Shallow gas fields have been developed in the basin; ongoing exploration for deeper oil and gas is not yet definitive. Potentially good source rocks in the deeper parts of the basin, underlying organic-rich Franciscan sediments, and the abundance of potential reservoir rocks higher in the section make this structurally complex onshore/offshore basin an attractive exploration target.

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Mid-Cretaceous Biostratigraphic Units, Unconformities, and Diastrophism in Wyoming, Colorado, and Adjacent Areas

In the central Rocky Mountains and adjoining Great Plains, lithologies and hiatuses within sequences of mid-Cretaceous formations reflect widespread fluctuations of sea level and intermittent tectonism during Cenomanian, Turonian, and Coniacian time (88 to 96 m.y.B.P.). Siliciclastic and carbonate strata of marine origin in the Graneros, Belle Fourche, Greenhorn, Carlile, and Niobrara Formations grade laterally into marine and nonmarine siliciclastic beds of the Frontier Formation. The clastic strata are products of uplift and erosion in both the Sevier orogenic belt of Utah, Idaho, and western Montana, and a contiguous region within Utah, Colorado, Wyoming, Montana, and Nebraska. The ages of these rocks, the durations of intervening hiatuses, and the times of diastrophism were determined mainly from a detailed succession of marine molluscan index fossils.

Outcrops at scattered localities in this region, in a western part of the Cretaceous seaway, as well as outcrops in eastern South Dakota and northwestern Iowa, near the eastern shore of the seaway, indicate a marine transgression in the Cenomanian and early Turonian (Belle Fourche and Greenhorn time), a marine regression in the middle Turonian (early Carlile time), and a marine transgression in the late Turonian and Coniacian (late Carlile and early Niobrara time). However, the stratigraphic record of these widespread events has been obscured in most of Wyoming and Colorado by submarine and subaerial erosion and attendant sedimentation associated with episodic orogenic activity during the Turonian and Coniacian (88 to 91 m.y.B.P.).

In central and northwestern Wyoming, strata as young as late Cenomanian (early Greenhorn age) are disconformably overlain by beds of early middle Turonian (latest Greenhorn) age. Uplift and erosion in these areas probably occurred during early to earliest middle Turonian time. In western Colorado, early middle Turonian strata (Fairport Member of the Carlile) and older rocks are disconformably overlain by late middle Turonian strata (Blue Hill Member of the Carlile), indicating deformation and truncation in the middle Turonian. Moreover, truncated beds as young as late middle Turonian (Codell Sandstone Member of the Carlile) are overlain by early late Turonian strata (Juana Lopez Member of the Carlile) in Colorado and Wyoming, reflecting earliest late Turonian orogenic activity in the vicinity of the Front Range, Laramie Range, and Bighorn Mountains. Some of the rocks of early late Turonian age (a lower part of the Wall Creek Member of the Frontier) were, in turn, uplifted and eroded during later late Turonian time in an area that extends from Yellowstone Park to central Wyoming. Furthermore, at outcrops near the Laramie Range, truncated beds of late Turonian age (Wall Creek Member of the Frontier) and the overlying Coniacian strata (basal Niobrara) indicate earliest Coniacian tectonism and erosion in southeastern Wyoming.

Elongate areas of uplift and erosion and of discrete sedimentary facies of mid-cretaceous age commonly trend approximately southeastward and northeastward in the central Rocky Mountains–western Great Plains region. From Yellowstone Park southeast to the vicinity of Casper, Wyoming, intermittent truncation and deposition during the Turonian are especially evident.

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Trace Fossils Within Limestone Interbeds, Oak Grove Member, Carbondale Formation (Pennsylvanian, Desmoesian), Northwestern Illinois

Most trace fossils have been described from terrigenous rocks, commonly sandstones or sandstone/shale interbeds. The prevailing opinion appears to be that carbonate rocks rarely contain trace fossils or that ichnofossils are more difficult to study in them. Neither is true. Methodology is especially important in these studies, and the peculiarities of carbonates make them particularly rewarding subjects for trace fossil analysis.

