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Assessment of Undiscovered Technically Recoverable Oil and Gas Resources of the Bakken Formation, Williston Basin, Montana and North Dakota, 2008

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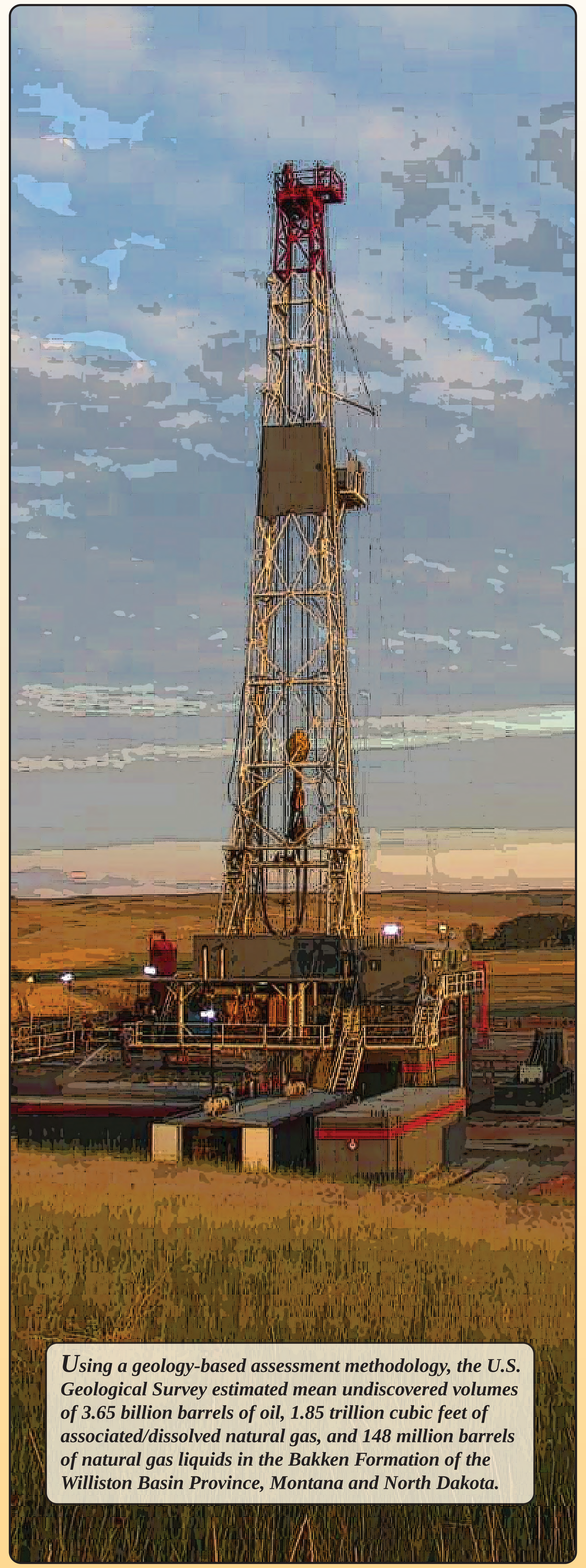
2008



Using a geology-based assessment methodology, the U.S. Geological Survey estimated mean undiscovered volumes of 3.65 billion barrels of oil, 1.85 trillion cubic feet of associated/dissolved natural gas, and 148 million barrels of natural gas liquids in the Bakken Formation of the Williston Basin Province, Montana and North Dakota.

