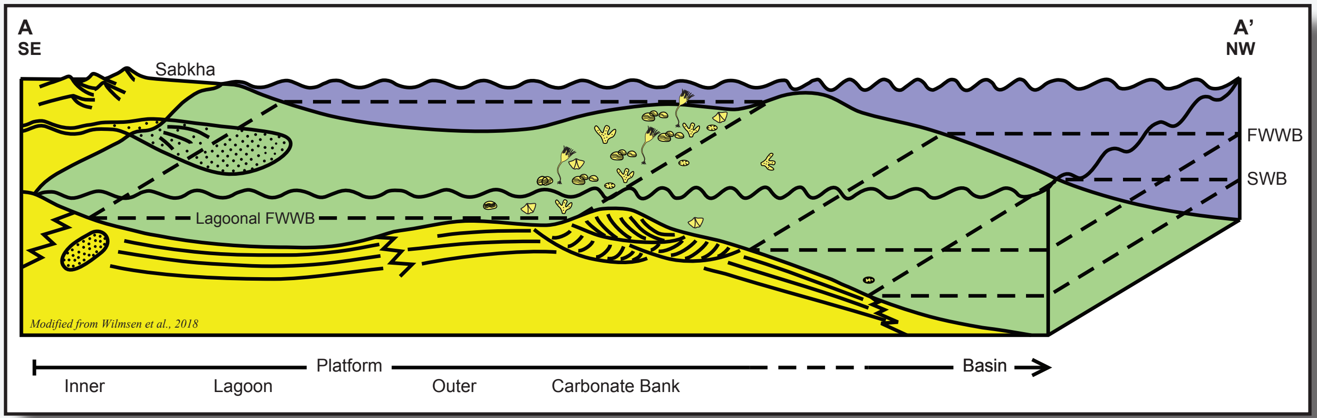

Figure 2. Generalized Birdbear-Duperow depositional setting. See figure 1 for cross-section A-A' location. Modifed from Wilmsen et al., 2018.