At Wolf Covered Bridge in Knox County, Illinois, the Desmoinesian Oak Grove Member is more than 5 m (16 ft) thick and consists mostly of shale with several thin carbonate (limestone and siderite) interbeds. The two thickest of these carbonates are a lower "gray septarian" (or "*Marginifera*") limestone about 0.2 m (8 in.) thick, and about 1.5 m (5 ft) higher a 0.3 m (1 ft) thick "*Linoproductus*" limestone. Both are sparse to packed mixed biomicrites with diverse and abundant fossils. The depositional environments of these limestones were similar: nearshore, quiet, delta-influenced, somewhat brackish, shallow water deposits interpreted by Merrill (in 1975) to have formed in water less than 20 m (66 ft) deep.

Limestones were sliced perpendicular to bedding in the normal fashion and large slabs were also cut parallel to bedding with a wire saw. Serial sections cut perpendicular to bedding were photographed by X-radiography permitting three-dimensional reconstruction of some burrows. Large slabs cut parallel to bedding were etched and acetate peels prepared in the convention manner, but of unconventional size (some more than 1.0 m, 39 in., long). The polished surfaces were later gridded, coated, and the distribution of body and trace fossils mapped both megascopically and microscopically from the peels.

The level of bioturbation is exceedingly high, especially in the "*Marginifera*" limestone. Several generations of truncating trace makers are evident. Recognizable ichnogenera include a spectacular *Rhizocorallium* 40 cm (16 in.) long with waves of spreite outlined by calcitornellid (pseudopthalmid) foraminifers, numerous *Chondrites* up to 10 cm (4 in.) high, and common *Planolites*. Lithologic differences among burrow types are striking and many vague, relict, earlier generations of traces remain, traced primarily by allochem distribution. Substrate stabilities differed between the pair of limestones and bearing strength was probably a major factor controlling community structure. There are suggestions of "ghost biota" and lack of significant compaction of the micrite in the lower carbonate interbed.

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Geochemistry of Regionally Extensive Calcite Cement Zones, Mississippian of New Mexico

Carbonate cements from Mississippian skeletal limestones of southern New Mexico are dominated by echinoderm-syntaxial calcites that comprise 4 regionally extensive compositional zones. Previous petrography and cement stratigraphy proves that the oldest three zones (zones 1, 2, and 3) are pre-

Pennsylvanian in age, and thus precipitated at temperatures around 25°C (77°F); they are interpreted as meteoric phreatic cements. The youngest cement, zone 5, is interpreted as a pre-Permian burial cement precipitated at temperatures less than about 80°C (176°F) and at burial depths less than about 1 km (3,300 ft).

Originally defined on the basis of luminescence and staining, each zone has a distinctive assemblage of C^{13}, O^{18}, Mg, Mn, and Fe contents. The low MgO contents (less than 0.25 wt. %) in all zones indicates that sea water was insignificant in their precipitational waters over most of the region. Their FeO and MnO contents are compatible with their subsurface interpretations.

The isotopically most positive values from bioherm muds and synsedimentary former high-Mg calcite cements (+4.5‰ δC^{13}, −1.5‰ δO^{18} PDB) are interpreted as marine values, and offer a baseline with which to compare isotope values of non-marine cements.

The pre-Pennsylvanian cements, zones 1, 2, 3, are markedly different from one another and show a progressive decrease in δC^{13} and δO^{18} with decrease age (δC^{13} = +3.7, +2.4, −0.8‰ PDB, respectively; δO^{18} = −1.3, −2.8, −3.7‰ PDB, respectively). This decrease in δC^{13} is interpreted to reflect increased contribution from soil or atmospheric CO_2 carbon. The decrease in δO^{18} is interpreted to reflect a decrease in O^{18} content of precipitational waters rather than an increase in temperature. The δC^{13} of all three zones is less than the interpreted marine values, which reinforces their fresh-water interpretation. The δO^{18} of zone 1 is greater and the δO^{18} of zones 2 and 3 is less than the interpreted marine values.

We propose a model in which zones 1, 2, and 3 precipitated in fresh phreatic groundwaters largely uncontaminated by sea water. Their chemistries reflect progressive stages in the chemical evolution of the water-rock system. This evolution resulted from either a progressive change from a rock-dominated to a water-dominated system, or may have involved a progressive climatic change from arid (zone 1) to wetter and more seasonal (zone 3). The carbon for these cements derived from Mississippian skeletal and lime mud components plus contributions of light organic carbon. Crinoids, the main skeletal component, could have been major sources only for zone 3 if they had C^{13} contents comparable to modern crinoids. More likely, they had C^{13} contents comparable to Mississippian marine values and were major sources of carbon for all three zones via pressure solution and dissolution at the pre-Pennsylvanian unconformity.