Introduction

The U.S. Geological Survey (USGS) has completed an assessment of the undiscovered oil and associated gas resources of the Upper Devonian to Lower Mississippian Bakken Formation in the U.S. portion of the Williston Basin of Montana and North Dakota and within the Williston Basin Province (Pollastro and others, 2008). The assessment is based on geologic elements of a total petroleum system (TPS), which include (1) source-rock distribution, thickness, organic richness, maturation, petroleum generation, and migration; (2) reservoir-rock type (conventional or continuous), distribution, and quality; and (3) character of traps and time of formation with respect to petroleum generation and migration. Framework studies in stratigraphy and structural geology and modeling of petroleum geochemistry, combined with historical exploration and production analyses, were used to estimate the undiscovered, technically recoverable oil resource of the Bakken Formation. Using this framework, the USGS defined a Bakken-Lodgepole TPS and seven assessment units (AU) within the system. For the Bakken Formation, the undiscovered oil and associated gas resources were quantitatively estimated for six of these AUs.

The general approach to assessing the Bakken Formation was as follows:

1. Define the total petroleum system(s) and each of the elements (source, reservoirs, traps, seals, pod(s) of active source rock, migration, areas of undiscovered resource).
2. Are accumulations conventional or continuous?
3. Define the geologic factors that might control differences in drainage area (cell size) and well production from estimated ultimate recovery (EUR) for continuous accumulations.
4. Define geologic assessment units (AU) – the resource plays.
5. Input for required elements on the assessment form must reflect the geology (or geologic factors) and statistical distribution of production characteristics for the AU, such as cell size, EUR, "sweet spot" area, and success ratio.

