As the cumulative production of oil from the Big Horn basin approaches the 2 billion bbl mark, it is appropriate that we look at the geology once again.

The Big Horn basin, located in northwestern Wyoming and south-central Montana, is bordered on the east by the Big Horn Mountains; on the south by the Owl Creek Mountains; on the west by the Absaroka and Beartooth Mountains; and on the north by the Nye-Bowler lineament. The combination of a great reservoir-source duet in the Paleozoic rocks and the creation of large anticlines during the Laramide orogeny has been the key to the Big Horn basin's success as an oil producer.

Stratigraphy of the Big Horn basin can be divided generally into (1) the Middle Cambrian clastics, (2) the Paleozoic shelf carbonates, (3) the Mesozoic clastics, (4) the Late Cretaceous to Tertiary synorogenic clastics, and (5) the Tertiary post-orogenic clastics and volcanics.

By far the most economically important formations have been the Permian Phosphoria and Pennsylvanian Tensleep Formations. This dynamic duo consists of porous eolian and shallow marine, quartz sandstones of the Tensleep overlain by shallow marine, oil-rich carbonates of the Phosphoria. The two have combined to produce over 1.5 billion bbl of oil in the Big Horn basin alone.

The draping of the Tensleep and Phosphoria over large Laramide structures (closures of over 5,000+ ft, 1,500 m, and areal extents up to 15 mi^2, 40 km^2) was the final key. An upcoming afternoon session of papers will explore the proposed anatomies and mechanisms of folding in the Cordilleran foreland.

There is a controversy over the morphology of the folds in the foreland. Put simply, there is some disagreement over how much the horizontal or thrusting component contributes to these folds. Stearns, who described the fold at Rattlesnake Mountain in the 1971 Wyoming Geological Association guidebook, favors drape folding over near-vertical faults in the Precambrian. Berg in the 1962 AAPG *Bulletin* and Gries in the 1983 AAPG *Bulletin* favor a more thrusted model with reverse fault planes dipping 60° to 30°. Sales in the 1968 AAPG *Bulletin* agrees with the morphology of Berg and Gries, but feels that the folds in the foreland were generated by faults with strong lateral components.

Concerning other problems, Stone in the October 1967 AAPG *Bulletin* pointed out that the Paleozoic reservoirs often have a common oil-water contact (OWC) within individual structures. He attributed the common OWC to fractures joining the reservoirs. The OWC is commonly tilted; this he attributed to hydrodynamic flow. An understanding of fractures and tilted oil-water contacts is imperative for successful exploration and production programs in the Big Horn basin.

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Paleotectonic Control of Depositional Facies (Mississippian), Southwest Montana

Mission Canyon deposition occurred in southwest Montana on a shallow carbonate platform that extended to the Antler orogenic foreland basin, the eastern margin of which is near the Idaho-Montana border. Deposition on this platform did not take place in regular facies belts paralleling depositional strike, but instead occurred on fairly regular shelves (Alberta and Beartooth) in the east, and along shoals, emergent islands, and deeper water channels throughout most of the area. The facies that were deposited in these zones are directly related to the northeast-southwest and northwest-southeast structural trend imposed on the area during late Precambrian time, and the movement of paleostructural elements during Mission Canyon and pre-Big Snowy time. The thickest sequences in the Mission Canyon are those comprised of low-energy mudstones and wackestones, which were deposited in trough areas such as the Ruby and Centennial troughs, and the high to moderate-energy grainstone and packstone sections that typify the far western shelf margin sequences.

High-energy shoal (lime grainstone) and low-energy island (algal boundstone) deposits are concentrated both on and around fault-bounded paleohighs (e.g., Pioneer Mountains in the Belt Island Complex) present during early Mission Canyon time; they are represented by thins on the Mission Canyon isopach map. Paleolows, such as the Ruby-Crazy Mountain and Centennial troughs, developed on east-northeast-trending, downdropped, fault-bounded basement blocks, and were filled with thick sequences of mostly restricted marine dolomite mudstones and wackestones. These restricted marine lithologies also occur as relatively thin zones in the upper portions of the fining upward high-energy shoal sequences in the lower Mission Canyon. However, they are most extensively developed in the upper Mission Canyon, where they contain regionally correlative evaporite units that are represented on outcrop by solution collapse breccias. Only minor amounts of low energy, normal marine rocks occur in the Mission Canyon Formation, and most of these were deposited near the far western margins of the carbonate platform.

A major lowering of sea level took place in middle Mission Canyon time. This resulted in the deposition of a regionally correlative supratidal sequence. The ensuing regional transgression resulted in the development of a new shelf margin farther to the west, and deposition of the restricted marine and evaporite units, mentioned above, behind it. Deposition of the Mission Canyon Formation ended with the total withdrawal of the sea from southwest Montana, regional exposure, and the formation of an extensive karst system and widespread solution collapse breccias.

