Birdbear Formation in North-Central North Dakota – Additional Production Potential

Julie A. LeFever

Introduction

Gas development started along the east flank of the Williston Basin (primarily Renville and Bottineau Counties) in 1908 when the North Dakota Gas Company began drilling wells near the town of Westhope (Harrison, 1978, oral communication). Oil production began in this area in 1952 when a random wildcat well (#1 Edwin Berentson, SWSE Sec. 21, T163N, R79W) drilled by the Zach Brooks Drilling Company discovered the Westhope Field. The discovery of the Westhope Field resulted in further exploration, development, and ultimately significant production along the eastern flank of the Williston Basin (fig. 1). Currently production is restricted to various intervals within the Madison Group (Mississippian) and overlying Spearfish Formation (Triassic). There are a few unsuccessful tests deeper than the Madison along this portion of the basin.

This paper will examine the future oil and gas potential of the Birdbear Formation (Devonian) in north-central North Dakota and its relationship to recent exploration and production from the southwest portion of North Dakota along the Bicentennial, Beaver Creek, and Roosevelt trend.

Birdbear Formation

The Birdbear Formation lies on top of the Duperow Formation and beneath the Three Forks Formation in the central part of the Williston Basin or beneath the Lodgepole Formation along the margins of the basin where the Three Forks is not present (For additional details see the stratigraphic column on page 28). Oil and gas has been produced from the Birdbear Formation in Saskatchewan and Montana since the early 1960s (Ehrets and Kissling, 1985; Martiniuk *et al.*, 1995) and in North Dakota since 1978.

The Birdbear Formation was deposited about 350 million years ago during the Devonian Period when North Dakota was situated just south of the equator on the slowly moving northward North American tectonic plate. The Williston Basin of North Dakota was part of an embayment that extended through Saskatchewan and Alberta to the open sea beyond. This embayment was repeatedly flooded by fluctuating sea levels, the maximum extent of which decreased throughout Birdbear time. This gradual decline in maximum sea levels resulted in the lower portion of the Birdbear Formation being dominated by deposits of shallow marine limestone and dolostones whereas the upper portion of the Birdbear is dominated by onshore deposits containing anhydrite. The presence of the evaporite mineral anhydrite and dolomitized limestone in the onshore deposits suggest that during this time North Dakota periodically experienced arid conditions similar to the modern sabkha environment of the Persian Gulf. This depositional history led to the development of porous and permeable dolostones encased in impermeable anhydrite and fine-grained carbonates. Tilting of these reservoirs by basement-related faults and multi-stage salt solution collapse structures allow for the formation of traps where the reservoir dolostones are draped over or pinchout along the flanks of structural highs. Oil in the Birdbear Formation is also trapped in extensively dolomitized stromatoporoid banks (stromatoporoids are an extinct carbonate secreting organism similar in some respects to modern sponges) and biostromes ("reefs") that lie immediately below a layer of interbedded anhydrite and tidal flat carbonates (fig. 2).

Table 1. Summary tables of basic Birdbear Field information presented to the North Dakota Industrial Commission.

Producing Interval	Producing Fields	Average TVD	Vertical Thickness (Ave., Ft)	Porosity (%)	K (md)	Water Saturation (%)	Oil Gravity (°API)	BHT (°F)	Initial BHP (psia)	Fm Value Factor	GOR	GAS Gravity	Reservoir Drive
"A" Zone Only	18	10475	4	13.9	4.7-30	27	38.4-44	228	4100-5265	1.43	877	0.856	Solution Gas-Water Drive
"A" & "B" Zones	8	10954	9.4	13.8	8.6	43	42.3-45	243	5153-5312	1.55	843		Solution Gas
"B" Zone Only	9	10805	12	12.8	4.8	44	39-43.6	244	4960-5240	1.51	709		Water Drive/Solution Gas

Producing Interval	Producing Fields	OIP (MBO)	Primary Recovery	EUR (MBO)
"A" Zone Only	17	844	17.7	221
"A" & "B" Zones	6	879	22	286
"B" Zone Only	9	590	20	137