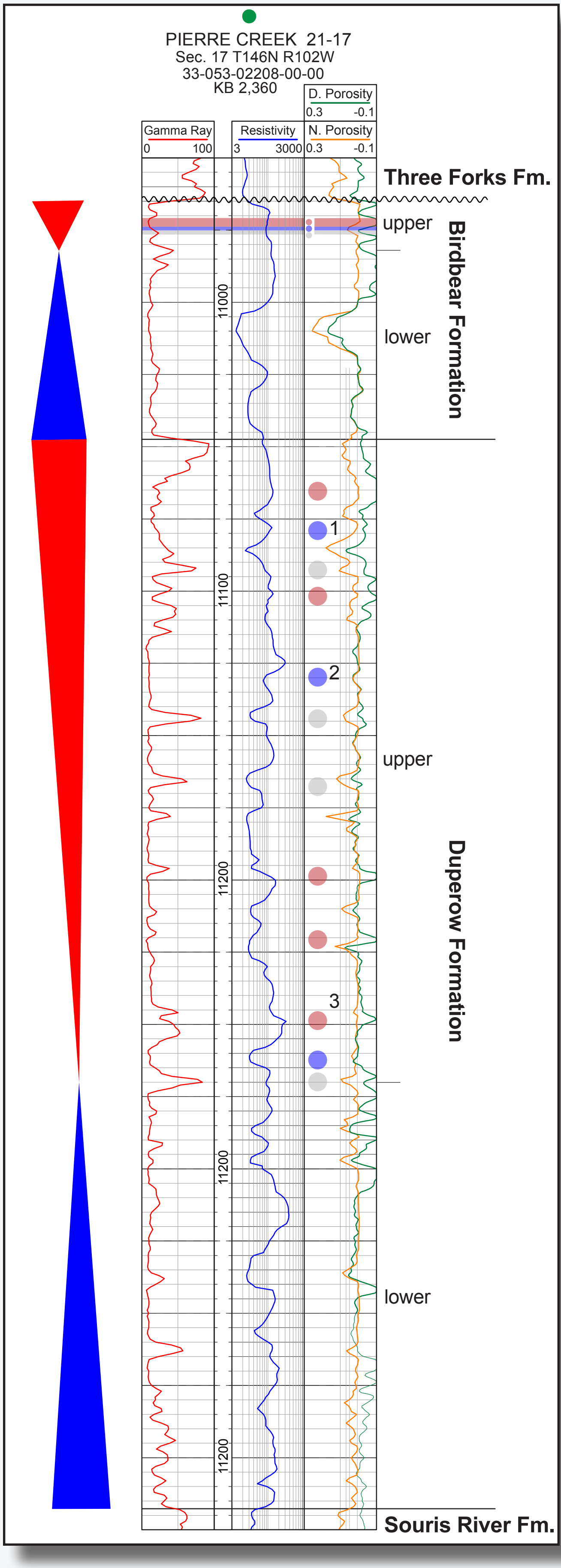

Figure 3. Geophysical logs from the Pierre Creek 21-17 well, McKenzie County, North Dakota. Red and blue triangles indicate shallowing and deepening upwards packages, respectively. Gray = potential source rock; purple = potential reservoir rock; pink = seal rock.

The Birdbear Formation is similar to the Duperow in lithology and also can be informally divided into upper and lower units. The lower member consists of a cycle of limestone and dolostone capped by thick anhydrites interbedded with dolomitic units (Burke and Sperr, 2006). Carbonates of the lower member were deposited within a carbonate platform (figs. 1 and 2) and consist of burrow mottled to nodular, fossiliferous mudstone containing gastropods, brachiopods, and rugose corals (fig. 4) (LeFever, 2009). Platform facies are overlain by biohermal rocks (bank facies) consisting of anhydritic mudstone to wackestone (figs. 1 and 2). This facies is extremely fossiliferous with a bioclastic lower zone containing corals, stromatoporoids, brachiopods, and crinoids (fig. 4A). A middle zone makes up the main bioherm and consists of wackestone to boundstone composed predominantly of stromatoporoids with lesser amounts of coral (fig. 4B). The upper portion of the bioherm bank facies is a wackestone to grainstone containing corals, ostracods, and brachiopods (fig. 4C).

The upper Birdbear is composed of two to three, thin, carbonate and evaporite packages that represent 4th-order regressive cycles (figs. 4D, 4E, and 4F) (Burke and Sperr, 2006; LeFever, 2009). Each cycle contains an interbedded sequence of thin shale and massive dolostones, overlain by nodular (chickenwire) anhydrite. These cyclic sedimentary packages are ideal for hydrocarbon entrapment as source rock, reservoir, and seal are juxtaposed properly in the stratigraphic sequence, with shale underlying carbonate reservoir rock that are, in turn, overlain by impermeable anhydrite seals (fig. 4).

Production

Cumulative production maps for the Duperow and Birdbear are presented as figure 5. The Duperow has generally produced along a north-south trend in McKenzie, Billings, Williams, and Dunn counties (fig. 5). Production is dominantly from the dolomitized stromatoporoid bank facies (Pilatzke et al., 1987) along major structures such as the Nesson, Antelope, and Billings Nose anticlines. Stratigraphic traps associated with the dolomitized stromatoporoid bank facies are also present. Estimated in-place reserves from the formation are unknown; however, the Duperow has produced nearly 153 MMBO in North Dakota to date.

Birdbear production has generally occurred along a north-south trend extending from Williams County southwards into southern McKenzie and northern Billings/Golden Valley counties, with lesser production along major structural features to the east (fig. 5). Structural/stratigraphic traps (combination traps) exist where dolostones pinch out, or are present with closure, over structural highs (LeFever, 2009). Stratigraphic traps are in the extensively dolomitized stromatoporoid bank facies, and in the stromatoporoid facies where these porous units pinch out laterally against impermeable mudstones and packstones of the interbank facies (Martiniuk et al., 1995). The Birdbear is estimated to contain approximately 2,313 MMBO of which 644 MMBO is considered recoverable (LeFever, 2009). The Birdbear