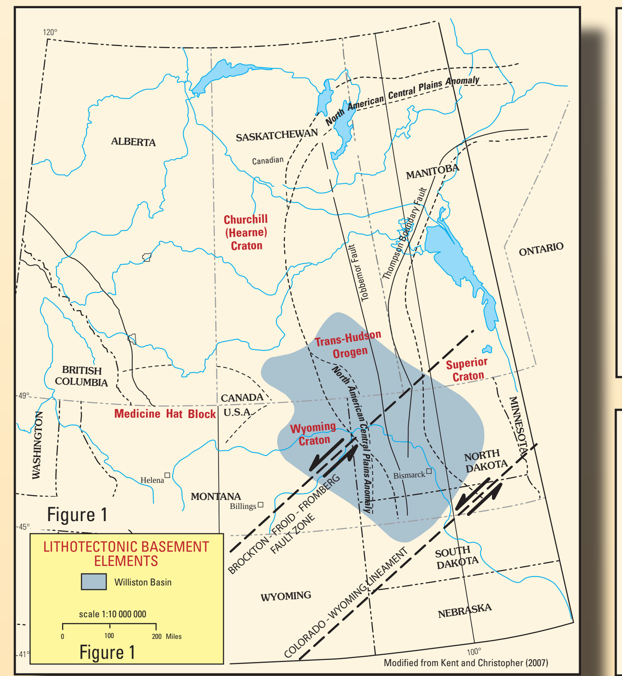


Figure 1

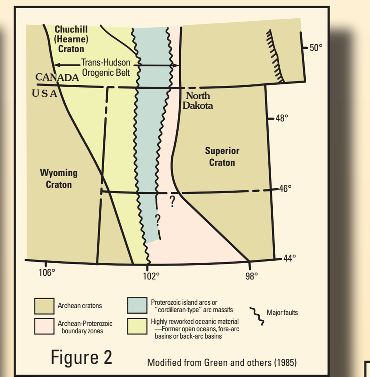


Figure 2

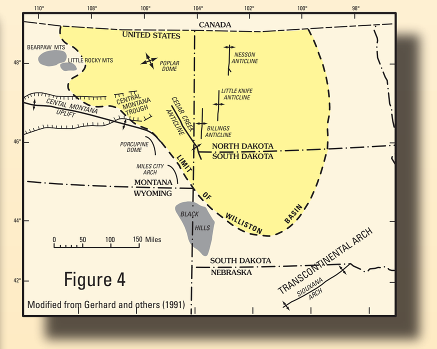


Figure 4

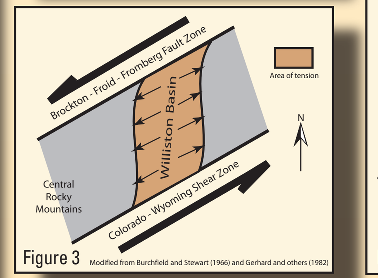


Figure 3

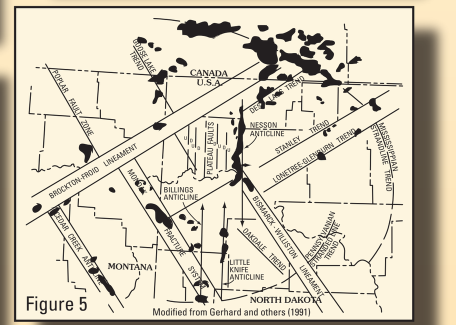


Figure 5

Basin Setting and Evolution, and Tectonic Elements

The Williston Basin is an intracratonic depression that developed on the North American craton during the Ordovician. The basin occupies approximately 300,000 square miles over portions of North Dakota, South Dakota, Montana, and adjacent Canadian provinces of Manitoba and Saskatchewan (fig. 1). Three Archean provinces underlie the Williston Basin: (1) the Superior province in the east; (2) the Wyoming and Churchill (Hearne) provinces in the west; and (3) an intervening Paleoproterozoic continent-to-continent collision suture zone known as the Trans-Hudson Orogenic belt which lies between the east and west cratonic provinces (fig. 2). The nature of this underlying accretion zone and subsequent movement controlled most of the north-south orientation of the prominent structural features within the Williston Basin (Green and others, 1985).

The Williston Basin developed initially during Ordovician subsidence about 495 Ma, with subsequent episodic subsidence to the present day. The interaction of two Archean shear systems, the Brockton-Froid-Fromberg and Colorado-Wyoming shear zones (fig. 3), is believed responsible for the formation of the Williston Basin by creating a depressed block between these systems and initiating sedimentation during the Late Ordovician (Gerhard and Anderson, 1988). Structural control, sedimentation, and major faults, lineaments, and fractures indicate that they are related to regional wrench-fault tectonics coupled with large-scale tears from these two major shear systems (fig. 4) (Thomas, 1974). This structural style partly explains oil production from the Bakken Formation reservoirs and the general distribution of hydrocarbons in the Williston Basin (fig. 5).

Williston Basin Stratigraphy, Total Petroleum Systems, and Hydrocarbon Production

Approximately 16,000 ft of sedimentary rocks of Cambrian through Tertiary age were deposited in the Williston basin. The structural simplicity of the basin is reflected by thinning of most sedimentary units from basin center to basin edge. Although the stratigraphic rock record of the Williston Basin is relatively complete, episodic erosional events occurred throughout the basin's history (fig. 6).

Sedimentary strata of the Williston Basin records several cycles of marine transgression and regression that caused alternating cycles of basin filling and basin draining with repeated deposition of carbonates and clastics. Paleozoic rocks are dominated by carbonates, whereas Mesozoic and Cenozoic strata consist mainly of clastic rocks. In preparation for an assessment of oil and gas resources of the Williston Basin Province, the USGS identified ten total petroleum systems (TPS). The stratigraphic distribution of the ten total petroleum systems is shown in figure 6.

Similar to most petroleum basins and provinces, the production of hydrocarbons in the Williston Basin is strongly controlled and distributed along structures (fig. 7). Most of the hydrocarbons are produced from Paleozoic rocks, although some Mesozoic strata are also productive. Since the initial discovery, the Madison Group (Mississippian) has produced the most oil, but significant volumes are also in the Red River (Ordovician) and Duperow (Devonian) Formations. Sandstones of the Spearfish Formation (Triassic) produce oil in north-central North Dakota and the Eagle Sandstone and Judith Formation (Cretaceous) produce natural gas in southwestern North Dakota.

Several cycles of exploration and development have occurred in the Devonian-to-Mississippian Bakken Formation since its first discovery at Antelope in 1953. Renewed interest due to new discoveries, improved horizontal drilling practices, increased oil price, and giant resource potential have made the Bakken Formation continuous (unconventional) accumulation a major exploration target.

