Birdbear Formation Lithofacies in west-central North Dakota: some characteristics and insight

Randolph B. Burke (North Dakota Geological Survey) and
T. Jay Sperr (Bill Barrett Corporation)

Renewed interest in the Upper Devonian Birdbear Formation is fueled by statistics showing high initial oil production rates, large cumulative production volumes, and by interpretations of an extensive reservoir (Burke, 2005). Initial production rates are commonly over four hundred barrels of oil per day and some have reported as much as six hundred barrels of oil per day. Most of these wells have less than fours years' of production history, but one, the Avaira State 30-2, has produced a cumulative volume of 124,000 barrels of oil in forty-nine months, for an average of 2,532 barrels of oil a month. The primary play area has been estimated to include over nine townships in the central portion of western North Dakota along the Montana border, Figure 1 (Sperr and Burke, 2005).

There are many relatively curious aspects to this play including: 1) production coming primarily from the upper Birdbear zone whereas previously it was from the lower Birdbear; and 2) a pay zone commonly two feet, or less, in thickness. This paper presents a detailed core description of the Birdbear Formation in the play area to show the different lithofacies that comprise the different zones, and then briefly discusses how these characteristics influence the play. The focus is on the Birdbear A to provide insight into how such large volumes of oil can be recovered from such a thin bed, and to aid exploration and exploitation of this unit.

The Birdbear Formation is a carbonate-evaporite unit that was deposited in a shallow sea during Late Devonian time. This sea extended from North Dakota into Alberta where it is the Nisku Formation. The Birdbear Formation was formally defined by Sandberg and Hammond (1958) in the Mobil Oil Producing Company No. 1 Birdbear well. The Birdbear is underlain by the carbonate-evaporite cycles of the Duperow Formation and overlain by the argillaceous carbonates and evaporites of the Three Forks Formation (Figure 2). The Birdbear is interpreted to represent a third-order depositional sequence within the overall second-order Devonian transgressive-regressive sequence. In this study, four fourth-order sequences are recognized, three of which are in the A zone.

The Birdbear Formation thins to the west and southwest, and a structure map of the study area shows northerly trending noses and small closures on a northeasterly dipping surface (Figure 1). An isopach map of the upper Birdbear shows a general thickening in the area of greatest Birdbear production. An abrupt ninety degree change in orientation of the isopach contours to the northeast just south of Cook's Peak and Roosevelt Fields was interpreted by Sperr and Burke (2005) to possibly indicate the edge of a basement block where the block to the southeast was up during deposition of the upper Birdbear. Birdbear producing wells are most common where the structural noses and closures in the Birdbear are coincident with the greatest thickness of the Birdbear A.

The Birdbear Formation is informally divided into two zones, the upper (A) and the lower (B), based on log