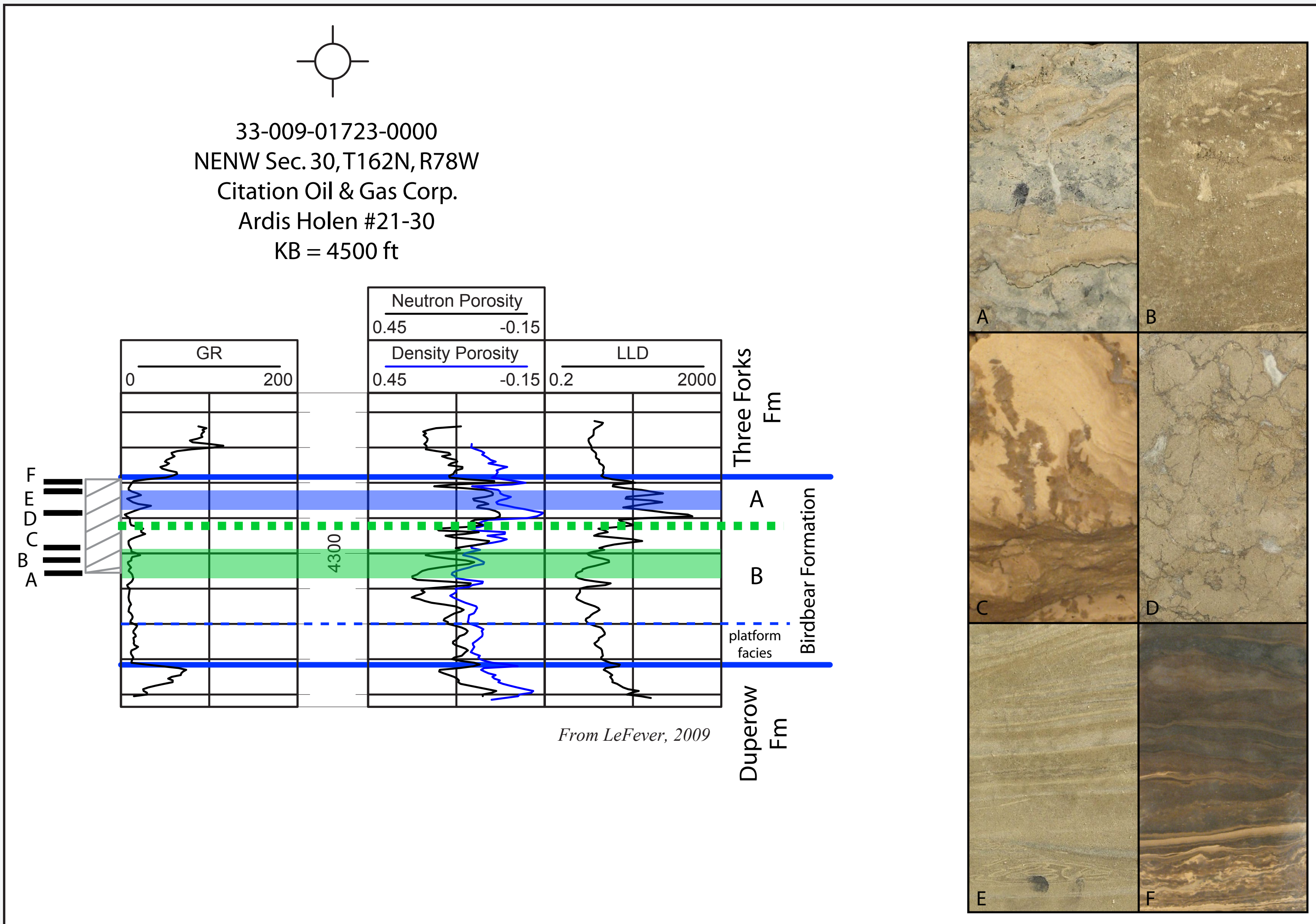

Figure 4. Geophysical logs from the Ardis Holen#21-30 well, Bottineau County, North Dakota. Purple and green = potential pay zones. A = Dolomitic limestone of lower bank facies in Lower Birdbear; B = wackestone and boundstone of main body of biohermal bank facies in Lower Birdbear; C = wackestone-grainstone of upper bank facies in Lower Birdbear; D = collapse facies from dissolution of underlying Prairie salt; E = thin dolostone interbeds of Upper Birdbear; F = massive anhydrite of Upper Birdbear. From LeFever, 2009.

has produced approximately 21 MMBO to date in North Dakota (NDIC, 2018).

Exploration Trends and Trapping Mechanisms - Is Structure the Key?

