which is immature. Surface samples from the White Knob thrust plate in the Pioneer Mountains west of Arco in the southwestern part of the area have a conodont alteration index of 2 and vitrinite reflectance ranging from 0.45 to 0.64. Where the McGowan Creek Shale on the White Knob plate extends into the subsurface to appropriate depths, it should be generating oil and gas at the present time. Additional sampling and drilling may indicate the existence of other cooler areas.

The McGowan Creek Shale acts as a seal on 5,000 ft (1,524 m) of lower Paleozoic dolomite. At least 1,500 ft (457 m) of this dolomite section may have enough porosity to be effective oil or gas pay.

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Coral Zonules: New Tools for Petroleum Exploration in Mission Canyon Limestone and Charles Formation, Williston Basin, North Dakota

Study of the distribution of corals and rock types in the Mission Canyon Limestone and the lower part of the Charles Formation (Tilston, Frobisher-Alida, and Ratcliffe intervals) in 29 cores from wells in the Williston basin of western North Dakota resulted in recognition of four coral zonules and three regressive carbonate cycles. Although coral diversity and abundance decrease eastward toward the basin margin and upward in the sequence because of the influence of increasingly restricted environments, two of the zonules in the lower part of the Mission Canyon extend into areas of western North Dakota where marker-defined intervals are difficult or impossible to recognize. The Nesson anticline, or a paleotopographic ridge following the same trend, may have been a barrier that hindered coral development in the east during later Madison deposition. Parallelism between the zonules and marker beds used to define standard intervals employed in subsurface stratigraphic correlation indicated that the marker beds are essentially time lines within the area studied. The first records of *Stelechophyllum micrum* and *S. banffense* in Madison rocks in the United States indicate a connection with the Alberta shelf and indicate that North Dakota was probably a part of the Central Western Interior subprovince during Osagean time.

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New Age Interpretation of Bell Creek Sandstone, Powder River Basin, Montana and Wyoming

Published data interpret the oil-productive sandstone (Muddy Formation) at the Bell Creek and Ranch Creek fields (T8S, R54E, and T9S, R53E) as marine-deltaic and barrier-bar sandstones that are facies equivalent to, or younger than, freshwater channel deposits on the east and south. Core and log studies now show the Bell Creek sandstone (an informal member of the Muddy Formation) to be removed by postdepositional erosion of an incised valley between the fields. Thus, impermeable valley-fill shale, siltstone, and sandstone, with thin coals, are younger than the adjacent Bell Creek sandstone.

The stratigraphic relationships are as follows: (1) the Bell Creek sandstone was deposited as a widespread regressive sandstone genetically related to the underlying marine Skull Creek Shale, (2) the younger incised valley between the Bell Creek and Ranch Creek fields is approximately 1 mi (3 km) wide, contains up to 30 ft (9 m) of impermeable fill, trends north-south, and probably connects with a major southwest-trending valley, 8 mi (26 km) to the south (Rocky Point field area), and (3) valley fill forms the seal along the east side of Ranch Creek, and possibly east of Bell Creek as well.

Isopach thinning of the combined interval of Skull Creek Shale and Muddy Formation indicates a northeast-trending paleostructure that may have controlled facies distribution, drainage incisement patterns, and fluid migration.

The new age interpretations can be related to a sea level highstand for deposition of the Skull Creek and overlying Bell Creek sandstone; erosion of valleys related to a lowstand; fill of the valleys during a rising sea level, followed by deposition of the marine Mowry Shale under highstand conditions.

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Minnelusa Formation Exploration, Powder River Basin, Wyoming: an Integrated Approach

The upper Minnelusa Formation has been an active exploration target in the northeastern Powder River basin, Wyoming, since 1960. To date, over 200 million bbl of oil have been produced from the upper Minnelusa Formation. Production is derived from eolian dune sands encased in shallow-marine carbonates. Hydrocarbons are accumulated by (1) erosional truncation of reservoir sand, (2) facies change from reservoir sand to impermeable marine carbonates, and (3) structural closure.

Integration of advanced seismic techniques with abundant well data is used to delineate reservoir sands with favorable trapping geometries. Resolution limitations on current seismic data are caused by the inability to delineate thin beds in the frequency ranges that can be acquired in the field and retained in the final processed sections. Seismic dip lines and geologic data from Timber Creek, Robinson Ranch, Raven Creek, and Dillinger Ranch fields illustrate the recognizable seismic response to the productive Minnelusa Formation reservoir.

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Discovery of a Mineralized Breccia Pipe in Mohawk Canyon, Northern Arizona

Hundreds of solution-collapse breccia pipes crop out in the canyons and on the plateaus of northern Arizona. Pipes originated in the Mississippian Redwall Limestone and stoped their way upward through the upper Paleozoic strata, locally extending into the Triassic Moenkopi and Chinle Formations. High-grade uranium ore associated with potentially economic concentrations of Ag, Pb, Zn, Cu, Co, and Ni in some of these pipes has stimulated mining activity in northern Arizona despite the depressed market for most of these elements.

More than 900 confirmed and suspected breccia pipes have been mapped during the past 6 years. Many exploration criteria for detecting mineralized breccia pipes were developed during this study. One pipe discovered on the west side of Mohawk Canyon during 1983, was selected for exploratory drilling in 1984 because it exhibited the following exploration criteria: (1) concentrically inward-dipping beds of Kaibab Limestone, (2) a circular erosion pattern, (3) anomalous radioactivity, which is highly significant for the oxidized surface exposure of breccia pipes, (4) goethite pseudomorphs and molds of pyrite, (5) colloform celadonite-stained chalcedony, (6) copper mineralization expressed on surface exposure as the supergene minerals malachite, azurite, brochantite, and chrysocolla, (7) breccia, and (8) anomalous concentrations in surface exposure of such trace elements as Ag, As, Cd, Co, Cr, Cu, Mo, Ni, Pb, Se, V, and Zn.

Five rotary and core holes were drilled into this pipe. Numerous drilling problems caused by 30-ft (9-m) caverns within the breccia limited the drilling results. Core recovered from holes in the center of the pipe shows breccia to total depth of 1,010 ft (308 m), abundant pyrite, and minor galena. Gamma logs of a rotary hole penetrating to 1,335 ft (407 m) show a 1-ft (0.3-m) interval of 0.52 eU_3O_8 at a depth of 1,191 ft (363 m); this is at the same stratigraphic horizon as the top of ore bodies in mines located on similar plateaus capped with Kaibab Limestone. Sufficient mineralization was verified in the Mohawk Canyon pipe that further drilling is warranted to assess its economic potential.

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Carbonate-Evaporite Cycles in Lower Duperow Formation of Williston Basin

The Duperow (Frasnian) sediments of the Williston basin consist of approximately 12 regular cycles. Stratigraphic and petrographic studies were made of the lower 300 ft (91 m) of these strata using cores, cuttings, and radioactivity logs from selected locations in North Dakota, Montana, and Saskatachewan. Each cycle consists of three members. The lower member consists of either dark-brown, burrowed, lithoclastic-bioclastic brachiopod-crinoid limestone with a mud matrix, or a stromatoporoid boundstone. A middle member consists of brown lime mudstone with a restricted microfauna of ostracods and calcispheres interbedded with unfossiliferous pelletoid beds or laminated lime mudstone. Bedded anhydrite and gray-green, silty, very fine-grained dolomite displaying intertidal and supratidal sedimentary structures cap each cycle.