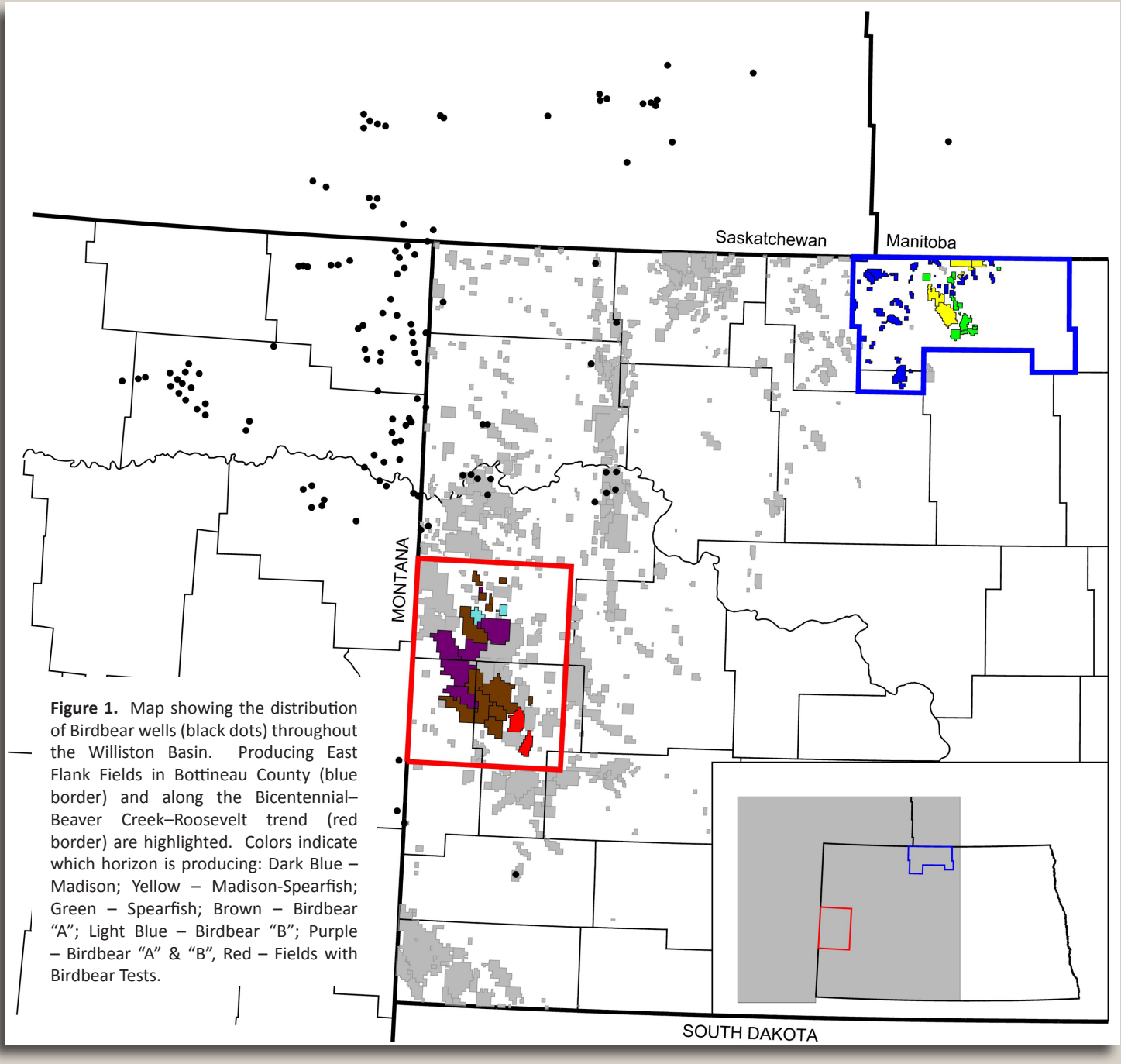

Figure 1. Map showing the distribution of Birdbear wells (black dots) throughout the Williston Basin. Producing East Flank Fields in Bottineau County (blue border) and along the Bicentennial–Beaver Creek–Roosevelt trend (red border) are highlighted. Colors indicate which horizon is producing: Dark Blue – Madison; Yellow – Madison-Spearfish; Green – Spearfish; Brown – Birdbear "A"; Light Blue – Birdbear "B"; Purple – Birdbear "A" & "B", Red – Fields with Birdbear Tests.