Production from the Duperow and Birdbear Formations has historically been from traps that are either structural or combined based on the distribution of pools and reservoir facies relative to major structures previously discussed (fig. 5). Such traps are formed purely by structural deformation related to faulting and/or folding. In other cases, the structure may control sedimentation and/or diagenesis, creating a combined trap. Traps of this type are common in the Williston Basin and include Bakken traps in the Elm Coulee and Sanish fields (Sonnenberg and Pramudito, 2009), and Madison production in the Little Knife Field (Lindsey and Kendall, 1980), among others. The growth of the Duperow stromatoporoid banks has been shown to have been partially controlled by earlier tectonic events that created positive structural highs that enhanced bank development in both Montana and North Dakota (Pilatzke et al., 1987). Fractures related to faulting and/or folding likely enhanced groundwater flow in these areas, thus facilitating diagenesis across the structural zone(s). Therefore, although these traps are considered combination traps, reservoir formation and later diagenesis and/or fracturing are controlled by the structure. Up-dip stratigraphic pinch outs against unconformities are also considered stratigraphic traps, but these traps also require a structural component of uplift/tectonics related to the unconformity. Finally, where pure stratigraphic traps exist (e.g., up-dip pinch out of reservoir facies capped by impermeable seals), areas of "naturally" fractured reservoirs will still be much more attractive than unfractured zones, possibly eliminating the need for fracing althogether. In addition, laterals

