The Winnipeg Sandstone is present throughout most of the Williston basin and extends into the Kennedy basin. At its featheredge (zero isopach), it is overlapped by the Winnipeg shale. The sand appears to have originally extended farther because isolated remnants occur in a few wells on the Pierre arch. An erosional episode is believed to have removed the sand from areas east of its present regional limit except in a few downwarped or downfaulted areas. This episode was followed by a rapid advance of the Middle Ordovician sea, during which no sand was deposited. The Winnipeg shale was deposited immediately after this transgression. The overlap creates a regional seal over the Winnipeg Sandstone reservoir.

The Winnipeg shale is a mature petroleum source bed in the northern part of the Williston basin. Maturation and migration probably occurred by Permian time when the Winnipeg was buried beneath about 6,000 ft (1,800 m) of younger beds. Although some of the petroleum migrated upward into the Red River Formation, the underlying Winnipeg Sandstone was an ideal conduit for lateral migration. Documented Winnipeg shows indicate that oil migrated at least as far as Mellette County, South Dakota. One of the shows appears to be a "fossil oil field," indicating that entrapment and accumulation did occur. Isopachs of the Minnelusa to Winnipeg interval indicate preferential directions of lateral migration. Live oil shows suggest the possibility of commercial accumulations.

The Winnipeg Sandstone is thick, porous, and permeable. Depending on local conditions, a Winnipeg oil well might yield up to 500,000 bbl or more. Anticlines located basinward from the regional pinch-out of the Winnipeg Sandstone are the most logical exploration targets. Subsurface mapping and interpretation of aerial photographs and Landsat images suggest several large structures capable of containing major oil fields.

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Mid-Tertiary Conglomerate Deposition and Structural Implications, Southwestern Wind River Range, Wyoming

Study of a granule-to-boulder conglomerate of probable middle to late Eocene age provides evidence that the last pulse of uplift of the Wind River Range occurred along a fault or fault zone within the crystalline core of the range. The conglomerate is preserved on the northeast side of the Continental fault between Tabernacle Butte on the west and Horsetrack anticline on the east. It overlies rocks of the Bridger Formation (Eocene), locally overlies Precambrian crystalline rocks, and appears to be overlain by lower Miocene strata.

The conglomerate consists of numerous coarse pebbles, cobbles, and boulders floating in a matrix ranging from coarse sand to granules. Many of the nonequidimensional pebbles and cobbles are imbricated and isolated, suggesting current scour on the upstream side of the pebbles, and are oriented with their long axes between transverse and longitudinal positions, indicating later reworking of orientations developed during initial high velocity flows. Thus, fabric indicates deposition in a fluvial system having highly variable current velocities.

Distributary paleocurrent patterns, proximity to a major uplift, and the presence of large boulders suggest deposition on alluvial fans. These alluvial fans were characterized by deposition of moderately to poorly sorted coarse sand to boulder-size material in a braided stream environment. Although the conglomerate is matrix supported, deposition by fluvial processes is indicated by well-defined stratification, lenticularity of bedding, common scour surfaces, local cross-stratification, channel fills ranging up to 31 m (102 ft) wide, and fabric as noted above. Evidence of mass flows is very rare in this unit.

Composition of pebbles and cobbles in the conglomerate is quite variable, indicating both the complex Precambrian geology and the erosion of Precambrian units within the core of the range as well as those exposed locally. The large amount of finer sediments (sand and granules) in the conglomerate at exposures near the Precambrian paleohighs suggests, at least in part, a distal source. Mapping of other Eocene sedimentary deposits in the Big Sandy Opening area suggests the presence of fluvial tributaries well within the crystalline core of the range. These characteristics suggest a middle or late Eocene pulse of uplift within the core of the range resulting in incision of tributary systems into the Precambrian rocks of the southwestern margin of the Wind River Range. A decrease in stream gradient at the southwestern limit of the uplifted crystalline rocks resulted in deposition of much of this core-derived sediment on basin-margin alluvial fans. This system was probably morphologically similar to but smaller in scale than, the modern Kosi fan system of northeastern India.

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Facies, Fabrics, and Porosity of Selected Pre-Permian Rocks in Williston Basin, North Dakota

Cores of pre-Permian rocks presented include most major carbonate depositional facies, fabrics, and porosity types, as well as a terrigenous-clastic delta and barrier island complex. Stratigraphic units discussed span the Tippecanoe to Absaroka sequences. Formations and intervals included are the Tyler, Mission Canyon, Ratcliffe, Frobisher-Alida, Bakken, "Sanish," Birdbear, Duperow, Winnipegosis, Ashern, and Interlake. All of these units, except the Ashern Formation, have produced substantial amounts of hydrocarbons, and cores show different facies, fabrics, and porosity types associated with them.