Williston Basin Stratigraphic Correlation Chart and USGS Total Petroleum Systems

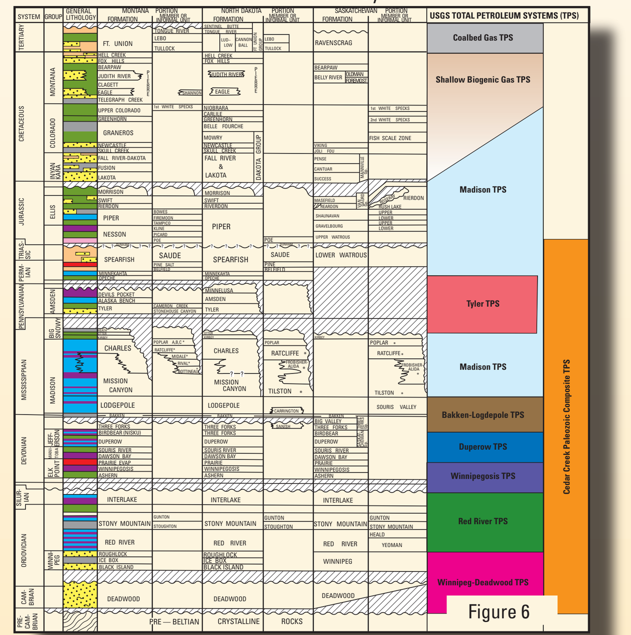


Figure 6

Oil (Green) and Gas (Red) Production and Dry Holes (Black), Williston Basin (Data from IHS Energy, 2007)

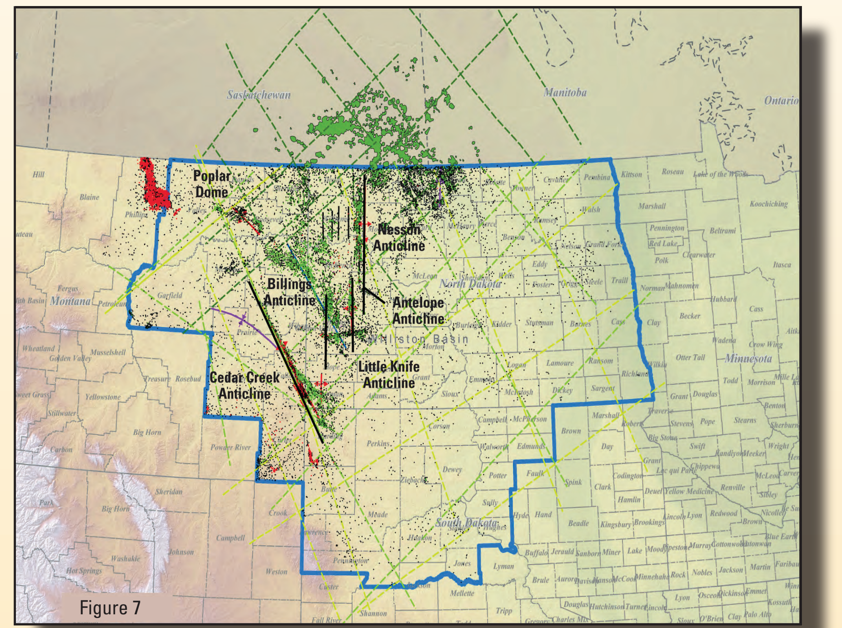


Figure 7

Bakken Formation and Bakken Composite Continuous Reservoir

Major uplift along the Transcontinental Arch and tilting of the Williston Basin northward during the Devonian changed the major marine communication from the Cordilleran shelf (Central Rockies depression/Montana trough) to a new access route via the Elk Point Basin of western Canada (fig. 8). This shift to the Elk Point Basin favored more restricted conditions for deposition of the organic-rich shales of the Bakken, and also explains the connection, geographic extent, and lithologic and stratigraphic affinity of the Bakken Formation with Canadian Devonian rocks rather than with Devonian rocks of the Cordilleran shelf. The Upper Devonian to Lower Mississippian Bakken Formation is a thin, but widespread unit within the central and deeper portions of the Williston basin in Montana, North Dakota, and the Canadian Provinces of Saskatchewan and Manitoba (fig. 9).