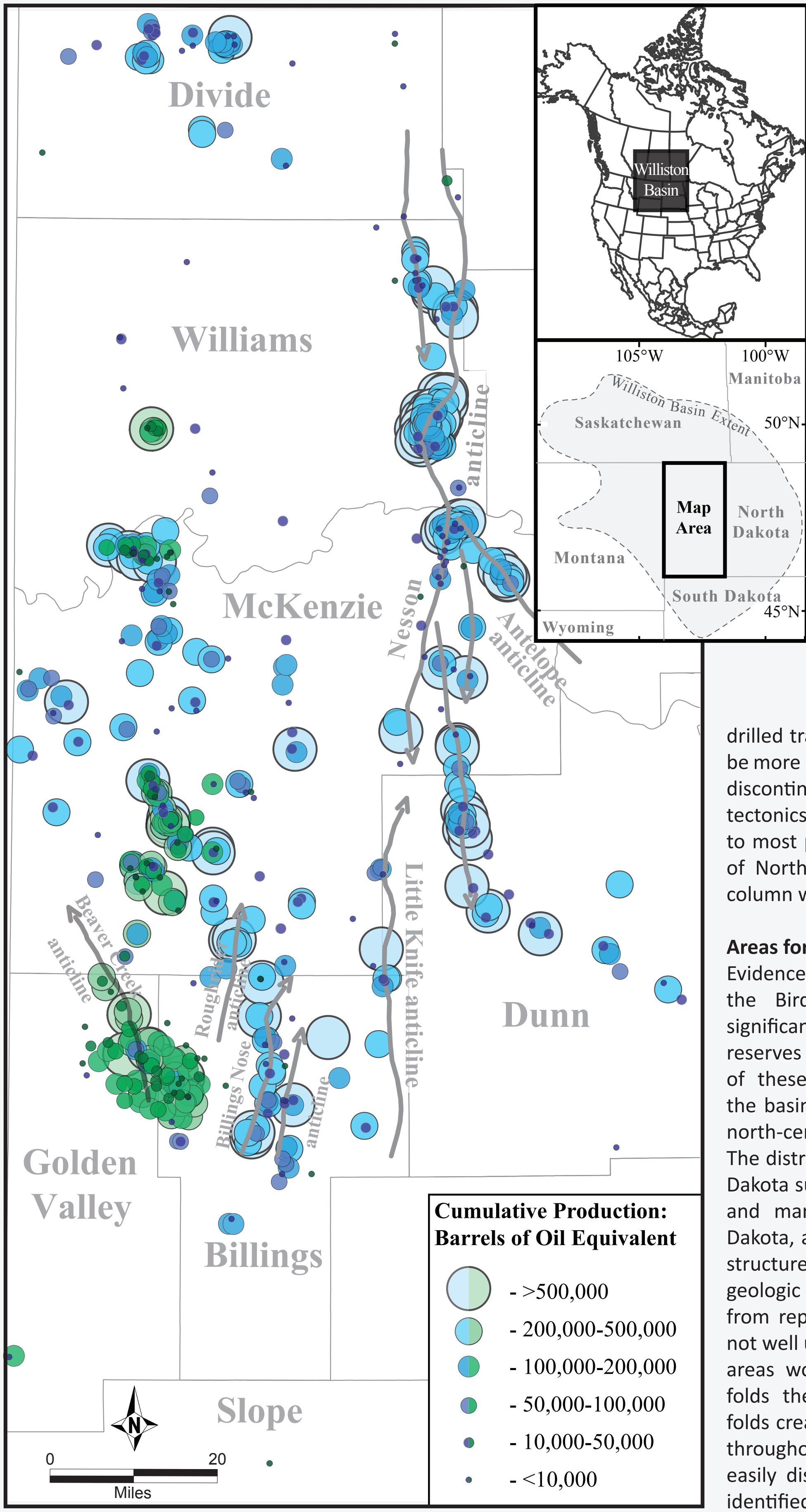

Figure 5. Duperow production map. Shades of green are Birdbear production and shades of blue represent Duperow. From NDIC, 2018.

drilled transverse to identified fracture trends will be more likely to intersect these zones of structural discontinuity. Thus, in one way or another, tectonics and structure are common components to most petroleum occurrences in the subsurface of North Dakota, across the entire stratigraphic column where 20 formations produce petroleum.

Areas for Future Exploration and Development

Evidence presented in this article indicates that the Birdbear-Duperow Formations may have significant in-place and untapped petroleum reserves across North Dakota. The stratigraphy of these units is remarkably consistent across the basin and has been well characterized in the north-central and western portions of the state. The distribution of oil accumulations across North Dakota suggests that oil reservoirs for these units, and many other producing intervals in North Dakota, are concentrated in areas where geologic structures are present. However, the nature of geologic structures and the resulting strain effects from repeated movement on these structures is not well understood. These structurally significant areas would include not only major faults and folds themselves, but also fracture zones and folds created from movement on the major faults throughout geologic time. Such features are not easily discerned and many have likely not been identified.

Anderson (2011), presented a basement-seated "fracture network" of vertical and sub-vertical faults mapped from seismic images in the Parshall and Sanish fields of Mountrail County, North Dakota. This fracture pattern corresponds nearly perfectly with a basement-seated sinistral (left-lateral) wrench fault trending approximately N25W - N30W. The orientation of the master fault(s) is consistent with the orientation of the Cedar Creek fault of eastern Montana and southwest North Dakota, and to the Heart River fault of south-central North Dakota. Therefore, it is proposed that sinistral movement on these major faults would create the fracture pattern observed on figure 6, not only locally in Mountrail County, but across the entire Williston Basin of North Dakota.

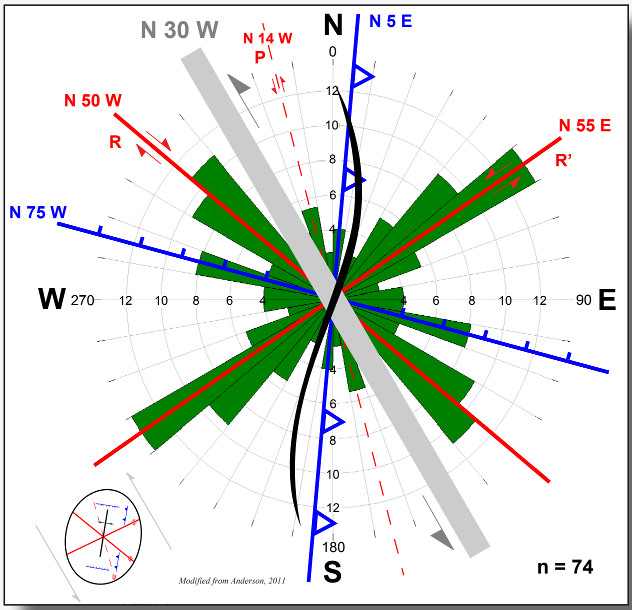

Figure 6. Rose diagram displaying dominant fault bearing (strike) from basement-rooted faults interpreted from 2D-seismic data in Mountrail County with strain ellipse for sinistral (left-lateral) wrench fault for comparison. Modified from Anderson, 2011.

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