Bicentennial-Beaver Creek-Roosevelt Trend

Production from the Birdbear Formation occurs along a trend that extends through Billings, McKenzie, and Golden Valley counties (fig. 1). Along this trend, Birdbear production from vertical wells is obtained from a dolostone reservoir known as the "B" horizon. The "B" horizon is from 8 to 20 feet in thickness and contains an average of 16% porosity with between 4 to 10 millidarcies permeability. Producible traps are formed where the "B" horizon overlies structural highs and is capped by impermeable anhydrites of the overlying "A" zone (Table 1) (Sperr and Burke, 2005; McClellan, 2006).

Additional production is sometimes possible where porous dolostones pinchout within the anhydrites of the overlying "A" zone. "A" zone dolostones are 2 to 4 feet thick with pay zone porosities that average 14% with permeabilities in the 4 to 30 millidarcy range (Table 1). A detailed analysis of this area is presented by Burke and Sperr (2005). Economic production from vertical tests of the Birdbear Formation is typically restricted to depths of less than 10,800 feet. However, economic quantities of oil can be produced from tests deeper than this when a 4,500 foot long horizontal leg is added to an existing vertical well. The potential of good production from the "A" zone, the stratigraphic nature of the trapping mechanism, and the possibility of multiple pay horizons suggests that significant Birdbear reserves may be found elsewhere in Williston Basin.

North-Central North Dakota

The rocks of the Birdbear Formation in the north-central portion of the Williston Basin are similar to those that produce along

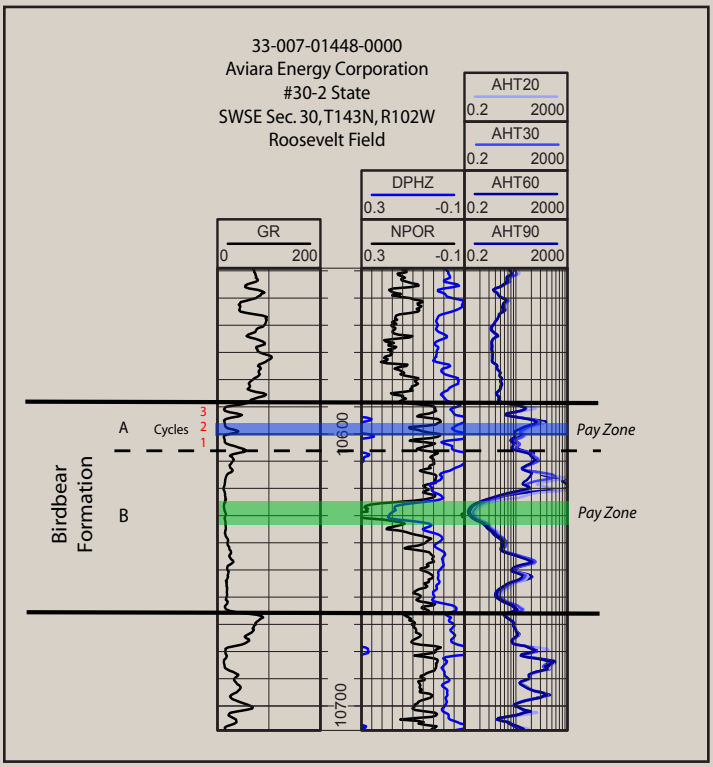

Figure 2. Wireline log from a producing well in southwestern North Dakota with a representative section of the Birdbear Formation. The conventional producing horizon is informal unit "B" and where productive, consists of stromatoporoid and biohermal banks indicated in green. Informal unit "A" is the focus of this paper and consists of an interbedded sequence of anhydrites and dolostones and its producing horizon indicated in blue (modified from Burke and Sperr, 2006).

