The Spearfish Formation – Another Unconventional Target

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The production history from the Spearfish Formation (Triassic) in the state is similar to the drilling history of the Bakken Formation and other unconventional reservoirs. Drilling in Bottineau County began with a random wildcat, the Zach Brooks Drilling Company - #1 Edwin Berentson (SW¼ SE¼, Sec. 21, T163N, R79W). Drilled and completed in November 1952, this well was the first commercial oil well in Bottineau County and the discovery well for Westhope Field. Early wells in the county produced primarily from the Madison Group (Mississippian) but strong oil shows in the overlying Spearfish Formation suggested that it might also be a target. Subsequent discoveries at Newburg (1955) and South Westhope (1956) fields proved this to be true (fig. 1).

Drilling activity reached record highs from 1957 to 1959 and continued through 1961 in the region as companies actively pursued the Madison Group and Spearfish Formation (LeFever and LeFever, 1991). A number of new fields were added at this time (fig. 1). It is interesting to note that marketing the oil in this area was difficult early in the exploration history of the region. Prior to 1963, production in the north-central portion of the basin was marketed by rail until 1963 when the Portal Pipeline was constructed to carry crude to refineries in Minnesota and Wisconsin (Gerhard et al., 1982). A successful waterflood was initiated by Amerada Petroleum Corporation in 1967 to reverse the gradual decline of production in Newburg Field. Drilling activity slowed basinwide from 1966 to 1974 (Gerhard et al., 1982).

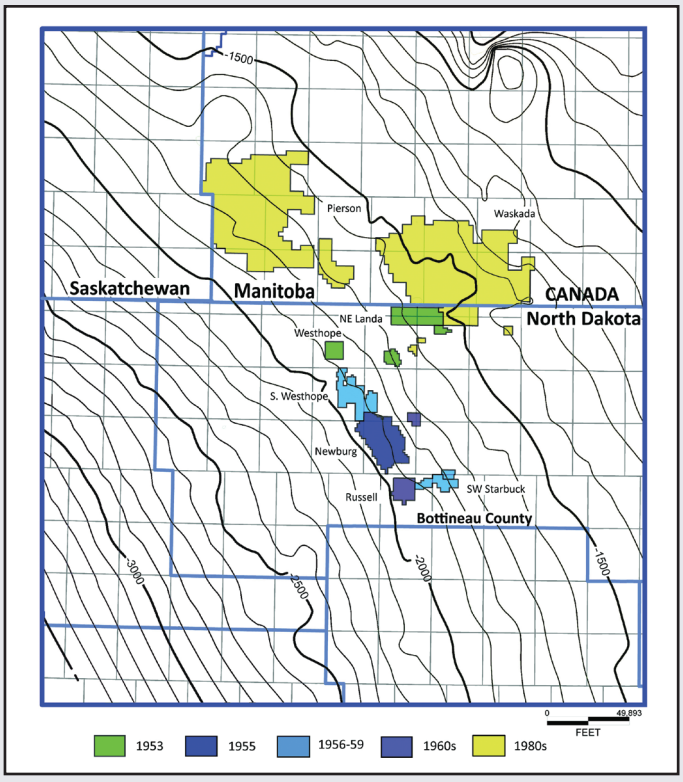

Figure 1. Structure on the top of the Madison unconformity surface. The distribution of Spearfish Formation producing oil fields in Bottineau County, North Dakota and Canada are also indicated. The fields are colored based on the discovery date (modified from LeFever and LeFever, 1991).

Figure 2. Outcrop photograph of red siltstones, sandstone, and mudstones of the Spearfish Formation taken in the town of Spearfish, South Dakota (wild turkeys for scale).

A discovery by Omega Hydrocarbons Ltd. in June 1980 resulted in renewed activity when the company recompleted a Madison producer in the Lower Amaranth Formation (Spearfish Formation equivalent) in Waskada Field, Manitoba (Barchyn, 1982). This discovery was followed by a significant lease play in north-central North Dakota, but the drilling success rate was variable and the play did not develop as expected. The play in southern Manitoba continued until 1990 when exploratory drilling became non-economic. Production from these fields continued with horizontal development drilling coupled with secondary recovery methods. Early in 2008, EOG Resources revisited the Waskada Field area with technology used to explore for the Bakken Formation in Mountrail County. The application of horizontal drilling in combination with

fracture stimulation resulted in wells that produce exponentially better than traditional vertical wells (Redekop, 2010). The Manitoba Petroleum Branch estimated that 300 wells would be drilled into the lower Amaranth in that province in 2010 at a cost of $1.5 million per well.

