and transmitting light microscope) from the Arctic, Bering Sea, Gulf of Mexico, Southern Atlantic, equatorial Pacific, California continental borderlands, Indian and Antarctic Oceans. Three groups of spongodiscid-type radiolarians were identified. (1) *Spongotrochus glacialis* group (robust spongy matrix, with or without spines, without arms) dominates the polar oceans. The diversity is low and the assemblage can inhabit the waters of the shelf as well as the slope. (2) *Stylochlamydium venustum* group (spongodiscid-type with distinct pores, spongy matrix, with or without spines, without arms) plus *S. glacialis*, dominate subarctic assemblages. (3) *S. glacialis* and spongodiscid-type with arms are found in the equatorial region. The diversity here is much greater than in any of the other areas. These results are plotted on a world map comparing the distribution of recent spongodiscid-type with surface-water temperature, water temperature at depth 200 and 400 m (656 and 1,312 ft), surface salinity, surface and bottom currents and bottom topography of the world ocean.

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A New Model of Succession of Middle and Late Pennsylvanian Fossil Communities in North Texas, Mid-Continent, and Appalachians with Implications on Black Shale Controversy

A new model for the succession of Pennsylvanian fossil communities, preserved in cyclothems, is proposed on the basis of more than 200 fossil localities in the Mid-Continent, Appalachians, and north Texas.

Early models for Mid-Continent cyclothems placed the black shales in shallow water, with maximum transgression at the fusulinid-bearing zone in the overlying limestone. The most recent model proposed that the black phosphatic shales, which commonly occur between two subtidal carbonates, are widespread and laterally continuous over great distances and represent maximum transgression.

The black phosphatic shales contain: ammonoids; inarticulate brachiopods; radiolarians; conularids; shark material and abundant and diverse conodonts. This assemblage represents a pelagic or epipelagic community developed in a stratified water column over an anoxic bottom.

The black shales grade vertically and laterally into dark gray-black shales which contain many of the same pelagic and epipelagic forms found in the phosphatic black shales, plus the following: low diversity of articulate brachiopods; large numbers and diversity of ammonoids together with other cephalopods; hyolithids; blastoids; trilobites; corals; and moderate diversity and numbers of bivalves and gastropods. This facies contains the deepest water benthic community. Most of these forms are immature, pyritized, and generally are preserved as molds. The ammonoids include both nepionic and late juvenile–early mature forms with the body chambers. These ammonoids, along with the other immature invertebrates, suggest mass mortality due to fluctuating low bottom oxygen as the deeper water stratification was breaking up.

The dark gray-black facies grades into a medium gray shale facies which contains a mature molluscan fauna. This assemblage contains many of the same benthics as the dark gray facies, but with greater diversity. The pelagics and epipelagics, including plants, are rare to absent, except for the conodonts, which are diverse and abundant.

The medium gray shale grades into a lighter gray facies, which is dominated by brachiopods, crinoids, and corals, with occasional bivalves and gastropods. Fusulinid and coral communities may also occur in the slightly shallower depths. (These facies are interpreted as being a moderate to shallow depth shelf community.)

The brachiopid-crinoid community is succeeded by shallow water communities which may have occupied shoreline, lagoonal, bay, interdeltaic, or shallow prodeltaic environments. These communities are low to high diversity molluscan assemblages, generally lacking ammonoids, and have a very low diversity conodont assemblage. These shallow water assemblages are discontinuous and occur commonly interbedded with sandstone, in the regressive and early transgressive portions of each cycle. In addition, coals are sometimes present that grade vertically into black carbonaceous shales that are non-phosphatic, lack benthic and pelagic forms, and contain plant compressions. These black shales are interpreted as being marsh deposits.

This model is consistent with the findings of Yancey and Stevens with the Lower Permian fossil communities in the western United States. In addition, this model agrees with Calver's work on the succession of communities associated with the cyclothems in the Westphalian of England.

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Geology and Petroleum Potential of Flathead Region, Flathead County, Montana, and Southeastern British Columbia

Discovery of oil seeps in the Flathead region led to wildcat drilling by 1902. Exploration on the U.S. side stopped by 1910 because of the formation of Glacier Park, and the fact that the oil seeps were in Precambrian sedimentary rocks. Exploration continued through the 1930s on the Canadian side with drilling in the vicinity of major oil seeps. Exploration in Canada from the 1950s to present has included seismic work and six wildcat tests in the Flathead region. A land play has been going on in northwestern Montana for the past several years and recently released seismic data have demonstrated major structures that apparently involve Paleozoic rocks. Plans for drilling have been announced.

The Glacier-Waterton and Flathead region are on the Lewis thrust plate. At the Sage Creek, British Columbia, oil seeps, drilling in 1952 penetrated the Lewis fault after drilling 4,400 ft (1,341 m) of Precambrian sedimentary rocks, and then drilled a strongly faulted sequence of upper Paleozoic carbonates and sandstones with several oil shows. The Precambrian rocks on the Lewis plate in the U.S. thin into Canada, eventually to zero where Paleozoic and Mesozoic rocks are carried by the Lewis fault. An area of hundreds of square miles of Paleozoic and Mesozoic outcrop, including the Fernie basin, is present immediately across the international boundary from areas of Montana which have been mapped as containing great thicknesses of Precambrian sediments. In the northern Whitefish Range of Montana, nearly 40 mi (64 km) from the leading edge of the Lewis thrust, is 30 mi^2 (78 km^2) of Paleozoic and Mesozoic outcrop containing several petroliferous units. This sequence is the only part of the extensive Paleozoic and Mesozoic outcrop of southeastern British Columbia which extends into the U.S., but it is important in understanding the involvement of Paleozoic and Mesozoic rocks in complexly faulted northwestern Montana. The Whitefish Range Paleozoic and Mesozoic sequence is cut by several minor thrust faults as well as having been overthrust by the Hefty plate, present now as klippe on the highest peaks of Paleozoic rocks. The Couldry and Tuchuck faults cut these rocks a few miles to the west.