The post-Mississippian zone 5 has a wide range of δO^{18} values (mean = −7.4‰ PDB), all less than those of the pre-Pennsylvanian zones. This light δO^{18} reflects elevated temperatures in the 40 to 60°C (104 to 140°F) range. Zone 5 has intermediate δC^{13} values which reflect complex, predominantly rock carbon sources, many of which were extraformational.

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Tectonic Control of Pennsylvanian Fan Delta Deposition, Southwestern Colorado

Cyclical deposits within the Lower Member of the Honaker Trail Formation (Desmoinesian), between Durango and Silverton, Colorado, have been studied in detail and indicate tectonically controlled sedimentation along the western flank of the Uncompahgre uplift. These cycles were previously considered the result of eustatic sea level fluctuation. Fan delta deposits form a thick wedge of coarse clastics and are interbedded with thin carbonates and siliciclastic shelf-bar systems. Significant lateral variation in depositional style and stratigraphic succession occurs along the strike of this faulted basin margin.

Two major types of cyclic sequences are recognized. Clastics found in the northern and southern portion of the study area near Molas Lake and Engineer Mountain are dominantly thin (10 to 15 m, 33 to 50 ft), sheet-like, rapidly shifting fan delta complexes. Three subfacies within these fan deltas can be distinguished. (1) The bottomset beds, (2.5 to 8 m, 8 to 26 ft, thick) are parallel-laminated and rippled, moderately sorted, micaceous, fine (0.125 mm) to medium-fine (0.25 mm) sandstones. Large plant fragments, as well as mascerated plant debris and bioturbation are common. (2) Forsets (2.5 to 4.5 m, 8 to 15 ft thick) are characterized by small to medium-scale trough cross strata and abundant soft sediment deformation in poorly sorted, arkosic, medium (0.25 mm) to coarse (0.71 mm) sandstones. (3) Topset beds (1.5 to 2.5 m, 5 to 8 ft thick) form a capping unit of very poorly sorted, arkosic, very coarse sandstones (2 mm) to conglomerates (4 mm +). Climbing units of topset beds are characterized by medium scale trough cross strata with occasional ripple stratification.

In association with these fan delta units are thin carbonates (0.5 to 2 m, 1.6 to 6 ft of wackestones/packstones) and nonmigrating shelf sands (0.25 to 2 m, 10 in. to 6 ft) with subparallel laminations and ripple stratification. The carbonates apparently do not cap the deltaic sequences but are more closely associated with the shelf sands. These fan deltas are fluvially-dominated with little or no evidence of reworking by marine processes.

The central region of the study area near Coal Bank Pass is characterized by marine-influenced high energy fan deltas (9 to 16 m, 30 to 52 ft) as evidenced by the abundance of hummocky cross strata at the base of the fan delta sequences and flanking shelf-bar systems. The topsets and forsets are similar in scale and in sequences of sedimentary structures and textures to those previously discussed. The bottomsets, however, are finer (0.17 mm), better sorted, and not as micaceous as those in lower energy areas.

Closely associated with these delta complexes are flat-bottomed, lense-shaped shelf sand-bars. These coarsening-upward, laterally migrating bars are the cleanest, most well-sorted, and finest (0.06 to 0.125 mm) sandstones. Oscillation ripple stratification subparallel laminations with both broad synforms and antiforms are the dominant sedimentary structures indicative of the marine reworking of fan delta sediments.

Variation in stratigraphic successions in adjacent areas and the areal distribution of fan delta types suggests major strike-slip motion along the bounding faults responsible for the development of upthrown and downthrown wedge-shaped blocks within the border fault zone.

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Petroleum Resource Assessment of Wilderness Lands

The U.S. Geological Survey is conducting an investigation of the oil and gas potential of the existing and proposed wilderness areas for the western United States. These current assessments are based upon a Wilderness System containing approximately 105 million acres (42 million ha.) of land (80 million acres [32 million ha.] in existing wilderness; about 16 million acres [6.5 million ha.] in proposed wilderness; and another 9 million acres [3.5 million ha.] potential wilderness lands under study).

It is necessary to consider the uncertainty in the estimates of petroleum resources in the wilderness tracts due to the limited data and lack of detailed geologic information available for many of the areas. In light of these limitations, maps were compiled on a state-by-state basis which delineate: (1) the boundaries of the wilderness land categories for the Forest Service, National Park Service, Fish and Wildlife Service, and Bureau of Land