the Bicentennial–Beaver Creek–Roosevelt trend. A cross section through these two areas demonstrates that the units are easily traceable across the basin (fig. 3). The north-central area was chosen for study on the basis of well control and the availability of cores. Thirteen cores provide insight into the distribution of the various depositional environments that formed the rocks (lithofacies) that represent the geologic history of this formation. The lowermost portion of the Birdbear Formation is a platform facies that immediately overlies the Duperow Formation. It consists of 30 to 43 feet of burrow mottled to nodular lime mudstone to wackestone containing gastropods, brachiopods, rugose (horn) corals and other skeletal debris. Commonly fractured and oil stained in this area, fluid movement has solution enhanced existing pinpoint and vuggy porosity, in addition to providing fracture porosity (Martiniuk et al, 1995). The platform facies is overlain by a biohermal facies consisting of a light brown anhydritic lime mudstone to wackestone. It is generally massive and may be burrowed or nodular bedded. Reaching a maximum of 27 feet, these rocks have porosities ranging from 8 to 19.5 % with permeabilities as high as 3.3 millidarcies.

The basal portion of the biohermal or bank facies in north-central North Dakota is a light brown, to medium brown-grey dolomitic limestone containing fossil fragments (bioclastic) that are either surrounded by or are "floating" in mud-sized carbonate sediment (packstone to wackestone). Fossils including *Thamnopora*, *Amphipora*, laminar and hemispherical stromatoporoids, rugose corals, brachiopods and crinoids are abundant. The porosity is vuggy, solution enhanced or moldic where skeletal material is present (fig. 4).

The main bioherm consists of a lime wackestone and boundstone that is comprised predominantly of laminar, bulbous, and digitate stromatoporoids. Other fossils include rugose corals, *Thamnopora*, *Amphipora*, and colonial corals (*Syringopora)*. Porosities range from 6 to 19% with permeabilities up to 237 millidarcies. Intergranular, moldic, intraparticle, pinpoint and vuggy are the common types of porosity and may or may not be solution enhanced. This is overlain by a lime wackestone to