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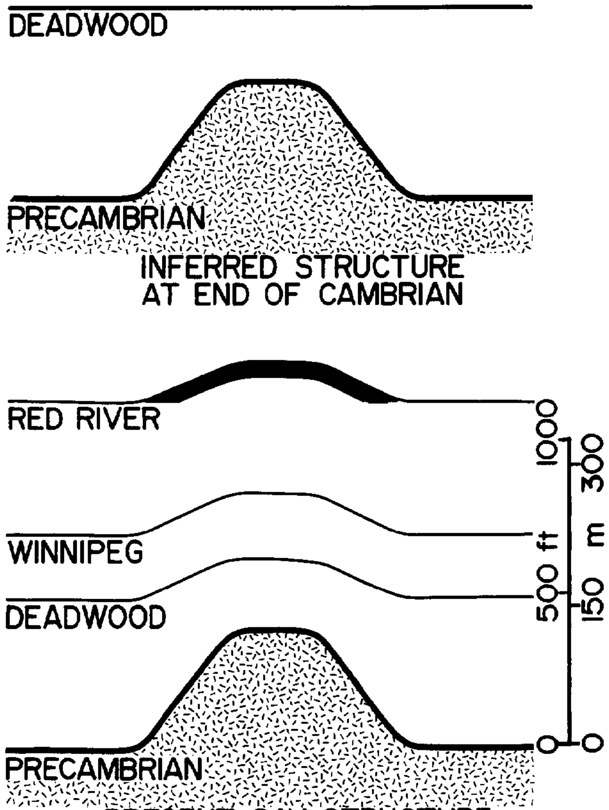
Development of Structure and Porosity at Medicine Lake Field in Northeast Montana Williston Basin

Medicine Lake field produces oil from the Mississippian Charles, Devonian Winnipegosis, Silurian Interlake, and Ordovician Gunton and Red River formations, and drill-stem tests show a potential for production from the Devonian Nisku and Deperow Formations. Porosity in the field is the result of bioclastic bank development, dolomitization, solution, and fracturing. Porosity development in the Winnipegosis and Red River Formations may have been influenced by the Medicine Lake paleostructure. The source of the oil in each of the producing formations is probably within that formation itself.



The Medicine Lake structure is roughly elliptical, 1 mi (1.6 km) in diameter, and has 125 ft (38 m) of structural closure at the top of the Red River Formation. Growth of the structure was essentially complete by the end of the Devonian. However, a similar structure at nearby Outlook field can be mapped from Paleocene outcrops, which shows that structural movement there continued into the Cenozoic.

The configuration of Cambrian and Precambrian rocks at Medicine Lake shows that the structure there formed by compaction of Cambrian sediments deposited around a hill on the Precambrian land surface. Regional-scale southeast-plunging anticlines in the eastern Montana Williston basin may also have formed by compaction of Cambrian sediments on a differential eroded Precambrian land surface.

JACOB, ARTHUR F., McMahon-Bullington, Englewood, CO

Undrilled Giant Anticline in Overthrust Belt, Broadwater and Gallatin Counties, Montana

Southeast of Helena, Montana, in the Missouri River valley, the Precambrian Belt Supergroup has been thrusted eastward over Paleozoic and Mesozoic reservoirs and source beds, and forms an undrilled anticline about 16 mi (26 km) long, 7 mi (11 km) wide, with about 1 mi (1.6 km) of structural closure. The Paleozoic and Mesozoic strata extend westward below the leading edge of the Belt, which is at the east edge of the anticline. Although the anticline is clearly evident on published cross sections, its axis does not appear on published maps. Cross sections constructed from surface data indicate that Paleozoic and Mesozoic strata may be present below the Belt in the anticline, but confirmation by geophysical work is needed.

Drill depths to Cretaceous targets should be about 8,000 to 10,000 ft (2,400 to 3,000 m). The Eagle Sandstone (Upper Cretaceous, 100 to 300 ft [30 to 90 m] thick) probably is a regressive shoreline and nearshore deposit. It is overlain and underlain by thick marine Cretaceous shale from which oil and gas were tested in nearby drill holes, and which could be a hydrocarbon source for the Eagle and other reservoirs. The Kootenai Formation (Lower Cretaceous, 400 to 1,000 ft [120 to 300 m] thick) is a coal-bearing deposit with fluvial sandstones which may form reservoirs having the coal as a gas source. Other important Mesozoic reservoirs may be the Morrison Formation and the Ellis Group.