The Bakken Formation consists of three informal members: (1) lower shale member, (2) middle sandstone member, and (3) upper shale member. Both the upper and lower shale members are organic-rich marine shale of fairly consistent lithology. These shales are the petroleum source rocks and part of the "Bakken composite continuous reservoir" (fig. 10) for oils produced from the formation. The middle sandstone member varies in thickness, lithology, and petrophysical properties throughout the Williston Basin. This unit is a major contributor to the Bakken composite continuous oil reservoir, and is also a proven conventional reservoir in Canada. Additional production from, and which is also included in the Bakken composite continuous reservoir, is the informal "Sanish sand" unit of the uppermost Devonian Three Forks Formation (fig. 10) that immediately underlies the Bakken Formation (fig. 11). Thus, estimates of undiscovered technically recoverable resources in the Sanish sand is considered in the Bakken Formation assessment.

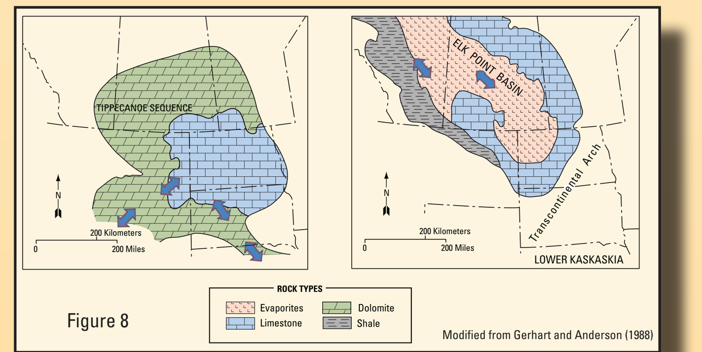


Figure 8

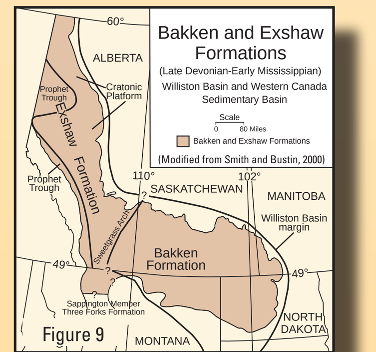


Figure 9

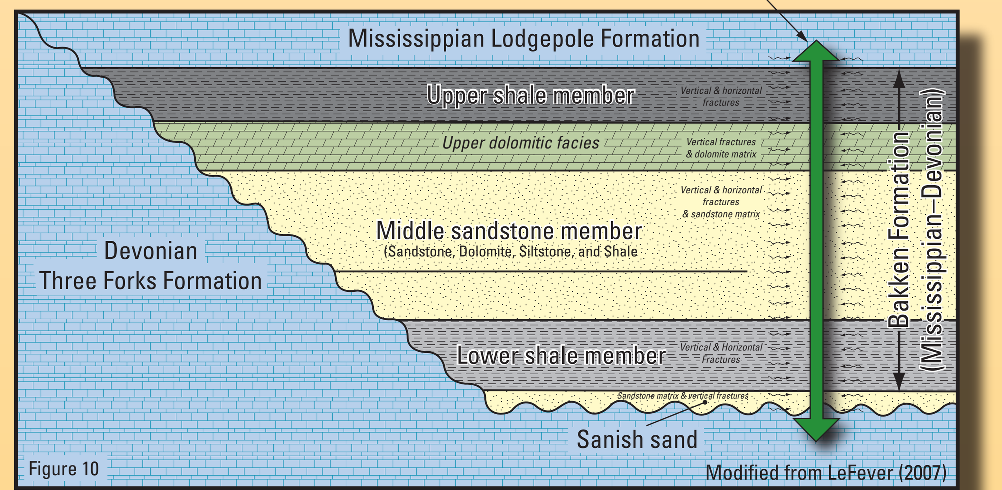


Figure 10 Modified from LeFever (2007)

