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

Management; (2) the petroleum province boundaries of the U.S. Geological Survey Resource Appraisal Group as used in the 1981 national assessments; and (3) the geologic boundaries which distinguish the sedimentary-rock provinces having petroleum potential from the crystalline-rock provinces having no petroleum potential. All of the wilderness lands are digitized for mapping purposes and for calculation of the areas for each respective wilderness tract within the boundaries of the sedimentary-rock province. A computer search and compilation of exploratory-well data from the Petroleum Information Corp.'s Well History Control System (WHCS) was conducted for all the wilderness areas and their immediate surrounding. This tabulation of known well data is a part of the geologic input to the resource-assessment procedures.

Assumptions incorporated into the resource-appraisal methods are: (1) resource potential is not uniformly distributed throughout a petroleum province; (2) the total distribution of all recoverable petroleum resources is considered, both discovered and undiscovered; (3) consideration of the geologic characteristics favorable for the accumulation of petroleum resources in all the wilderness areas; (4) probability distributions are used to calculate a range of resource values to deal with the risks of uncertainty; and (5) the use of several alternative resource-appraisal methods are critically assessed.

The petroleum-resource assessments are compiled and reported by petroleum province and for each state. A total aggregation of the estimated petroleum resources for the existing and proposed wilderness areas in the 11 western states are presented as probability distributions.

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Eocene to Oligocene Paleo-Oceanography of the Northern North Atlantic: Seismic, Isotopic, and Faunal Evidence

Seismic stratigraphic evidence from the western and northern North Atlantic indicates that a major change in abyssal circulation occurred in the latest Eocene to earliest Oligocene. In the northern North Atlantic, the widely distributed reflector R4 correlates with an unconformity that can be traced to its correlative conformity near the top of the Eocene. This horizon reflects a change from weakly (Eocene) to vigorously (early Oligocene) circulating bottom water. Sediment distribution patterns provide evidence for strong contour-following bottom water flow beginning at reflector R4 time; this suggests a northern source for this bottom water, probably from the Arctic via the Norwegian-Greenland Sea and Faeroe-Shetland Channel. Erosion and current-controlled sedimentation continued through the Oligocene; however, above reflector R3 (middle to upper Oligocene), the intensity of abyssal currents decreased. Above reflector R2 (upper lower Miocene), current-controlled sedimentation became more coherent and a major phase of sedimentary drift development began. This resulted from further reduction in speeds and stabilization of abyssal currents.

Late Paleogene paleontological and stable isotopic data support these interpretations. In the Bay of Biscay/Goban Spur regions, a major $\delta^{18}O$ increase began at ~38 Ma (late Eocene), culminating in a rapid (<0.5 m.y.) increase in $\delta^{18}O$ just above the Eocene/Oligocene boundary (~36.5 Ma). A rapid $\delta^{13}C$ increase also occurred at ~36.5 Ma in these sites. Major changes in benthic foraminiferal assemblages also occurred between the middle Eocene and the earliest Oligocene: (1) In the Labrador Sea, a predominantly agglutinated assemblage was replaced by a calcareous assemblage between the middle Eocene and early Oligocene, (2) In the abyssal (>3 km, 10,000 ft paleodepth) Bay of Biscay, an indigenous Eocene calcareous fauna including *Nuttallides truempyi*, *Clinapertina* spp., *Abyssammina* spp., *Aragonia* spp., and *Alabamina dissonata* became extinct between the middle Eocene and earliest Oligocene, (3) In shallower sites (<3 km, 10,000 ft paleodepth) throughout the Atlantic, a *Nuttallides truempyi*-dominated assemblage was replaced by a *Globocassidulina subglobosa-Gyroidinoides-Cibicidoides ungerianus-Oridorsalis* assemblage in the early late Eocene (~40 to 38.5 Ma). These faunal and isotopic changes represent the transition from warm, old, corrosive Eocene bottom waters to colder, younger (lower CO_2 and higher pH, hence less corrosive) early Oligocene bottom waters.

A ^{18}O enrichment noted previously in the Southern and Indian Oceans is synchronous with the enrichment in the North Atlantic. The enrichment probably cannot be attributed only to initial entry of Arctic/Norwegian-Greenland Sea sources of cold bottom water. There is evidence that initial formation of cold, vigorously circulating bottom water from both northern sources (as denoted by reflector R4 and Horizon A^u) and southern sources (as denoted by erosion of widespread unconformities and other changes previously described from the Southern and Pacific Oceans) began near the end of the Eocene. These events also were reflected by a major ^{18}O enrichment. High-salinity water provided by North Atlantic deep water is important in the formation of Antarctic bottom water today. Such linkages or "teleconnections" might be invoked to explain the formation of southern bottom-water sources following the tectonically-controlled entry of northern sources of bottom water into the North Atlantic.

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Paleogene Bathymetry and Oceanography of Deep-Sea Benthic Foraminifera from the Atlantic Ocean

Paleodepth estimates obtained from empirical age-versus-subsidence curves of oceanic crust allow an independent determination of the paleobathymetric distributions of deep-sea benthic foraminifera. Such "backtracking" of DSDP sites together with studies of planktonic biostratigraphy, seismic stratigraphy, lithostratigraphy, and isotopic studies allows the placement of benthic foraminifera into a chronologic, paleobathymetric, and paleoceanographic framework. This approach has proven to be successful in recognizing several bathymetrically distinct deep-sea foraminiferal biofacies from the Paleogene of the Atlantic Ocean. Paleocene species have broad bathymetric ranges, but Eocene and Oligocene species tend to be bathymetrically more restricted.

Paleocene deep-water benthic foraminifera are predominantly relict Cretaceous taxa. Comparison of Paleocene deep-water benthic foraminiferal faunas with Cretaceous benthic faunas shows that, unlike planktonic organisms, there was no crisis in benthic foraminifera at the end of the Cretaceous. Most of the faunal variation in the Paleocene is attributable to the gradual bathymetric restriction of the shallower *Gavelinella beccariiformis* assemblage and the bathymetric expansion of the deeper *Nuttallides truempyi* assemblage. Such depth migrations, both expansions and restrictions, are prominent among the faunal changes noted in deep-sea benthic foraminifera studied to date. A major benthic faunal crisis occurred in the latest Paleocene (Zone P6a) with rapid massive extinctions at the generic and specific levels. Most of the extinctions occurred in the shallower *G. beccariiformis* assemblage containing predominantly Cretaceous relict species; the *N. truempyi* assemblage was characterized