

characteristic of shallower environments represent a displaced fauna.

Recognition of the Eocene *Ophiomorpha nodosa* Lundgren in the subsea fan deposits of the northeastern Olympic Peninsula documents an upper bathyal occurrence for this trace fossil.

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Late Neogene Depositional and Climatic Cycles in Yakataga Formation, Gulf of Alaska

Lithofacies and chronostratigraphic analyses indicate three relatively warm and three relatively cool paleoclimatic intervals within the 5,000-m-thick strata of the lower Miocene through Holocene Yakataga Formation of the Robinson Mountains, eastern Gulf of Alaska. The cycle identified correlates with the widely recognized paleoclimatic cycle of warm middle Miocene, fluctuating late Miocene, cool terminal Miocene, warm early Pliocene, and cool to cold late Pliocene and Pleistocene. Glacial periods, recognized by the predominance of glacial lithofacies associated with populations of *Neoglobigerina pachyderma* s.l., are interpreted for the cool intervals. In the sections studied, the interglacial intervals have little or no glacial deposits.

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Hydrocarbon Potential of Sitkalidak Formation, Eocene Submarine Fan Complex, Kodiak Island Archipelago, Alaska

The middle upper Eocene Sitkalidak Formation is a 4,000-m thick sequence of interbedded sandstone, shale, and conglomerate. The formation crops out along the southeast side of the Kodiak Island archipelago and is believed to underlie the continental shelf for several hundred kilometers along a northeast structural grain. The Sitkalidak Formation, as used here, includes marine sandy flysch previously mapped as Sitkinak Formation.

The Sitkalidak Formation is a complex of submarine fans deposited at mid- to upper-bathyal depths in a northeast-trending structural trough. This trough was probably an accretionary basin located on an oceanic trench inner slope. The submarine fan deposits were subsequently faulted and uplifted during late Eocene subduction along an ancestral Aleutian trench. Emplacement was complete by early Oligocene time as the Sitkalidak Formation is overlain with angular discordance by the nonmarine Sitkinak Formation of Oligocene age.

Sitkalidak Formation sandstones were deposited as quartz-poor and mineralogically unstable feldspathic lithic arenites. Diagenesis has greatly reduced primary porosity and permeability to an average 2.5%  $\phi$  and 0.01 md k (101 samples —  $\phi$  = 1.0 to 7.5%; k = 0.0 to 1.3 md).

Sitkalidak Formation shales are gray to black silty claystones which contain dominantly terrestrially derived organic matter. Total organic content averages 0.44% (217 samples — TOC = 0.01 to 2.38%), suggest-

ing lean source-rock potential for liquid hydrocarbons. Vitrinite reflectance values average 0.80% (53 samples —  $R_o$  = 0.54 to 0.92%), suggesting thermal maturity levels sufficient for oil generation.

Despite the presence of thick sandstone sequences and potential structural and stratigraphic traps, the Sitkalidak Formation has a low potential for hydrocarbon production because of the poor reservoir character of the sandstones and poor source potential of the shales.

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The Mississippian System of New Mexico and Southern Arizona

Lower Mississippian rocks of New Mexico and southern Arizona (pre-zone 7 Tournaisian age) are unconformable on rocks of Late Devonian to Precambrian age. Mississippian rocks were deposited during transgression on a surface of low relief. Tournaisian transgression began in southern Arizona, depositing the Escabrosa Limestone and, in southwestern New Mexico, the Keating (207 m), Caballero (18 m), and Lake Valley (180 m) Formations. At the end of Tournaisian time, epicontinental seas flooded southern and central Arizona, depositing the younger parts of the Escabrosa and Redwall Limestones. Osagean seaways extended to central and northern New Mexico depositing Kelly (35 m) and Espiritu Santo (35 m) Formations. The Espiritu Santo consists of subtidal to supratidal quartz sandstone and carbonate rocks. Zuni Highlands and Pederal Highlands formed two low islands. The end of the Tournaisian is marked by marine regression, regional uplift, and erosion. Major regional marine transgression in early Visean is represented by parts of Escabrosa Limestone of southern Arizona, massive encrinites of the Hachita Formation (107 m) in southwestern New Mexico, basin carbonate rocks of the lower part of the Rancheria Formation (46 m) in south-central New Mexico, and the subtidal Tererro Formation (18 m) in north-central New Mexico. The Cowles Member (10 m) of the Tererro Formation indicates that sedimentation ceased in northern and central New Mexico in late Visean time. In southwestern New Mexico, the Paradise Formation (134 m) represents shallow-marine sediments and ranges from zone 15 into zone 19 (late Visean and Namurian). The Rancheria Formation (69 m) and the Helms Formation (50 m) of south-central New Mexico are deep-water facies of the Paradise Formation.

Pennsylvanian sedimentary rocks in southern Arizona and in New Mexico truncate Mississippian sedimentary rocks of Namurian, Visean, and Tournaisian age.