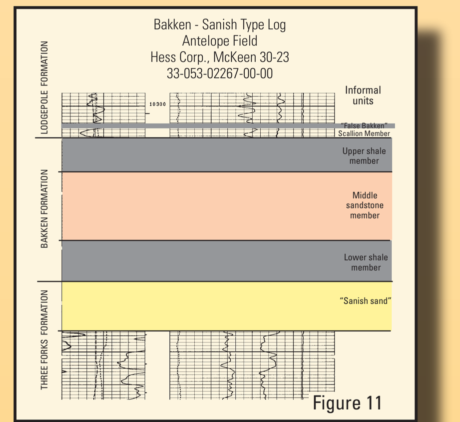
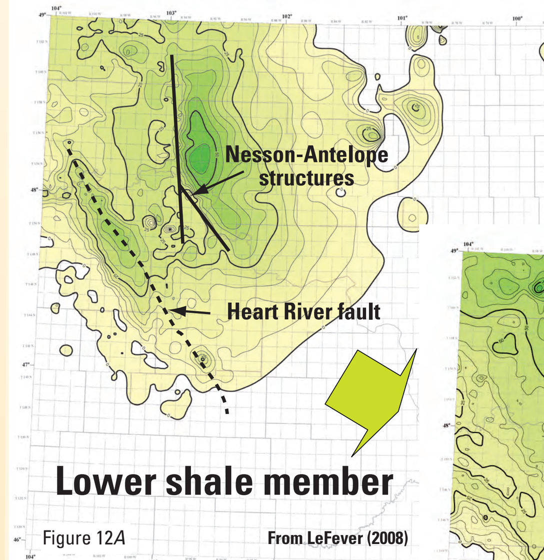


Figure 11

Bakken Deposition and Bakken-Lodgepole TPS

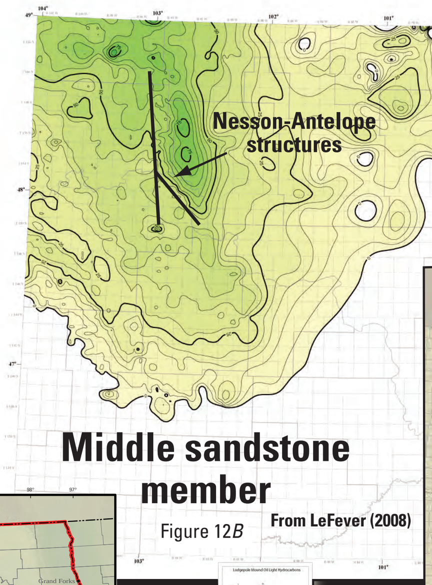
Each overlying younger member of the Bakken Formation is of greater geographic extent than the directly underlying older member. Isopach mapping of members of the Bakken Formation by LeFever (2008) shows that the Nesson-Antelope structures (fig. 7) were active, as was the Heart River fault, during deposition of both the middle sandstone member and the lower shale member (figs. 12*A*, 12*B*). Although the upper and lower shale members are somewhat uniform in lithology, the depositional environments, lithology, and subsequent diagenesis of the middle sandstone member are diverse (fig. 12*C*). Oil-filled matrix porosity from sandstone and dolomite facies in the middle sandstone member is important to successful Bakken production. Matrix porosity of the middle sandstone member is particularly well developed (5-14 percent) along the Nesson-Antelope structures, Elm Coulee field, and Parshall and Sanish fields (fig. 12*C*).