Facies and fabrics vary considerably both interformationally and intraformationally throughout the presented pre-Permian sequences. Depositional facies represented in the rocks include subtidal, intertidal and supratidal deposits from both the marine and transitional marine (deltaic and barrier island) depositional environments. The most common carbonate lithofacies are mudstones, wackestones, and packstones, although boundstones and grainstones are also present. The most common terrigenous clastic lithofacies are shales, silty mudstones, and both mature and immature sandstones. Notable facies include evaporites (both shallow and deep water), stromatoporoids, ostracodal limestones, and thin coal beds. Significant sedimentary structures include burrows, flat pebble intraclasts, desiccation cracks, birdseye structures, cone-in-cone structures, compaction slickensides, and collapse breccias.

Porosity types common to all, except the Ashern, Bakken, and Tyler, are intercrystal, interparticle, moldic, vuggy, and breccia. Significant porosity in the Sanish, Ashern, and Bakken formations is from fractures, whereas in the Tyler, interparticle porosity dominates.

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Geothermal Development and Problems in South Dakota

Geothermal applications in South Dakota have been ongoing on a small scale since the early 1950s with a few additions in the 1960s. The real surge developed as a result of the oil embargo in 1973 and the efforts of ERDA and DOE. South Dakota started its first study in 1975.

Application of hot water has focused primarily on the Madison Limestone as the main source of water due to wells already in the aquifer and some history from oil tests. Three feasibility studies and four demonstration projects have been funded by the federal government and one by the state government. In addition, three privately funded projects have begun. All but one project are for space heating of buildings, primarily state and municipal. The other project is for grain drying.

To date, corrosion is the largest single problem, followed closely by scaling, and disposal of the spent fluid. Because of the quality of most of the waters tested to date, the disposal has been limited primarily to dumping into reservoirs from which it is used for irrigation or other conventional uses.

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Eocene Paleotectonics and Sedimentation in the Rocky Mountain-Colorado Plateau Region

The Laramide orogeny (c. 80 to 40 m.y.B.P.), which culminated during early Eocene time, resulted in the development of numerous uplifts and basins in the foreland of the western United States. Uplifts are assignable to three general classes: (1) Cordilleran thrust belt uplifts, (2) basement-cored, fault-bounded uplifts of the classic Laramide Rocky Mountains, and (3) monocline-bounded uplifts of the Colorado Plateau. Basins were also of three types: (1) Green River type—large equidimensional to elliptical basins bounded on three or more sides by uplifts and commonly containing lake deposits, (2) Denver type—asymmetrical, synclinal downwarps with a related uplift along one side, and (3) Echo Park type—narrow, highly elongate basins with through drainage and of strike-slip origin. Green River-type basins exhibit quasiconcentric zonation of facies, in contrast to the unidirectional, proximal-to-distal facies tract of Denver-type basins. Facies distribution in Echo Park-type basins is complex and often difficult to reconstruct due to faulting, erosional truncation, and cover.

The prevalence of en echelon structures in the deformed zone east of the Colorado Plateau, and evidence for significant crustal shortening north of the plateau, suggest that the major structural features of the Laramide foreland were produced by large-scale, north-northeastward translation of the relatively rigid Colorado Plateau block. The magnitude of this motion, as indicated by dextral offset of lineaments which cross the eastern margin of the plateau and by the amount of crustal shortening in the Wyoming province, may be as great as 65 to 120 km (40 to 75 mi). This translation probably resulted from the interaction of relatively competent Colorado Plateau lithosphere with the underlying, gently dipping Farallon plate, which was being overridden by the western United States in Laramide time.

Evidence for increased strain rates in early Eocene time includes: (1) markedly higher rates of deposition and sand/shale ratios in the Gulf Coast geosyncline (Wilcox Group), (2) formation of several new basins in the southern Rocky Mountains in which Eocene deposits rest unconformably on pre-Cenozoic rocks, and (3) the generally coarser and more arkosic nature of Eocene sediments, as compared to older Laramide deposits, in many areas throughout the foreland. The early Eocene culmination of Laramide tectonism appears to result from two factors. First, the subducted Farallon plate achieved its shallowest dip at about 55 m.y.B.P., resulting in increased viscous coupling with the overriding continental lithosphere. Second, changing spreading-center geometries in the Labrador Sea, Norwegian Sea, and Arctic Ocean caused the maximum horizontal stress direction to shift to a northeasterly orientation, causing the Colorado Plateau block to increasingly decouple from the craton along north-trending wrench faults in the southern Rocky Mountains. Translation of the Colorado Plateau to the north-northeast during Laramide time resulted in a series of transpressive uplifts and basins along its eastern margin and large-scale crustal shortening in the Wyoming province to the north.