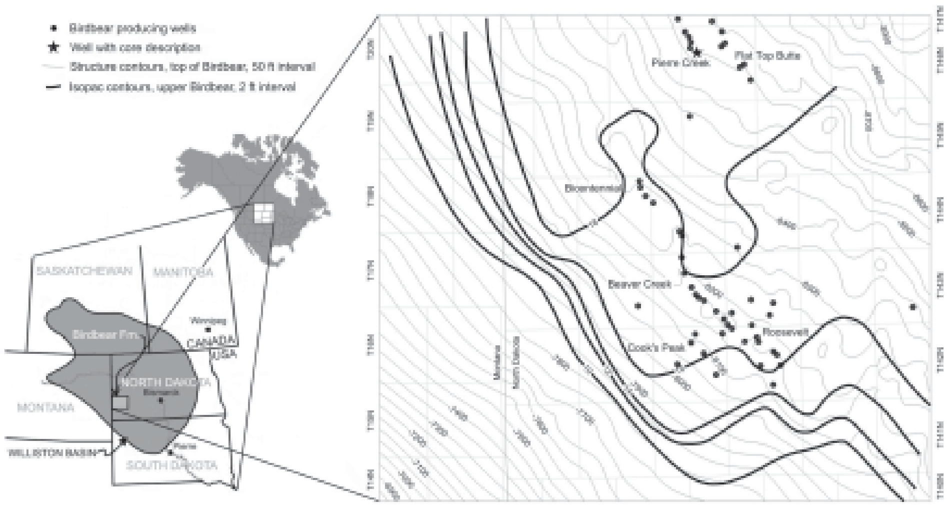

Figure 1. Location map showing the primary play area of the upper Birdbear Formation A zone. The large dots indicate Birdbear producing wells. The light line weight contours are sub-sea level elevations on top of the Birdbear Formation in 50-foot intervals. The heavier lines are isopach contours of the thickness of the upper Birdbear at 2-foot intervals. Field names are indicated adjacent to the well symbols. The star indicates the location of the well for the core description.

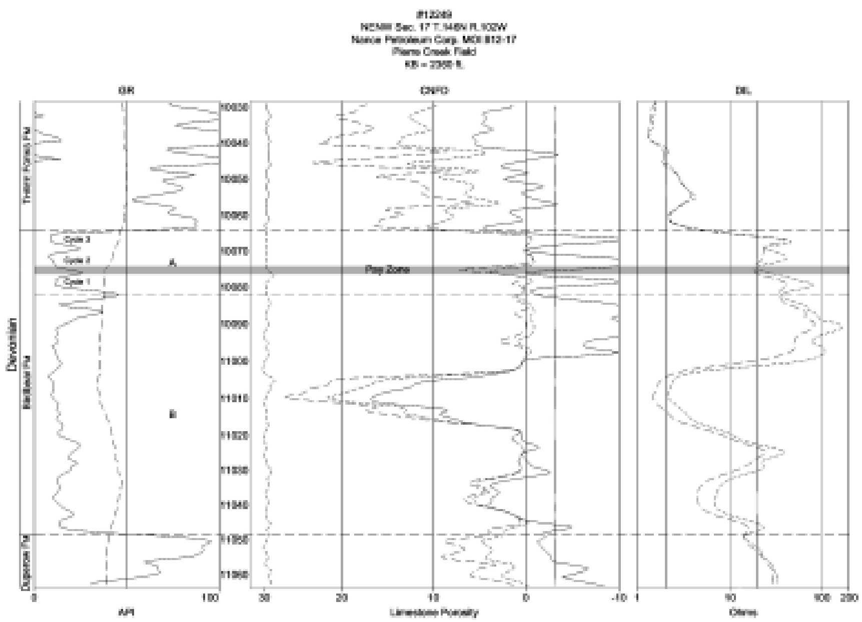

Figure 2. Geophysical logs representative of the Birdbear Formation in the study area with the contacts of the overlying and underlying formations indicated. The informal upper and lower zones are designated by A and B respectively. The fourth-order cycles in the Birdbear A zone are indicated. The primary target of the current play is shaded gray. GR = gamma ray; CNFD = compensated neutron formation density, IL= induction log

characteristics and lithologies. The top of the B zone is picked on the gamma ray log at the highest gamma ray reading above the top of the Duperow Formation that corresponds to the top of the first thick evaporite-dolomite sequence capping the cleaner carbonate at the base of the B zone.

The A zone consists of a series of carbonate-evaporite cycles overlying the B zone (Figure 2). The cycles are designated in depositional order from the bottom up as one through three in figure 2 and recognized on the gamma ray logs by peaks of increased gamma ray intensity. All three cycles are not always present in the study area where cycle three thins from east to west, either by erosion, or nondeposition (Sperr and Burke, 2005). The pay zone in the A is commonly in the second cycle and generally around two feet in thickness with porosities of about ten percent. Thin bed effects on geophysical logs make it challenging to accurately map the reservoir and account for the large volumes of oil produced from this zone. Drainage areas must be large and permeability very good to account for the large volumes of oil coming from some of these wells. Cycle one also has good porosity in some wells and this could contribute to storage capacity if there is communication between cycles through the anhydrite capping cycle one. Examination of a horizontal core cut in the F.H. Petroleum Corporation State #14-16 well revealed another potential mechanism for the transmission of large volumes of oil. In this case, the only significant porosity was along a swarm of non-suture seam stylolites. Stylolites represent a zone of pressure dissolution and compaction where insoluble residues are concentrated to form these diagenetic structures and provide a zone for fluid movement. The stylolite zone in the core extended for approximately twenty-two feet, almost the entire length of the core. Water placed on the face of the polished core was readily absorbed along the stylolite zone showing this to be the best porosity in this core (Figure 3). Dolomite crystals along the stylolites are larger than those in the surrounding rock, thereby explaining the increased porosity along the stylolite zone. It is likely that stylolite swarms serve as conduits for the movement of hydrocarbons in this zone to help drain the large area necessary to account for the large production volumes from the A.