A Bakken-Lodgepole TPS was defined where oils generated from upper and lower organic-rich shales of the Bakken Formation have accumulated primarily in the Bakken composite continuous reservoir and in Waulsortian mounds of the Lodgepole Formation immediately overlying anomalously thick sections of the upper shale member due to dissolution of the underlying Devonian Prairie Salt (figs. 6, 13*A*, 13*B*, 13*C*). The Bakken-Lodgepole TPS is defined by the eastern limit of the upper shale member (as defined by LeFever, 2008) and the extension of the 12-mile-wide buffer zone (figs. 13*A*, 14) defined by Burke and Diele (1993).



Lower shale member

Figure 12*A* From LeFever (2008)



Middle sandstone member

Figure 12*B* From LeFever (2008)

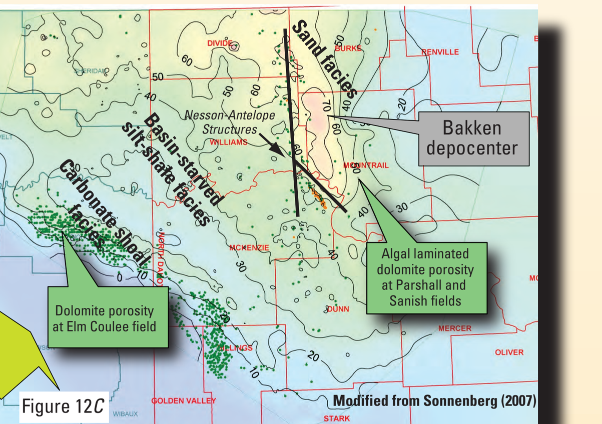


Figure 12*C* Modified from Sonnenberg (2007)

Middle Sandstone Member

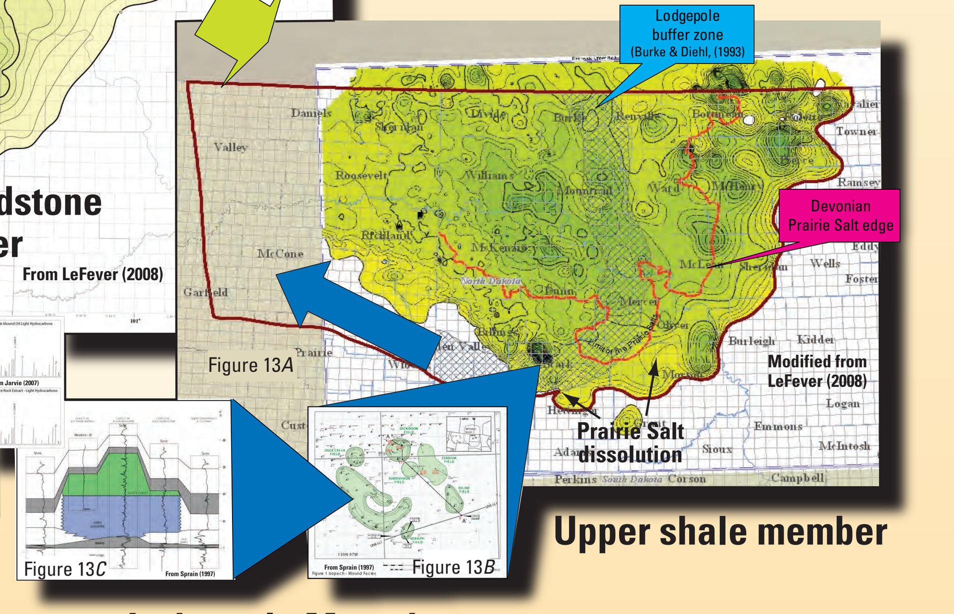


Figure 13*A* Modified from LeFever (2008)