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Oxic-Anoxic and Carbonate Cycles in Cretaceous Organic Carbon-Rich Marine Strata

Sedimentary sequences of Early to middle Cretaceous

age that are rich in organic carbon (C-org) are common in the deep seas and in shallow interior and shelf basins of the world. High concentrations of C-org and the presence of fine laminations suggest that these strata accumulated in environments that were anoxic or nearly anoxic at and possibly above the seafloor. Many organic-rich sequences display a marked cyclicity in amount of C-org and, if deposition was near or above the carbonate compensation depth, in  $\text{CaCO}_3$  as well. These cyclic C-org and  $\text{CaCO}_3$  variations result in interbedded lighter and darker shale, marlstone, and limestone that have cycle periods ranging from 20,000 to 100,000 years. Variations in degree of bioturbation parallel changes in C-org and  $\text{CaCO}_3$  because burrowing organisms were most active at times of deposition of relatively low C-org and high  $\text{CaCO}_3$  sediments.

Such cycles are best developed in sediments deposited during episodes of lower dissolved oxygen concentration (so-called "oceanic anoxic events"), but similar cycles of C-org and  $\text{CaCO}_3$  variation having periods of tens of thousands of years occur in strata of almost every geologic age. The periodicities are similar to those in pelagic sediments of Pleistocene age that are known to be climatically induced. Studies of geochemistry, stable isotopes, and mineralogy show that older organic cycles are also related to climatic changes that produced fluctuations in the amount of wind- and river-borne clastic sediment and terrigenous organic matter delivered to the oceans, and to coincident variations in surface-water salinity, productivity, and mid- to deep-water oxygen concentration. Regional paleogeography and paleodepth determined the amount and type of organic matter preserved within the sediments.

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#### New Exploration and Evaluation of Coal Resources in Complexly Faulted Area Containing Old Petroleum Production

The use of standard core-drilling methods to evaluate commercial possibilities of deep Pennsylvanian coals in southwestern Indiana is difficult if not prohibitively expensive owing to complex faulting and the presence of numerous alluvial channels.

In Posey County, where complex faulting is common, more than 5,000 oil tests have been drilled, most having electric logs or other geophysical logs run more than 20 years ago. Correlation of these logs with nearby coal-test cores, lithologic strip logs of well cuttings, and sparse outcrop information has resulted in: (1) mapping of zones of closely spaced normal faults (as many as four individual faults in a single well) with vertical displacements of 20 to more than 300 ft (6.1 to  $>91.4$  m) and horizontal lengths of as much as 20 mi (32 km); (2) rapid mapping of coal thicknesses to an accuracy of about 1 ft from old geophysical logs; (3) delimiting of channels that are contemporaneous with peat deposition (related to thickness and sulfur content of coals); and (4) correlating for the first time several lithologic units in rocks of Pennsylvanian age. Through study of modern mining techniques in an area of closely spaced drilling in Indiana and Illinois we are able to consider

the potential for underground mining in highly drilled areas of old petroleum production. Data integration from these diverse sources facilitates rapid outlining of prospective areas of minable deep coals that would not be possible otherwise.

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#### Petroleum Prospects of Anambra Basin, Southern Nigeria

The Anambra basin occupies an area of about 40,000 sq km in southern Nigeria. Twenty-one exploratory wells have been drilled in the basin between 1952 and 1974. None tested formations older than lower Turonian. Five of the exploratory wells discovered gas while only one well encountered oil. These discoveries indicate that the basin is dominantly a gas-condensate basin. Because of plans to build an LNG plant in the neighboring Niger delta, an intensive exploration must be carried out in the basin to determine the gas reserves which can be tied into the proposed Niger delta LNG.

About 5,000 m of sediments ranging in age from Aptian(?) to Miocene are exposed in the basin. The sediment distribution consists of shales and limestones in the central part of the basin which grade into coarse-grained sandstones in the northwestern and eastern flanks of the basin.

Evaluation of wells drilled shows that the basin is most prospective where peripheral sandstones interfinger with or are overlain by shale units. Future exploration efforts should be concentrated on Turonian and Maestrichtian objectives which show good sand development beneath the zone of freshwater flushing.

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#### Promising Morrow Sandstone Discoveries in Southeastern Colorado

Eight new Morrow oil and gas fields have been discovered in southeastern Colorado during the past two years. The latest discovery resulted in a well flowing oil from a Morrow sandstone at an initial rate of 700 bbl of oil per day and 750 Mcf of gas per day. The trapping mechanism in this well, as in most, is a stratigraphic and structural combination.

The depositional history of Morrow sandstones in southeastern Colorado was strongly influenced by regional tilt into the Anadarko basin, established at the close of Mississippian time. Mississippian rocks were subject to truncation in the area of the Las Animas arch and development of karst topography on the erosion surface. Transgression of the sea from the southeast in Morrowan time resulted in the deposition of a sandstone and shale sequence.

The Morrow series consists of a basal transgressive sandstone member (Keyes sandstone) overlain by at least three sandstone units deposited during regressive pulses in an overall transgressive sequence. These Morrow sandstones generally trend from northwest to southeast toward the Anadarko basin; their source is inferred to have been the ancestral Rocky Mountain