Between the Whitefish Range and the Livingstone Range of Glacier Park lies the Kishenehn basin, a graben to half-graben formed by the listric normal Flathead fault on the Lewis plate. This basin is filled with Oligocene Kishenehn formation, a fluvial

to lacustrine sequence, which may be as thick as 16,000 ft (5 km) on the east side, thinning to a few thousand feet or to zero on the west where fault bounded. The Kishenehn formation contains lignite and oil shale beds which may be buried deep enough in parts of the basin to generate hydrocarbons; recent drilling discovered oil and gas shows at less than 200 ft (61 m).

The presence of oil and gas shows in many formation as well as the presence of major structures containing porous host beds indicates that this area has an excellent potential for the discovery of hydrocarbons.

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Dissolution of Plagioclase as Hydrocarbon Reservoirs

Plagioclase feldspar is an important contributor to reservoir porosity as indicated by studies of first-cycle Miocene basins of south Texas (Frio Formation) and southern California (Stevens Formation). In the former case study, volcanic plagioclase (An_{32}) exhibits secondary porosity with associated partial albitization. In the latter case, plutonic plagioclase (An_{30}) exhibits secondary porosity without albitization, although petrographically albite was stable with respect to the leach fluids. In both examples, dissolution was highly selective proceeding 2 to 3 times faster along cleavage planes than normal to them.

The dissolution by-product is chiefly kaolinite such that the overall reaction is $2H^+ + H_2O + CaAl_2Si_2O_8 = Al_2Si_2O_5(OH)_4 + Ca^{++}$. Formation water compositions indicate the leach reactions are occurring today at about 100°C (212°F).

Petrographic, microprobe, and mass balance calculations indicate that alumina is conserved on the scale of a thin section. Calcium is particularly mobile on a scale of tens of meters.

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Thermal-Mechanical Modeling of Early Paleozoic Miogeoclinal Sequences in Southern Canadian Rockies

We have applied 2-dimensional thermal-mechanical stretching models to palinspastically restored sections of the early Paleozoic miogeocline in the southern Canadian Rocky Mountains. Results of modeling suggest that the miogeocline consists of an inner easterly tapering wedge of mainly carbonate rocks over 200 km (124 mi) wide in which early Paleozoic tectonic subsidence was controlled mainly by thermal contraction as predicted by the passive margin model for the miogeocline. To the west lies a complex and much wider belt of uplifted, carbonate platforms and downfaulted shale-filled basins in which subsidence was episodic and probably controlled by recurrent movement along high angle or listric normal faults. The boundary between the two belts is the Kicking Horse Rim, a narrow northwest-trending reeflike tract of stacked algal complexes. Preliminary analyses of early Paleozoic miogeoclinal strata north and south of the southern Canadian Rockies suggest that these belts can be traced through most of the Cordilleran miogeocline.

We have analyzed stratigraphic relations within the inner carbonate belt east of the Kicking Horse Rim using one- and two-layer stretching models that include lateral heat flow and time-space dependent flexure. Each model was applied to three palinspastically restored cross sections of Upper Cambrian to Upper Ordovician strata restored to their original thicknesses and densities through time using delithification procedures we have developed for fully compacted lithologies in ancient basins. Both models (1) produce the overall shape of the carbonate wedge, (2) imply that thermal subsidence could not have begun earlier than about 550 to 600 m.y. ago, and (3) suggest an eustatic rise and fall occurred between Middle Cambrian and Middle Ordovician time. However, the widespread sub-Cambrian unconformity and the rapid eastward pinch-out of Early Cambrian strata within the carbonate wedge can be produced only by the two-layer model. In addition, lateral heat flow predicted by the two models at the outer edge of the carbonate wedge causes a small uplift whose position and timing could account for the sub-Middle Cambrian unconformity beneath the Kicking Horse Rim and shoaling required for growth of the algal complexes of the rim itself.

Both models imply that a hinge zone (zone separating crust thinned by stretching from crust of normal thickness) trended northward and lay close to the restored position of the McConnell thrust at about 52° lat. To the south at about 51° the hinge zone bends westward and at about 50° it lies along the west-trending St. Marys–Dibble Creek fault zone. We suggest that west-trending middle Precambrian high angle faults recognized along the St. Marys–Dibble Creek Zone controlled the position of a west-trending reentrant in the early Paleozoic margin. Between 52° and 51° the position of the hinge zone on a palinspastically restored base coincides closely with a distinct step in the depth to Moho indicated by refraction data. This relation may indicate that fundamental crustal structures of rifted margins such as hinge zones can be preserved in Moho topography over geologically long periods of time even where subsequent compressional events have occurred.

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Vitrinite Reflectance and Temperature Gradient Models Applied at a Site in Piceance Basin, Colorado

Two adjacent DOE multiwell experiment (MWX) boreholes were drilled to a depth of 2,520 m (8,268 ft) below the valley of the Colorado River near Rifle, Colorado. High quality vitrinite reflectance data ranging from 0.88 to 2.07% were obtained from cores from the Upper Cretaceous coaly interval (1,340 to 2,423 m; 4,396 to 7,949 ft). Remnants of basalt flows that cap highlands above the valley are 9 m.y. old, and 1,500 m (4,921 ft) of Eocene and Pliocene sediments have apparently been eroded from above the site by the Colorado River since the basalt was extruded. The excellent reflectance data and the geologic setting allow a test of three ways to evaluate maturation of vitrinite.