EOG Resources announced in April 2010 that they had moved the Spearfish play across the border into north-central North Dakota. This prospect, referred to as the Waskada South Field, is considered to be a small accumulation (20 million barrels) with a very high rate of return (Papa, 2010).

Spearfish Formation

The Spearfish Formation was originally described by Darton (1898, 1899-1900) for a sequence of red sandy clay, or shale with anhydrite beds that outcrop in the Blacks Hills of South Dakota (fig. 2). The Spearfish Formation in North Dakota occurs only in the subsurface, and consists of three members, in ascending order: the Belfield, the Pine Salt, and the Saude. The formation is present over half of the state, reaches a maximum thickness of 750 feet, and is equivalent to the Lower Watrous in Saskatchewan and the Lower Amaranth in Manitoba.

Only the uppermost member of the Spearfish Formation is present in the north-central portion of the state at a depth ranging from 2,900 to 3,400 feet. The Spearfish Formation onlaps the Madison unconformity surface in Bottineau County and into southern Manitoba where it is productive (fig. 3). This portion of the formation over the study area is a 125- to 220-foot-thick red bed sequence consisting primarily of quartzose sandstones that are occasionally cemented with anhydrite or having anhydrite nodules, siltstones, shales, shaly sandstones, and some thin anhydrite beds (figs. 4, and 5; Dow, 1967; LeFever and LeFever, 1991).

The sequence of shales, siltstones, and sandstones that comprise the Spearfish Formation were deposited in a subtidal to supratidal environment. The sandstones were probably derived from coastal dunes that were inundated by transgressive seas. The reworking and re-deposition of these sands produced a widespread sheet-like morphology. Periodic emergence resulted in evaporitic conditions and extensive oxidation. In addition, a series of subtidal channels cross cut the interval. These deposits are characterized by channel lags (recognizable on logs and highly cemented), trough cross-bedding, and by planar-bedded and current-rippled sandstones (the trough cross-bedded and planar-bedded facies are the reservoir facies at Russell, Starbuck and South Starbuck fields (LeFever and LeFever, 1991; Oglesby and Fischer, 1991).

Reservoir Properties

Most of the available reservoir data are from the two largest fields with Spearfish pools, Newburg and South Westhope. Additional data was obtained in the early 1980s with the development of Waskada and Pierson fields on the Manitoba side of the basin and Manor Field in Saskatchewan.

Newburg and South Westhope Fields

Production in Newburg and South Westhope is from both the Berentson beds of the underlying Charles and Spearfish Formations (figs. 5 and 6, Table 1). These fields produce from a stratigraphic trap that occurs on the updip limb of a syncline formed from the dissolution of salt in the underlying Prairie Formation (Devonian). The productive section of the Spearfish Formation is unlike the majority of the overlying section because it is unoxidized, represented by a pale gray-green color.

The Spearfish pool ranges in thickness from 10 to 40 feet within the fields. The effective pay may be significantly less depending