Figure 13*C*

Figure 13*B*

Upper shale member

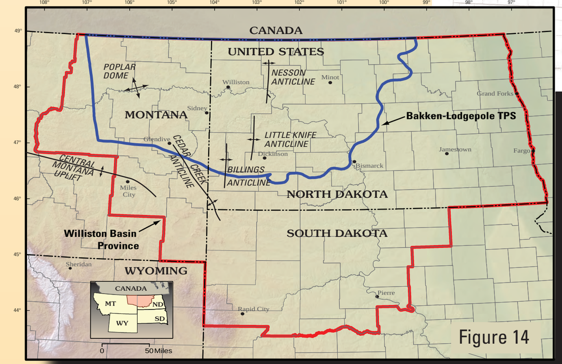


Figure 14

Bakken-Lodgepole TPS

Lodgepole Mounds

Bakken Composite Continuous Accumulation and Oil Generation

A primary requirement for a continuous shale (or chalk) source-rock accumulation is that the shale is now, or was at sometime in its burial history, within the thermal oil or gas generation window (fig. 15). Excellent examples of such continuous shale-oil and shale-gas source rock accumulations are the Bakken Formation and the Mississippian Barnett Shale in north-central Texas, respectively. Thus, these hydrocarbon-generation "windows" must be defined stratigraphically and geographically before continuous resource plays can be identified and assessed. Although mean vitrinite reflectance (R_o) is a routine and useful measure and indicator of thermal maturity in humic (Type III organic matter) source rocks, it has been well established that its utility in source rocks containing primarily marine organic matter (Type 1 and Type II organic matter) is questionable as measurements of R_o are commonly suppressed (figs. 16, 17, 18).

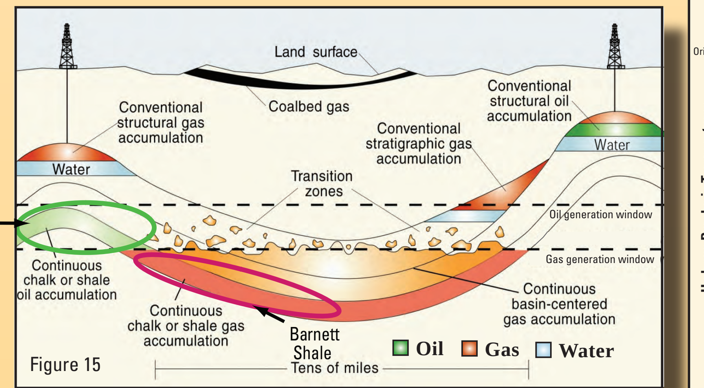


Figure 15

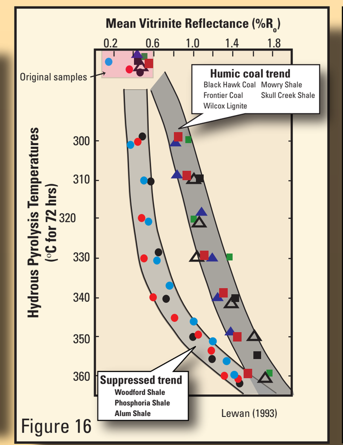


Figure 16

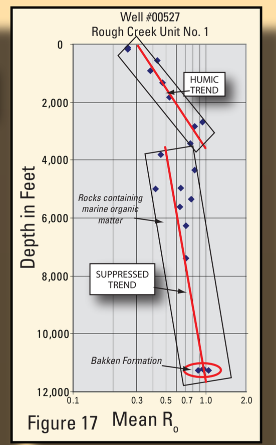


Figure 17 Mean R_o

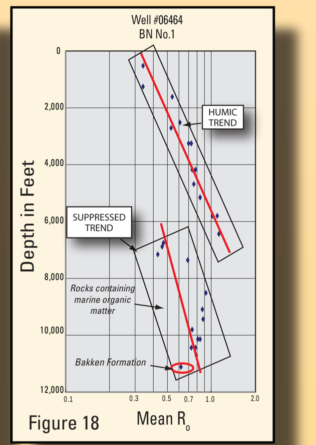


Figure 18 Mean R_o

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