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.

The Duperow cycles are widespread and constituent beds only 10-15 ft (3-5 m) thick can be traced completely across the Williston basin. Deposition occurred within a vast back-reef lagoon lying south of the Woodbend reef platform of southern Alberta and stretching to a sandy shore in South Dakota and northern Wyoming. This lagoon was periodically and rapidly flooded with normal marine water, permitting organisms to flourish; the sea then gradually shallowed as sediments filled the basin.

Desiccation produced extensive tidal flats and evaporitic sabkhas and was perhaps responsible for some dolomitization of the carbonates on shelves outside the basin.

The cause of such cyclic sedimentation might have been slow, steady subsidence of the basin with a superimposed climatic rhythm that may have speeded up reef growth and periodically choked off seawater from the basin. Perhaps this process operated coincidentally with sporadic eustatic sea level fluctuation or with abrupt periodic subsidence of the whole basin. The low bathymetric relief that permitted rapid flooding certainly would have aided in development of such cycles.

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Depositional Environments and Diagenesis of D Sandstone, Wild Horse Field, Weld County, Colorado

Wild Horse field is located on the gentle east flank of the Denver basin, northwest of Fort Morgan, Colorado. Production was established during 1981 from a 12-ft (3.7 m) thick porous sandstone in the lower part of the D sandstone of Cenomanian age. To date, 10 producing wells have been completed. Proven productive area is 1,800 ac and estimated reserves are 1.2 million bbl oil equivalent.

D sandstone facies form complex reservoirs associated with regressive deltaic and marine sandstone deposited during a regional sea level drop 95 Ma. Traps are primarily stratigraphic in nature although fracturing has enhanced production. The D sandstones in the Wild Horse field area are interpreted to be the product of an episodic northwestward progradation of a lobate river-dominated delta system.

On the basis of differences of the internal structure, textures, mineral composition, and trace-fossil content, the D sandstone is divided into five lithofacies: shoreface, prodelta platform, delta front, delta plain, and transgressive marker sandstone. The producing sandstones occur in overlapping bars proximal and lateral to principal channels in a bay-filled sequence. Calibration of well logs using cores allows detailed subsurface mapping of producing facies for more efficient development of the field.

Original porosity has been reduced mainly by quartz overgrowth cementation. Porosity interconnection is present due to dissolution of framework grains and of the early diagenetic calcite cement. Pore-filling cements such as chlorite, kaolinite, and pyrite may produce formation damage if not treated during completion operations.

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Geologic Characterization of a Field Laboratory for Coalbed Methane Exploration and Development

Two coalbed methane wells have been drilled at Red Mountain Unit in the Piceance basin near Collbran, Mesa County, Colorado. The wells were drilled as part of the Deep Coal Seam Project, a multi-well project sponsored by the Gas Research Institute to develop, improve, evaluate, and communicate the technology required to produce gas from deeply buried coals. To better characterize the geologic parameters controlling coalbed methane production, research efforts have been directed at a single coal seam at a depth of 5,500 ft (1,800 m). The thickness of the objective or D seam coal, included in the Cameo coal member of the Williams Fork Formation, Upper Cretaceous Mesaverde Group, ranges from 16 to 20 ft (5 to 6.5 m) throughout the unit and is substantiated by nearby well control.

A continuous core, over 200 ft (61 m) thick, was recovered from the first well. Routine and special core tests were performed on samples from both the objective coal and overlying sandstone for the purposes of reservoir evaluation, log analysis, and stimulation design. Pressure transient testing of the objective coal in the first well confirmed the low permeability and/or high skin damage caused by deep invasion of drilling and completion fluids. Interpretation of in-situ state of stress measurements indicates that a conventional hydraulic fracture initiated in the coal will grow upward into the overlying sandstone. Geologic characteristics of the coal and bounding formations were incorporated in a stimulation design to maximize enhancement of the cleat or natural fracture system of the coalbed methane reservoir.

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Tectonics and Sedimentation of Middle Proterozoic Belt Basin, and Their Influence on Cretaceous Compression and Tertiary Extension in Western Montana and Northern Idaho

The Belt Supergroup was deposited in an intracratonic basin, occupied during much of its history by alluvial aprons that sloped down to a landlocked sea. Belt rocks are here analyzed in terms of 13 "sediment types," descriptive taxa in which the metamorphic overprint is filtered out and the original sedimentary aspects are emphasized. The lower Belt records maximum transgression of the Belt sea, during which turbidite sand and pelagic mud were deposited in the central part of the basin, carbonate mud accumulated on its eastern margin, and coarse conglomerate accumulated along its fault-bounded southern side. The Ravalli Group records extensive alluvial apron/mudflat progradation from the south and west. The middle Belt carbonate, representing a second large transgressive period, is characterized by terrigenous-carbonate cycles in the eastern part of the basin and by turbidite sand and mud, derived from the west, in the deeper, locally slumped, western part of the basin. The Missoula Group represents a series of northwest-facing prograded alluvial aprons alternating with transgressive mudflat and shallow-water deposits. The Garnet Range Formation, near the top of the Missoula Group, represents incursion of open marine waters into the Belt basin.

The Belt basin subsided as a group of at least four large crustal blocks, separated by three nearly east-west fault lines and a northwest-trending fault line. Differential subsidence of the blocks is recorded in abrupt thickness changes and soft sediment deformation along the fault lines. Cretaceous thrusting formed western and eastern thrust belts which are continuous across the blocks, but which are segmented and broken along the east-west lines. Tertiary extensional dislocations along the lines.

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Distribution and Significance of Hydrocarbon Source Rocks in Greater Rocky Mountain Region

Stratigraphic and geographic distribution of possible Rocky Mountain source rocks determine which stratigraphic sequences in each geologic province might be considered "hydrocarbon machines" or generation-accumulation cells. Knowledge of source rock facies distribution enables the explorationist to: (1) understand local, regional, and global depositional frameworks, (2) construct useful models of burial history and maturation patterns, (3) reconstruct the most likely migration pathways, (4) correlate these facies to hydrocarbons reservoired in known accumulations, and (5) efficiently explore for undiscovered accumulations. Source rock distribution must be integrated with evaluation of reservoir, seal, and trap distribution as well as with changes in heat flow, diagenesis, tectonics, hydrodynamics, and burial history through time.

The significance of Rocky Mountain source rock facies can be evaluated in terms of the number of accumulations and volume of reserves attributable to each. Unproven source rock facies are evaluated by highlighting their potential based on their geochemical characteristics.

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Stratigraphy of Upper Morrison and Lower Dakota Group of Front Range, Colorado: New Play in Central Denver Basin?

Examination of surface sections along the Colorado Front Range from Walden to Beulah, Colorado, reveals that five sandstone units in the