in porosity and permeability between the two rock types appear to be related solely to a unique set of diagenetic conditions. The two rock types can be defined by log analysis, hydrocarbon pore volume calculations, and permeability-thickness data.

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Paleotectonic Influence of Precambrian Wyoming Province and Adjacent Terranes on Phanerozoic Sedimentation on Western Cratonic Shelf

The Archean Precambrian Wyoming province is bounded on the north and south by regionally extensive early Proterozoic mobile belts. Archean rocks have been remobilized by early Proterozoic tectonic events in the northern belt, but the southern belt does not appear to contain rocks as old as Archean. On the east, an early Proterozoic suture belt separates the province from the Archean Superior province. The western margin lies under the western Overthrust belt. The paleotectonic articulation among these anisotropic Precambrian lithostructural terranes, in response to cratonic and continental margin vertical and horizontal forces, influenced the distribution of many Phanerozoic stratigraphic facies. An analysis of the major unconformities in the stratigraphic record in light of the Precambrian lithostructural history of the western shelf discloses new observations concerning the petroleum source rock and reservoir rock stratigraphy of the northern Rocky Mountain region. A correlation between these tectonic terranes and the localization of regional hydrocarbon accumulations has been observed and has been useful in basin analyses for exploration.

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Age Correlation and Tectonic Significance of Wildcat Peak Formation, Northern Toquima Range, Nevada

The Wildcat Peak Formation is exposed only in the northern part of the Toquima Range, Nye County, Nevada. It lies on western siliceous assemblage rocks (Ordovician Vinini Formation) and eastern carbonate assemblage rocks (Ordovician Pogonip Group and Silurian Roberts Mountains Formation), which were juxtaposed by thrusting during the Antler orogeny. The Wildcat Peak consists of three datable marine tongues separated by intervals of coarse clastic deposits. The coarse clastic intervals resulted from truncation following sporadic and cyclic uplifting that continued after the emplacement of the Roberts Mountains allochthon.

In the literature, age assignments for the formation range from Early Pennsylvanian (Atokan) to Early Permian (Wolfcampian). These age assignments are correct, but they only represent the middle and upper parts of the formation. Microfossil analysis has now established that the lower part of the Wildcat Peak is mid-Mississippian (Meramec). All microfossil dates are from material collected from transgressive limestones.

The new information indicates that major Antler thrusting ceased prior to mid-Mississippian time in the Toquima Range. This restricts the length of time of the Antler orogeny from Late Devonian to pre-middle Mississippian (Meramec) instead of Late Devonian to mid-Pennsylvanian. Such an interpretation is consistent with recently published data from the Pinyon Range area, Nevada.

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Thrusting and Synorogenic Sedimentation in Central Utah

The thrust belt in central Utah can be divided geometrically into four major thrust systems, from west to east: the Canyon Range, the Pavant, the Gunnison, and the Wasatch thrust systems, Biostratigraphic correlations together with constraints imposed by the geometry indicate the following ages for thrusting events: late Albian for the Pavant 1 thrust, late Santonian–early Campanian for the Pavant 2 thrust, middle to late Campanian for the late Canyon Range thrust, late Maestrichtian for the Gunnison thrust system, and late Paleocene for the Wasatch thrust system.

In the hinterland, a combination of structural, stratigraphic, and chronologic evidence indicates that shortening was accommodated by the development of a backbreaking (overstep) thrust sequence: Pavant 1 thrust, Pavant 2 thrust, (late) Canyon thrust. This led to the formation of successive overlapping unconformities of late Cenomanian, early-middle Campanian, and late Campanian age. In the foreland, the Gunnison thrust system has a ramp-flat geometry; a series of blind, splay, imbricate faults are associated with a major ramp beneath Sevier and Sanpete Valleys. Late Cretaceous and Paleocene unconformities coincide with the development of an imbricate fan, which was subsequently deformed during the late Paleocene by formation of a deeper duplex structure within the Wasatch thrust system. Associated back thrusts accommodated shortening toward the surface at the west side of the Wasatch Plateau.

The times of superimposed thrusting phases, when compared with eustatic episodes recorded in the Cretaceous seaway, indicate that episodes of continental tectonism were approximately synchronous with eustatic rises in central Utah.

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Pennsylvanian-Permian Block Faulting in Subsurface of Piceance Basin, Colorado

Pennsylvanian-Permian age block faulting has been identified on two regional seismic lines in the Piceance basin. At the south end of a north-south line along the west side of the basin, the Mesozoic section unconformably overlies the Precambrian. Five miles (8 km) to the north, reflectors of the Mississippian Madison Limestone appear in a series of fault blocks downthrown to the north. These faults generally do not displace overlying Mesozoic rocks. In the vicinity of Douglas Creek field, this block faulting created a large horst block on which Madison Limestone is faulted step-wise up the flanks of the structure. The overlying Pennsylvanian Maroon Formation is 50% thinner over the crest of this structure than it is 10 mi (16 km) to the north. Similar features can be seen on a second seismic line running east-northeast through the central portion of the basin between DeBeque field and the Grand Hogback. Coming off the ancestral Uncompahgre highland, Madison reflectors appear near the southwest end of the line in a series of fault blocks downdropped to the northeast. Near Rulison field, a large Pennsylvanian-age horst block is present that may have Madison Limestone stripped from its crest. Near the Grand Hogback, Madison Limestone is faulted up to the east to form a Pennsylvanian-age basement high between the Piceance basin and the Eagle basin to the east.

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Oil and Gas Potential of Idaho Thrust Belt North of Snake River Plain

The thrust belt north of the Snake River plain in south-central Idaho has the elements necessary for major oil and gas accumulations: large traps, thick reservoir rocks, top seals, rich oil-source rocks, and in at least parts of the area, a favorable temperature history. Only drilling is lacking.

The Utah-Wyoming Sevier thrusting extended north of the Snake River plain into southwestern Montana and south-central Idaho. Styles of thrusting and resulting traps are similar to the Utah-Wyoming portion of the thrust belt. After thrusting, large listric normal faults formed northwesterly trending valleys that were filled with Tertiary sediments. Some companies are looking for traps in thrusted Paleozoic rocks; others are exploring the valleys looking for stratigraphically trapped oil generated from deeply buried Tertiary sediments.

Paleozoic strata thicken westward from a normal cratonic sequence consisting of about 5,000 ft (1,524 m) of chiefly carbonate rocks in the east to more than 30,000 ft (9,144 m) of sandstones, conglomerates, shales, and carbonates in the west. Of particular importance as a hydrocarbon source rock was the accumulation of about 3,000 ft (914 m) of organic-rich Mississippian McGowan Creek Shale in a starved basin between the Antler uplift on the west and the craton on the east. Outcrop samples of this shale contain from 0.8-6.3% total organic carbon.

Paleotemperatures in much of the area were too hot for preservation of oil according to alteration of conodonts. At least two important exceptions to the generally high paleotemperatures exist. The Tendoy thrust plate in the eastern part of the area has a conodont alteration index of 1, 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.