Drill depths to Devonian and Mississippian targets should be about 15,000 to 18,000 ft (4,500 to 5,500 m). The Big Snowy Group (Upper Mississippian, 0 to 400 ft [120 m] thick) consists of marine sandstone, limestone, and black shale; many outcrops are notably petroliferous. The Mission Canyon Limestone (Lower Mississippian, 700 to 1,500 ft [210 to 460 m] thick) has abundant porosity and overlies the Lodgepole Limestone (Lower Mississippian, 300 to 750 ft [90 to 230 m] thick), which is thin bedded and dark and may be a hydrocarbon source for the Mission Canyon and other reservoirs. The Jefferson Dolomite (Upper Devonian, 400 to 700 ft [120 to 210 m] thick) is dark colored, marine, fetid, and has outcrops with oil seeps. Other important Paleozoic reservoirs may be the Phosphoria and Amsden Formations.

This geologic setting is similar to the giant Waterton field to the north just across the Canadian border where the Belt has been thrusted eastward over Mesozoic clastics and Paleozoic carbonates. The latter are the major reservoirs at Waterton and may be productive in the study area. Some drill holes at Waterton spud in the Belt.

In the study area, the Belt so much resembles younger sedimentary rocks that it has been misidentified as Cretaceous shale on sample logs available from a reputable commercial firm. It should present no great hindrance in geophysical or drilling programs.

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An Economic Appraisal of Oil Potential of Williston Basin

An economic appraisal was made of the oil potential of more than 80 producing fields in the Williston basin of Montana, North Dakota, and South Dakota. The major oil producing formations investigated were in the Mississippian, Devonian, Silurian, and Ordovician.

Data for the study came from field production and drilling statistics. An extrapolated oil production decline curve for a theoretical "average" producing well first was made for each field. The value of the total extrapolated amount of producible oil for the average well was then calculated, discounted for royalty, taxes, etc, and divided by the estimated cost for a completed producing well. This gave an estimate of the return per dollar invested. No considerations were given for exploration and land acquisition costs.

The estimated return per dollar values, after posting on Williston basin geologic maps, show relative economic comparisons of producing formations and where within the basin the best economic returns can be expected.

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Seismic Interpretation in Cordilleran Thrust Belt

Seismic data acquisition and quality are affected considerably by the rugged terrain and complex geology of the Cordilleran thrust belt. With conventional CDP gathers and batch processing, it is surprising that we get interpretable data in some areas. Other problems affecting data interpretability are velocity pull-ups and migration. Velocities can produce antiforms on seismic data that appear to have thousands of feet of closure, while migration is critically important in recreating the subsurface geologic picture.

Seismic sections across the major producing trends of the Central thrust belt illustrate the structural forms of producing fields. It is noted that the structural style is similar in other areas of the Cordilleran thrust belt.

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Williston Basin Red River Formation: Exploration Success, Development Failure

Hydrocarbon reserves in Red River limestones are typically found in porosity zones created by paragenetic dolomitization and diagenetic calcite solution and microfracturing. The porosity developed on the tops and flanks of low-relief carbonate highs in a shallow marine environment. Since basement structure and topography controlled the location and limits of porosity development, we attempt to reconstruct Ordovician topography (structure) in our search for Red River prospects. Our attempts at mapping prospects with seismic data are hampered by velocity errors and data resolution.

Most Red River fields are composed of small topographic bumps with associated pods of porosity. Clusters of bumps may be aligned locally and may form regional trends reflecting paleoshorelines. Exploration along these trends can be very successful. However, direct offsets to good discovery wells may be disappointing for several reasons: seismic data may not be able to adequately define the structure, the structure or reservoir may be too small to provide offset potential, porosity may not be developed, or acreage ownership or spacing regulations may restrict optimum well positioning. Unfortunately, lease or drilling deadlines generally have the habit of compounding these problems.

Examples of seismic structures and "porosity" anomalies illustrate the problems of offset drilling. Extension prospecting appears to be a more practical approach to development in the Williston basin.

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Paleotectonics and Sedimentation in Sweetgrass Arch, Montana

The Sweetgrass arch has been part of the stable platform known as the Alberta shelf throughout its tectonic history. This resulted in major periods of emergence interrupted by periods of shelf marine and/or fluvial deposition. The present-day Sweetgrass arch has been in a position coincident or proximate to a marine to nonmarine transition throughout geologic history. Approximately one half of geologic time is represented in the stratigraphic record of the Sweetgrass arch. The remainder of geologic time was occupied by major hiatal periods leaving significant unconformities in the sedimentary column.

Sedimentary history of the Sweetgrass arch is recorded in a stratigraphic column averaging less than 5,000 ft (1,500 m) thick. This thickness grades eastward into a Williston basin stratigraphic column of up to 15,000 ft (4,500 m) and westward into a depositional thickness of more than 100,000 ft (30 km) in portions of the Cordilleran geosyncline.

This discussion will relate tectonic history of the Sweetgrass arch to the sedimentary record, relate tectonic events in the Sweetgrass arch to those in surrounding areas and to the classic orogenic episodes of Rocky Mountain geology, draw some conclusions with respect to tectonic influence on oil and gas accumulations in the Sweetgrass arch, and examine implications for future energy exploration in the Sweetgrass arch.