Figure 3. Water on core surface is brightly reflected and only readily absorbed along a thin zone in the middle of the photo (arrow). The middle portion of the core is characterized by a swarm of non-suture seam stylolites along which dolomite rhombs are enlarged relative to the surrounding matrix forming a high porosity conduit for fluids. This zone extended for over twenty-two feet in this horizontal core cut in the F.H. Petroleum Corporation State #14-16 well (NDIC File #15625). Photo of core sample from an approximate measured depth of 12,673 feet.

It is clear from geophysical log analysis that the most porous rocks in both the A and the B zones are from dolomite, but constituent analysis of Birdbear Formation cores taken from the study area show that the dolomite in the A zone is depositionally quite different from that in the B (Figure 4). The Birdbear B consists of a cycle of limestone and dolomite capped with a thick sequence of anhydrites interbedded with dolomites, anhydritic dolomites and organic-rich, slightly argillaceous dolomites. Numerous seams and thin beds up to two inches thick of apparently organic-rich sediments are

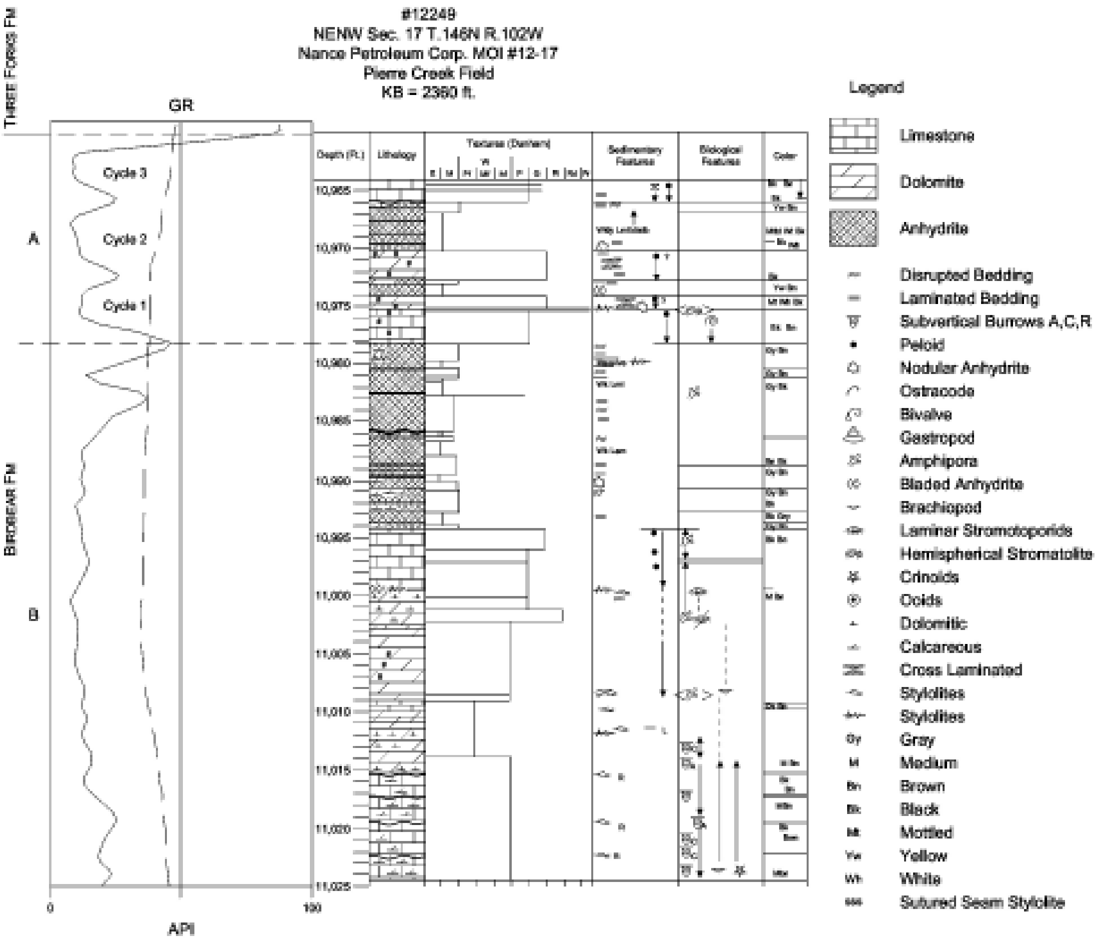