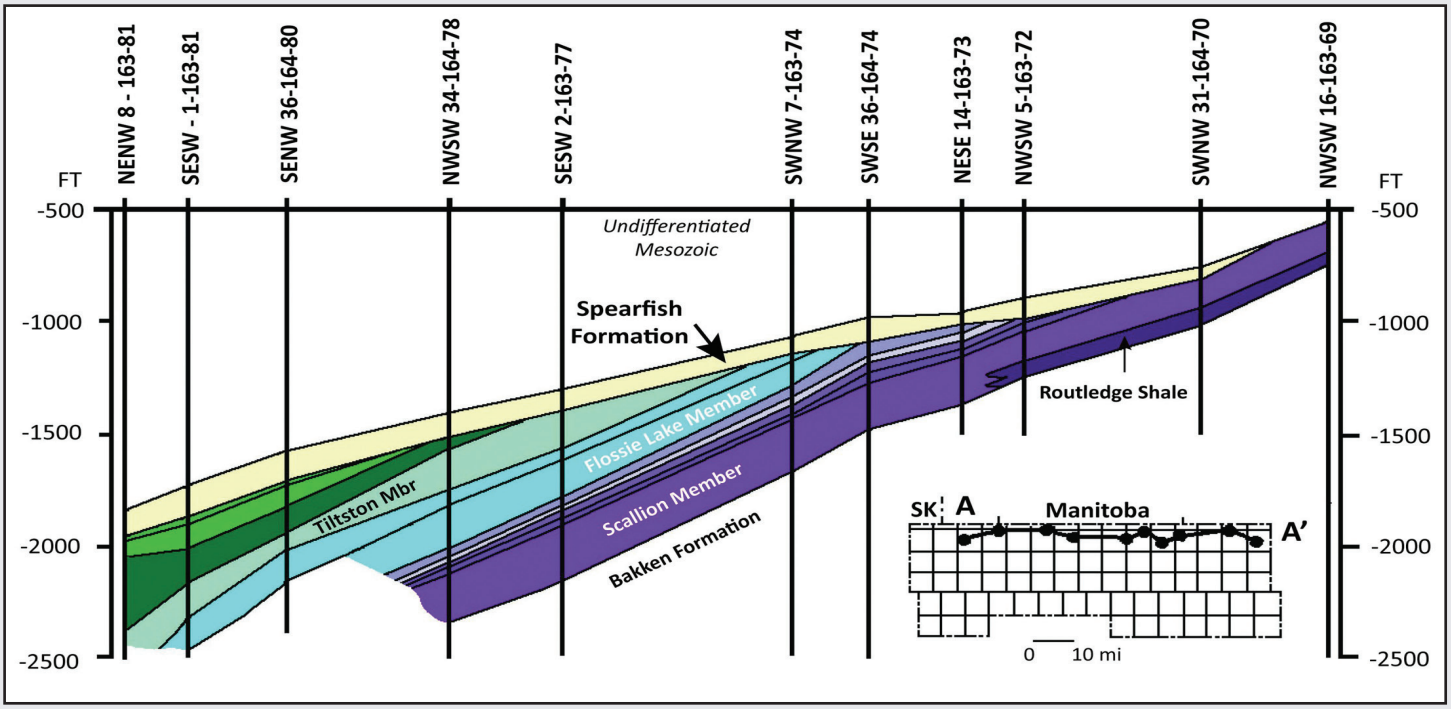

Figure 3. Schematic cross-section showing the onlap of the Spearfish Formation over the Madison unconformity surface in Bottineau County, North Dakota. The shades of green represent the various members within the Mission Canyon Formation. The shades of blue and purple represent members of the Lodgepole Formation (modified from LeFever and LeFever, 1991).

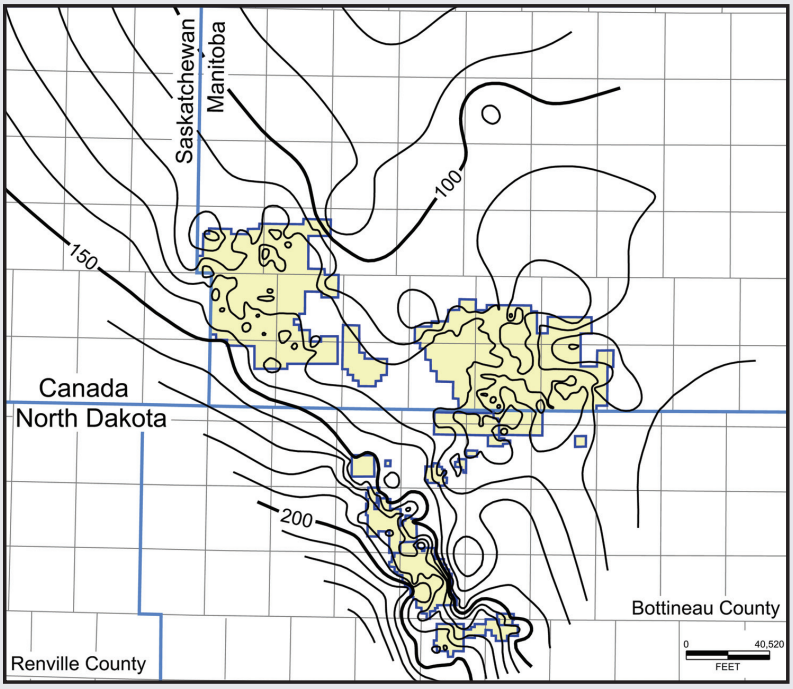

Figure 4. Isopach of the Spearfish Formation through Bottineau County and southern Manitoba. Oilfields represented in figure 1 are outlined in blue.

on the lithology. The reservoir has measured intergranular porosities of 12 to 15% with permeabilities ranging from <0.1 to 320 millidarcies (md). There is little effective vertical permeability. Water saturation can be as high as 50 to 60% and oil saturations range from 0 to 37% and vary on a well-to-well basis. The reservoir is undersaturated with gas-oil ratios of 100:1 or less. Production is aided by natural and secondary water drives.

Russell and Starbuck fields fall along the same trend as Newburg-South Westhope fields. The reservoirs for Russell and Starbuck show similar reservoir characteristics although they result from a slightly different depositional environment. Recovery efficiencies are very good for these two fields and appear to be a function of reservoir energy. Wells in the Russell Field have high recoveries with abundant water production related to the strong water drive. In contrast, South Starbuck has a lower volume, with nearly water-free production.