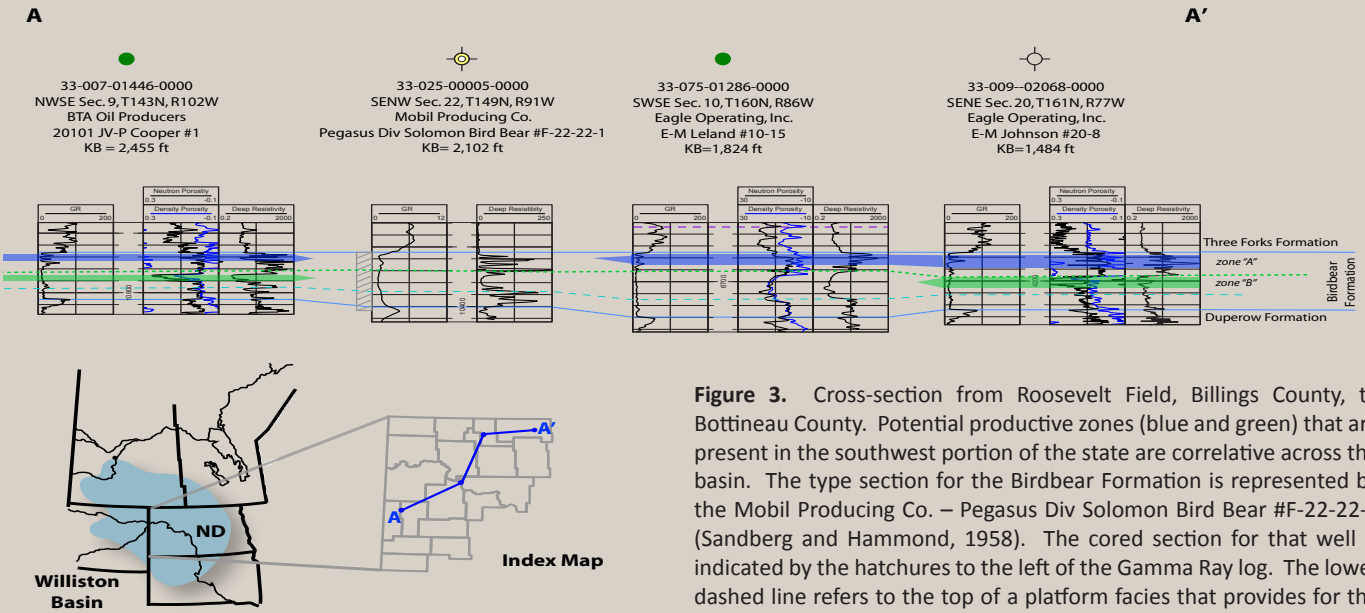

Figure 3. Cross-section from Roosevelt Field, Billings County, to Bottineau County. Potential productive zones (blue and green) that are present in the southwest portion of the state are correlative across the basin. The type section for the Birdbear Formation is represented by the Mobil Producing Co. – Pegasus Div Solomon Bird Bear #F-22-22-1 (Sandberg and Hammond, 1958). The cored section for that well is indicated by the hatchures to the left of the Gamma Ray log. The lower dashed line refers to the top of a platform facies that provides for the development of the potentially productive overlying biohermal or bank facies (Martiniuk et al., 1995).