Figure 4. Detailed core description of the Birdbear Formation for Nance Petroleum Corporations MOI #12-17 in Pierre Creek Field, NDIC file #12249 showing lithology, texture, sedimentary and biologic features, and rock color.

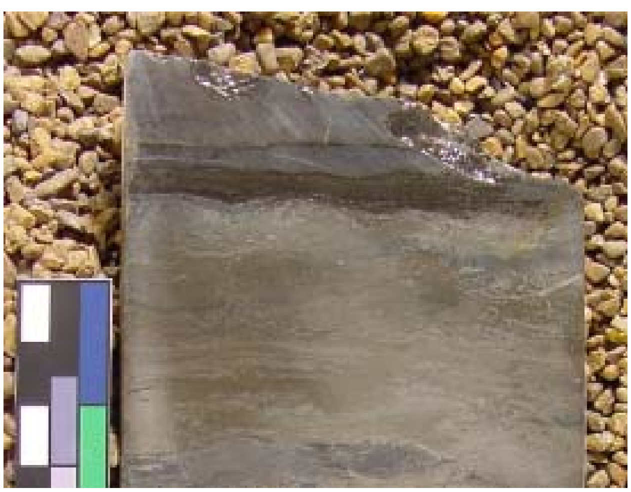

Figure 5. Note the 0.5-inch-thick wavy, dark-black thin bed at the top of this vertical core sample. These beds are not true shale; rather they are interpreted to be highly organic calcareous mudstones, possibly slightly argillaceous. These kinds of beds are abundant throughout limestone units and the thin interbeds of dolomudstones and anhydrites, and are the likely source rocks for this play. Photo of core from the Meridian Oil Company #21-17 MOI well from a depth of 10,980 feet (NDIC #12249).

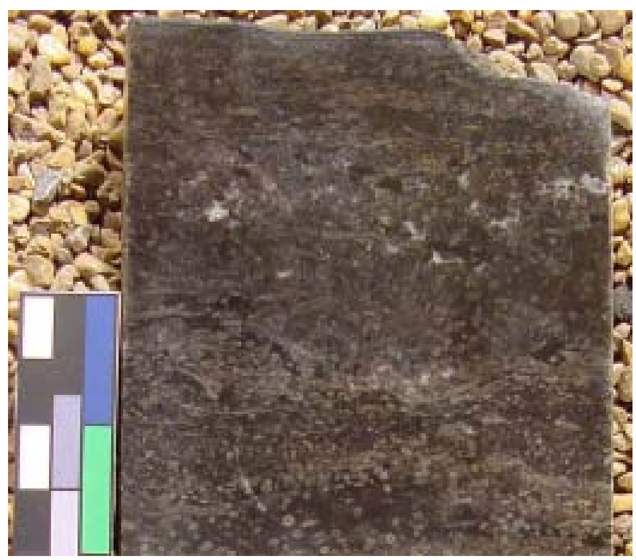

Figure 6. Core photograph of dark black-brown grainstone immediately below the dolomudstone anhydrite cap at the top of the lower Birdbear B zone. Light-colored, rounded and elongate grains are fragments of *Amphipora*, a delicate branching stromatoporid. The sharp contact with the overlying anhydrite and lack of significant compaction of the grains contributes to evidence indicating a relatively abrupt increase in salinity within the depositional environment. Photo of core from the Meridian Oil Company #21-17 MOI well from a depth of 10,994 feet (NDIC #12249).