Waskada and Pierson Fields

The Lower Amaranth pools (Spearfish equivalent) in Waskada and Pierson fields are represented by red dolomitic siltstones and sandstones interbedded with argillaceous siltstones and shale (Barchyn, 1982). Barchyn (1982) noted that the dolomite is associated primarily with the finer grained silty material, whereas anhydrite cements the coarser sandy material and occurs as nodules and lenses.

Again, the trap is stratigraphic with the reservoir located in the coarser grained lithologies -- the siltstones and sandstones. Porosities average 14.5% with an average permeability of 14.8 md. Slightly higher values have been noted from the sandstones at Pierson Field (Husain, 1990). The fields were initially developed with vertical wells followed by secondary recovery through waterflooding. Horizontal drilling has successfully increased production and reserves.

Manor Field

Manor Field in southeastern Saskatchewan is different from the previously discussed fields, in that prior to horizontal drilling there was no commercial production from vertical wells. The vertical tests were used to delineate the field by identifying the distribution and reservoir quality of the sandstones. Production is from the basal sands of the Lower Watrous Formation (Spearfish Formation equivalent). The Lower Watrous is interpreted as a marginal marine to tidal flat environment with the reservoir in the interbedded to bioturbated sandstone and muddy siltstone facies, interpreted as subtidal shoal deposits. These beds onlap truncated Mississippian strata (Musial, 1995). An isopach map of the top of the Lower Watrous to the Mississippian unconformity is a good indicator of the presence of the basal reservoir sandstone. The sand is deposited in areas of low Mississippian relief.

Porosity, permeability and pay thickness are similar to Newburg/South Westhope and Waskada/Pierson. Porosity values range from 15 to 24%, averaging 19%. Permeabilities average 10 md with an average net pay of 16 feet. The reservoir at Manor is also undersaturated, with a gas-oil ratio of 292.

Current Activity

As previously stated, the current activity began in southwestern Manitoba with EOG Resources. Applying the drilling advancement acquired in Mountrail County with the Bakken Formation, the company has been horizontally drilling and fracture stimulating the Lower Amaranth successfully (table 1). Reserves for the Manitoba portion of the play are estimated to be 25 million barrels.

In April 2010, EOG Resources, Inc. announced that it was extending the play from southwestern Manitoba into North Dakota. Two wells have been completed in the Souris Field to date, as part of its Waskada South prospect. Wells currently require four days to drill and complete at a cost of approximately $1 million. Reserves for the North Dakota portion of the play have been placed at 20 million barrels.

	Southwestern Manitoba	North-Central North Dakota
Formation Depth (ft); TVD	2,935	3,000 ft
Thickness (ft)	78	50
Average porosity	14.5%	14%
API Oil Gravity	35°	36°
Initial Production	208-337 Bopd	285-305 Bopd
Oil-in-Place per Section	9-15 MMbo	13 MMbo

Table 1. A comparison of the reservoir characteristics of the current Spearfish play (modified from Papa, 2010; Redekop, 2010; NDIC Case #12076). TVD = true vertical depth, Bopd = barrels of oil per day, MMbo = millions of barrels.