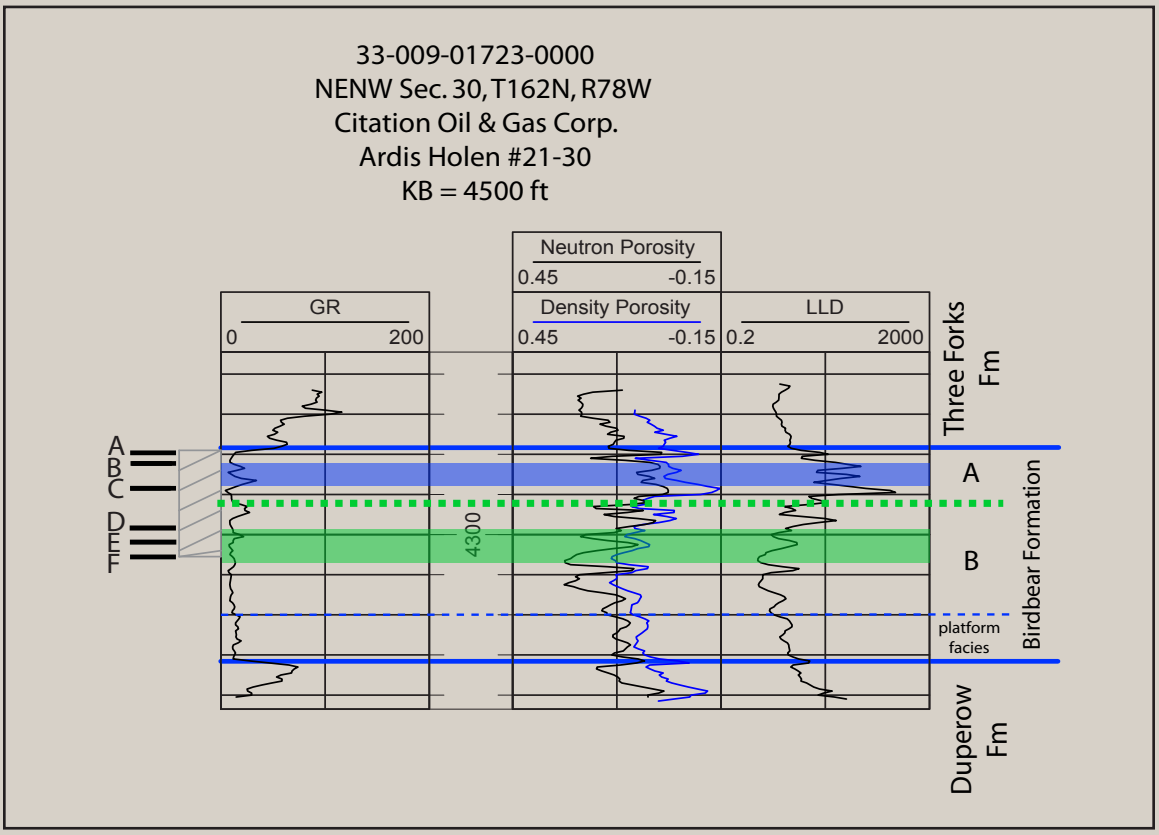

Figure 4. The Citation Oil & Gas Corp. – Ardis Holen #21-30 well in Bottineau County is displayed in this figure. This Birdbear test shows similar intervals to the wells present in the southwest part of the state. The portion of the well cored is indicated by the hatchures on the left side of the diagram. In descending order: A (4,272 ft) – medium grey massive anhydrite; B (4,281 ft) – thin dolostone interbed; C (4,293 ft) – localized collapse facies in this well due to the dissolution of the underlying Prairie salt; D (4,300 ft) – the lime wackestone to grainstone with tabular stromatoporoids of the bioherm; E (4,305 ft) – the lime wackestone to boundstone section of the bioherm; and, F (4,310 ft) – the basal portion of the bioherm or bank lithofacies.

grainstone. Localized mudstones are also present in the area. Fossils include *Amphipora*, *Thamnopora*, rugose and *Syringopora* corals, ostracods, and brachiopods. This portion shows similar types of porosity to the lower section but with lower porosity and permeabilities probably due to limited dolomitization. The interval is commonly heavily oil stained (Martiniuk et al., 1995).

The equivalent to the "A" zone in this area is characterized by an interbedded sequence of massive, chickenwire, or nodular mosaic anhydrite with thin shale partings. Interbedded within the anhydrite sequence are massive dolostones, very fine-grained (microsucrosic) dolostones, algal laminated dolostones, and mottled lime mudstones. The carbonate sequence is oil stained and commonly contains intergranular, intercrystalline and solution enhanced vuggy porosity.

Exploration and Development Potential

Significant potential exists for production from the Birdbear Formation on the east flank of the Williston Basin. This portion of the basin is well known for its salt tectonics. Newburg and South Westhope fields are located on the updip side of a prominent syncline resulting from the dissolution and collapse related to the Prairie salt (Anderson and Hunt, 1964; LeFever and LeFever, 1991). The activity in this area has produced the necessary structure to develop the correct facies relationships for production from the "B" zone. This may be tied further to the trapping mechanism related to two stage salt dissolution and collapse as seen in producing areas in northeastern Montana and southern Saskatchewan.

Cores also suggest that fluids have enhanced porosity and permeability. This may provide a diagenetic-stratigraphic trap where enhanced reservoir beds are trapped updip by tighter facies. Also, there is additional potential in horizontally drilling the thin dolostone beds of the "A" interval as exhibited by the well along the southwest portion of the basin.

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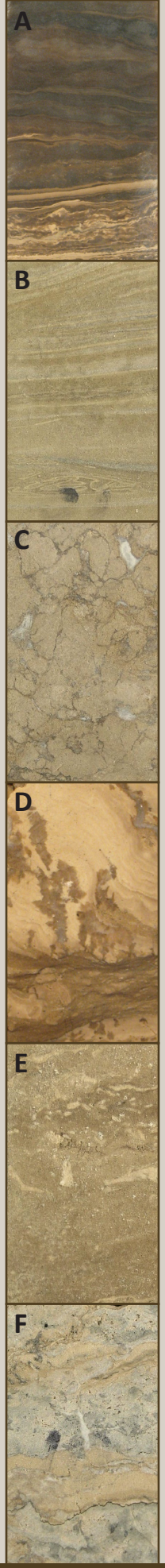

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