common in the cap rock (Figure 5). Fossils in the B zone dolomite include organisms such as brachiopods and *Amphipora* that are good indicators of reasonably normal salinity water. The light coloration, medium-brown, may indicate an oxygenated environment. Thorough dolomitization of calcite obscures textures but they are interpreted to be wackestones suggesting a relatively low-energy depositional environment. Limestones overlying the wackestones are a dark black-brown color below the interbedded anhydrite and dolomudstone cap and are dominated by very fine-grained peloids with a few *Amphipora* fragments (Figure 6). The absence of mud suggests deposition in a relatively high-energy environment, probably with reduced oxygen concentrations in the water that resulted in the preservation of organic matter, which provides the black coloration. Overlying dolomites have mudstone textures and anhydrites have crystal morphologies all indicating subaqueous deposition.

Birdbear A in this core consists of three separate cycles of carbonates capped with anhydrites (Figure 7) and anhydritic dolomites with abundant organic-rich, slightly argillaceous, calcareous thin beds. The predominant grains in all cycles are peloids, with hemispheroidal stromatolites (Figure 8) and ostracodes (Figure 9) abundant locally in cycle one, and small subrounded intraclasts in cycle three. The pay zone in cycle two is uniformly dolomitized and only the ghosts of peloids can be used for interpretation. The dolomites are very finely crystalline rhombohedrons ranging from 20 to 50 microns in size (Figure 10). Pore and pore throat geometries in such uniform dolomites can contribute to high recovery efficiencies on the order of 45%. Well-developed laminations, cross laminations, and cut and fill structures (Figure 11) indicate relatively high-energy current deposition in cycle two. All of the constituent grains in all cycles are compatible with hypersaline depositional conditions. Salinities were sufficiently concentrated to precipitate halite in cycle one where hopper crystals (Figure 12) are preserved in the peloidal grainstone.

Figure 7. Massive anhydrite with argillaceous and organic seams defining replaced, large, erect, gypsum crystals interpreted to have been growing on the sea floor. This anhydrite provides the seal for the cycle one petroleum system and is similar to anhydrites capping each cycle in the Birdbear. Photo of core of the upper Birdbear at the top of cycle one from the Meridian Oil Company #21-17 MOI well from a depth of 10,974 feet (NDIC #12249).

Figure 8. The right side of the core is composed of a hemispheroidal stromatolite and the upper left has small nodules of anhydrite (bright white) precipitated in, and disrupting, a thinly laminated dolomudstone. These are all indicators of an elevated salinity environment in relatively shallow water depths. Photo of core from the upper Birdbear at the top of cycle one in the A zone of the Meridian Oil Company #21-17 MOI well from a depth of 10,975 feet (NDIC #12249).

Figure 9. Thin section photomicrograph showing the abundance of ostracodes ($\simeq$1 mm across - see arrows) and peloids ($\simeq$ 200 microns, or fine sand) characteristic of the grainstone to packstone textures commonly at the base of each cycle of much of the upper Birdbear A zone. Anhydrite replaces some carbonate and plugs porosity in the upper left of the photo. Photo of the upper Birdbear at the base of cycle one in the A zone of the Meridian Oil Company #21-17 MOI well from a depth of 10,976 feet (NDIC #12249).

Figure 10. Thin section photomicrograph shows dolomite pay zone with localized anhydrite plugging (large bright rounded areas) making recognition of original grain types difficult to determine. They are interpreted to have been very fine to fine sand-size peloids similar to those seen in figure 9. Dolomite rhombs range in size from 20 to 50 microns and are seen here as bright pin points. Some of the larger, more well-defined rhombs are circled. Photo of the upper Birdbear near the top of cycle two in the A zone of the Meridian Oil Company #21-17 MOI well from a depth of 10,971 feet (NDIC #12249).