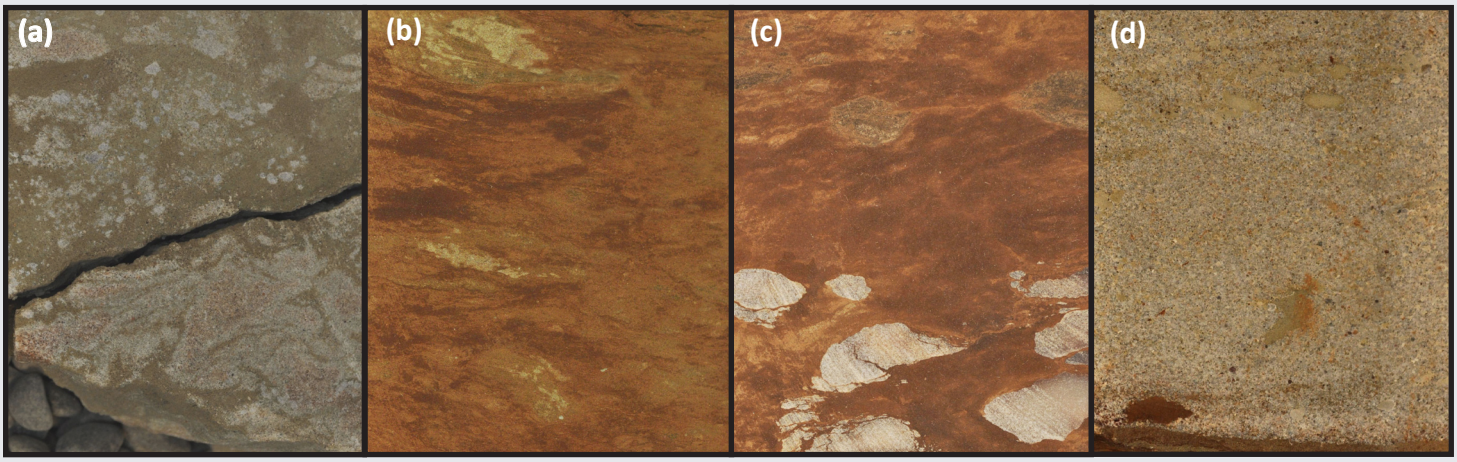

Figure 5. Representative core photographs of the Spearfish Formation from producing wells in Bottineau County - **(a)** Newburg Field Spearfish pay sandstone at a depth of 3,357 feet (Amerada Hess Corp.-Newburg-Spearfish-Charles Unit P-713, NE¼ NE¼, Sec. 16, T161N, R79W, 33-009-01390-0000) (width in photograph represents 3.25 inches of core); **(b)** Typical Spearfish Formation shale bed at a depth of 2,977 feet (Norcen Energy Inc.-Lindstrom 34-1, NW¼ NE¼, Sec. 34, T164N, R78W, 33-009-01599-0000) (width is 4 inches); **(c)** Spearfish Formation shale with anhydrite nodules at a depth of 2,987 feet (Norcen Energy Inc.-Lindstrom 34-1, NW¼ NE¼, Sec. 34, T164N, R78W, 33-009-01599-0000) (width is 4 inches); **(d)** Spearfish Formation sandstone bed with rip-up clasts at a depth of 3,020.5 feet (Norcen Energy Inc.-Lindstrom 34-1, NW¼ NE¼, Sec. 34, T164N, R78W, 33-009-01599-0000) (width is 3 inches).

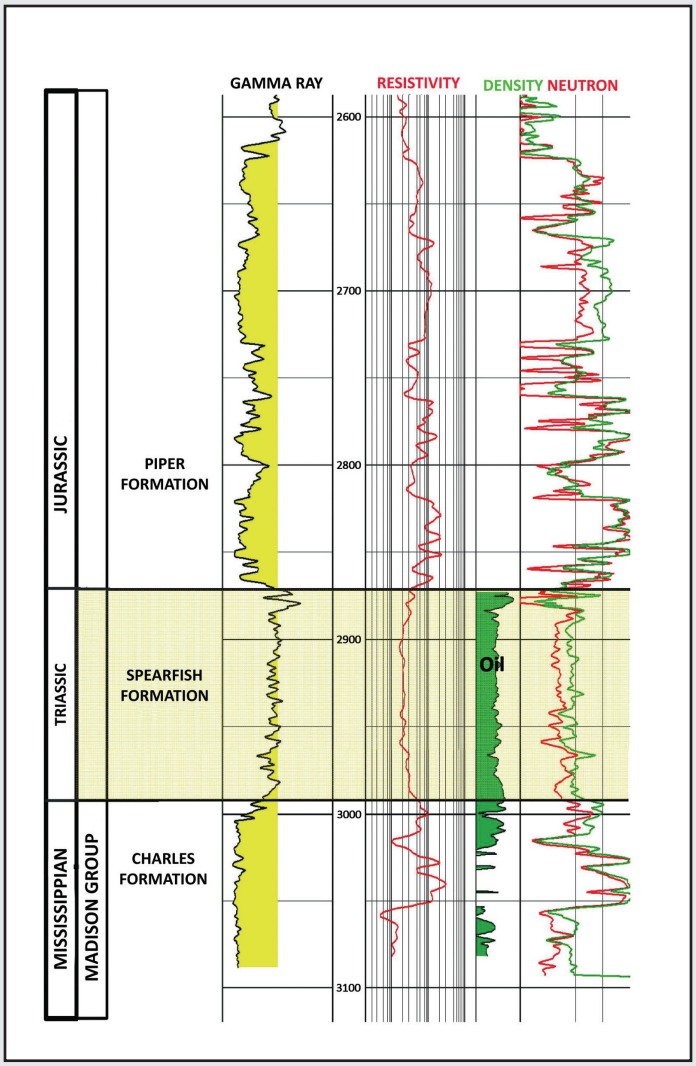

Figure 6. Typical log from the current play in the Spearfish Formation (modified from Papa, 2010).

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