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Relation of Lithofacies and Diagenesis to Porosity Development, Mississippian Mission Canyon Formation, Eastern Montana and Western North Dakota

The ability to map lithofacies trends suitable for hydrocarbon reservoirs is critical for a successful exploration program. In exploring basins with carbonate reservoirs, diagenetic alterations must also be understood in relation to porosity development. The Mississippian Mission Canyon formation of the Williston basin provides an excellent example of the need to understand the lithofacies/diagenesis relation.

During the Mississippian the Williston basin was the site of subtidal to supratidal carbonate deposition. In general, depositional environments became more restricted from Montana eastward into North Dakota. Subsurface mapping suggests a strong relationship between the degree of marine restriction and diagenesis and porosity development in carbonate sediments. Two fields that produce from the Mission Canyon interval illustrate this relationship.

MonDak field, situated on the Montana-North Dakota border, lies west of the limit of massive Mission Canyon anhydrite in a sequence of normal marine sediments. Reservoir porosity is due to fracturing of tight, fine-grained limestones. Low matrix porosity and sparse, erratic fracturing are responsible for low daily production rates.

The Billings Nose-Little Knife trend (Billings, Dunn, and McKenzie Counties, North Dakota) is well within the limit of massive anhydrite. Reservoir porosity consists of a thick sequence of intertidal-supratidal sucrosic dolomites which are sealed by 20 to 25 m (65 to 82 ft) of massive anhydrite. Reflux of magnesium-rich brines is believed to be the process leading to dolomitization.

Good matrix porosity and permeability allow for higher daily production rates. Regional mapping indicates that the presence or absence of anhydrite correlates directly with the development of good matrix porosity.

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Cedar Creek—A Significant Paleotectonic Feature of Williston Basin

Cedar Creek is the major anticlinal structure demarcating the southwest flank of the Williston basin. This pronounced fold developed through a geologic history of recurrent tectonic movements along a northwest-southeast striking fault zone. The four major periods of tectonism documentable in the Cedar Creek area from early Paleozoic through mid-Tertiary affected the local and regional distribution, erosion, and/or preservation, and, though moderately, the depositional facies of sedimentary strata since Ordovician time.

Post-Silurian-Pre-Middle-Devonian.—Uplift and fault movement accompanied north and east tilting of the main Cedar Creek block. Several hundreds of feet of Silurian strata were eroded prior to Middle Devonian time, and a karst plain developed on the Silurian surface. Middle and Upper Devonian sediments progressively onlapped and infilled the uplifted, northwest plunging element.

Late Devonian-Pre-Mississippian.—During latest Upper Devonian—possibly earliest Mississippian—pronounced fault movement occurred along the major fault zone. The Cedar Creek block was uplifted and tilted north and east; maximum displacement along the zone appears to have occurred in the vicinity of the Pine-Gas City-Glendive oil fields. Extensive erosion resulted in the near peneplanation of the structure and significant truncation of Upper Devonian strata. Continued paleostructural influence during Mississippian time is indicated by the distribution and facies of early and middle Mississippian rocks.

Late Mississippian (Chester) through Triassic.—In late Mississippian (Chester) and early Pennsylvanian time, the central and northern portion of the Cedar Creek area underwent gentle downwarping, and periods of subsidence occurred with relative down-to-the-east fault movement along parts of the ancestral master and subsidiary faults. Similar fault movement(s) and subsidence which continued to occur during the Permian and Triassic periods significantly influenced the deposition and preservation of these evaporite rich, red-bed sequences. Relative tectonic stability was attained by the Middle Jurassic and essentially maintained until post-Paleocene time.

Post-Paleocene.—The Cedar Creek block underwent its greatest magnitude of uplift during the post-Paleocene; younger Tertiary beds are not present in the area. This uplifting was accompanied by major flexuring, the extensive linear belt of asymmetric drape-folding generally aligned with the ancestral fault zones, and deep fault adjustment. Northwest plunge along the crestal portion was significantly increased. The entire area was subsequently uplifted during epeirogenic phases of the mid-Tertiary in the northern Rocky Mountain region and about 1,500 ft (460 m) of Paleocene and Upper Cretaceous strata eroded along the axis of the present structure.

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Depositional Environment and Diagenesis of Teapot Sandstone (Upper Cretaceous), Converse and Natrona Counties, Wyoming

The Teapot Sandstone forms the upper member of the Upper Cretaceous Mesa Verde Formation in the Powder River basin. Previous interpretations of the Teapot based on outcrop or subsurface data range from nearshore marine to fluvial. Integration of outcrop data with subsurface data from cores provides a more complete interpretation of depositional