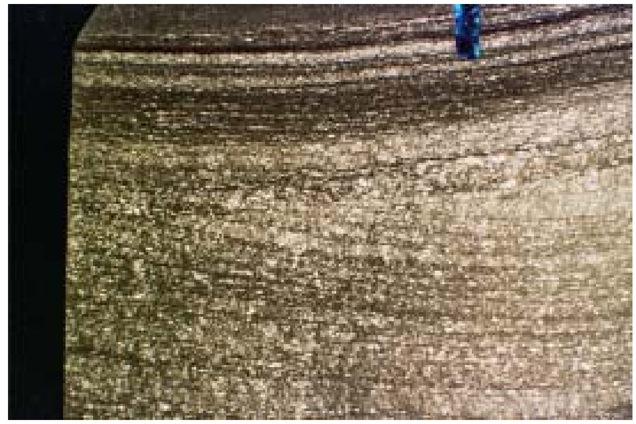

Figure 11. Lamination typical of the uppermost portion of Birdbear cycles one and two (the pay zone) in a photomicrograph plugged with anhydrite. Cross-laminations showing cut and fill structures providing clear evidence for grain transport and deposition with preservation of fine material (organics or clays) defining laminations. Photo of the upper Birdbear near the top of cycle one in the A zone of the Meridian Oil Company #21-17 MOI well from a depth of 10,974.5 feet (NDIC #12249).

No clear evidence for subaerial exposure was observed, suggesting these deposits represent brining upward depositional sequences. Hypersaline water is anoxic, which allows for the preservation of organic matter. Cycles one and two each contain the major components necessary for a complete hydrocarbon system: source (salinity preserved organics), trap overlying anhydrite seal, and reservoir (dolomitized peloidal grainstones). Rock evaluation analysis and oil typing would be very useful to test this hypothesis and may resolve the source rock issue.

Until recently, most oil production from the Birdbear Formation came for the B zone. The thick, high porosity in the B zone is easily seen on the compensated neutron density log in figure 2 and is very enticing. However, exploration determined that significant structural closure was required for trapping large volumes of oil and such structures are challanging to find. Despite this fact, over 12 million barrels of oil have been produced from more than 30 fields. Most of the fields had fewer than three wells and are widely scattered, suggesting the structures are small.

Figure 12. Salt "hopper" crystals (circled) replaced and infilled with anhydrite, indicates interstitial water was saturated with respect to the point of precipitation of halite. Photo of the upper Birdbear near the top of cycle one in the A zone of the F.H. Petroleum Brown 42-28 well from a depth of 10,709 feet (NDIC #15679).

In contrast, Sperr and Burke (2005) demonstrated that the current Birdbear A zone play is largely a stratigraphic play with a minor structural component (Figure 1). If their estimate of the size of the play area is accurate, and reasonable evaluation factors are assumed, there are over 40 million barrels of oil waiting to be produced from the A zone of the Birdbear Formation.

References

Burke, R.B., 2005. Evolving Birdbear (Nisku) Play in North Dakota: Geologic Investigations No. 6. (poster)

Sandberg, D.A. and Hammond, G.R., 1958. Devonian System in Williston Basin and central Montana: AAPG Bulletin v. 42, p. 2293-2334.

Sperr, Jay, T. and Burke Randolph, B., 2005. The Birdbear Formation (Nisku) of Western North Dakota: Another Emerging Williston Basin Horizontal Play. Power Point North Dakota Geologic Investigations No. 20, on NDGS home page.

Sperr, Jay, T. and Burke Randolph, B., 2005. The Birdbear Formation (Nisku) of Western North Dakota: Another Emerging Williston Basin Horizontal Play, *in* Meeting Program 2005 Rocky Mountain Section – AAPG Jackson Hole Meeting, September 24-26, Jackson, Wyoming, p. 49.