uplift and pediment cutting. At least 3 principal stages covering a vertical interval possibly as great as 1,300 ft have been identified. Soil profiles in Quaternary gravels capping the pediments show increase in maturity consistent with age inferred from topographic elevations. These local erosional stages may record tectonic events of regional significance. Their absolute ages need to be determined.

CONNOR, CAROL WAITE, U.S. Geol. Survey, Denver, CO

Sixty-Five Volcanic Events Recorded in Single Coal Bed

The preservation potential of a continual series of volcanic ash falls is slight. There must be a favorable depositional site downwind and within range of an area of pyroclastic activity. A favorable depositional site is a body of quiet or deep water, existing through a long period of time, with relatively rapid normal sedimentation that covers each ash fall before another fall occurs.

In a slowly subsiding basin, the early Paleocene Big Dirty coal swamp of central to eastern Montana provided an ideal depositional environment, and it was partially ringed by areas of volcanism 140-300 km north, northwest, and west of the western edge. As many as 65 ash falls, one by one, blanketed the swamp and were covered by organic debris. The resultant sedimentary package, the Big Dirty coal bed, is particularly well exposed in the Bull Mountain coalfield, northeast of Billings, Montana. Layers of altered volcanic ash and sanidine-rich crystal tuff average 1.5 cm thick and are separated by an average 7.6 cm of coal, tuffaceous coal, or carbonaceous tuff. The Big Dirty coal bed contains a rare continuous record of a period of frequent volcanic eruptions.

CONOLLY, JOHN R., Sydney Oil Co. Ltd., Sydney, Australia, and JOHN C. FERM, Univ. Kentucky, Lexington, KY

Volcanic Sediments—New Reservoir Fairways in Back-Arc Basins, Eastern Australia

Volcanic rocks and associated lithic sandstones, hitherto thought to be too tight and impermeable, may well form important new reservoirs in the extensive Permian back-arc basins of eastern Australia. Oil and gas production has already been established in these sediments in the Permian Bowen and Surat basins of Queensland with some new discoveries in tuffaceous rocks. Most of these volcanic rocks were derived from andesitic, dacitic, and rhyolitic island-arc complexes that lay to the east or the open paleo-Pacific side of a back-arc depositional area. The sediment in these back-arc areas is composed mainly of sand, conglomerate, and silt, all with low percentages of quartz and derived from the volcanic arc. These sediments are interbedded with 1-5 m thick subbituminous to bituminous coal seams, which have been mined extensively in open-cut and shallow subsurface areas of the Bowen and Sydney basins. Basin analysis, using coal stratigraphy and deep wells in the Sydney basin, has established several potential reservoir fairways controlled by facies distribution of the cleaner sands. The variation in reservoir properties within many new potential fairways can be illustrated for parts of both the Sydney and Surat basins. A combination of better understanding of the reservoir properties of these volcanic sediments combined with better drilling, completion, and stimulation techniques lends credence to the hope that these back-arc provinces may become important new oil and gas basins.

CORLEY, B. H., Birdwell Wireline Services, Tulsa, OK

Predicting Interval Transit Time for Synthetic Seismograms from Nuclear Well Logs

Sonic logs commonly were not included as part of the logging program on older wells. In certain areas, wells are drilled with air. The absence of drilling fluid in the borehole eliminates the possibility of recording a sonic log. In other areas, sonic logs are either of poor quality or, for one reason or another, omitted from the logging program. A method has been developed to predict interval transit times using nuclear well logs. It involves combining neutron, density, and gamma-ray log measurements into a log of predicted interval transit times referred to as a synthetic sonic log.

The method involves a combination of commonly used and accepted well-log interpretation techniques. It effectively accounts for lithology, shale, porosity and hydrocarbon effects. The method requires only 3 parameters, which may be selected based on the well-log data. The synthetic sonic log agrees well with actual sonic-log measurements over a wide variety of geographic areas and borehole depths. The method is effective for formations commonly encountered in geophysical well logging including salt, shale, sandstone, and carbonate.

The synthetic sonic log is an excellent substitute for use in generating synthetic seismograms and establishing time-depth relationships.

CORSO, WILLIAM, and RICHARD T. BUFFLER, Univ. Texas at Austin, Austin, TX

Seismic Stratigraphy of Lower Cretaceous Carbonate Platforms and Margins, Eastern Gulf of Mexico

Detailed seismic stratigraphic studies document the development of Lower Cretaceous platforms and margins along the Florida Escarpment and Jordan Knoll in the eastern Gulf of Mexico. Four different areas are characterized by relating seismic facies to depositional models: (1) northwest of DeSoto Canyon a rimmed platform margin with low paleo-relief (about 1,500 m over a distance of 20 km) grew in a stationary manner and developed an accretionary slope, (2) a rimmed platform with high paleo-relief (about 2,500 m over a distance of 6 km) is exposed along the Florida Escarpment from DeSoto Canyon south to about 24°30′N (this part of the platform margin also grew in a stationary manner but developed a bypass slope), (3) a rimmed platform margin with moderate paleo-relief evolved from about 24°30′N south to the Straits of Florida, and (4) an isolated platform with steep paleo-relief formed on a basement high at Jordan Knoll west of the Florida Escarpment. This platform also grew in a stationary manner and developed bypass slopes. The evolution of the various types of platform margins is related to their overall tectonic setting. Two episodes of platform drowning have been identified: (1) middle to late Albian(?) with the development of intrashelf basins and (2) middle Cenomanian when the platforms were terminally drowned due to a rapid change in relative sea level.

Erosional truncation of reflections along the base of the Florida Escarpment suggests that parts of the platform margin have retreated up to 2-5 km since the middle Cenomanian.

COVENEY, RAYMOND M., JR., Univ. Missouri at Kansas City, Kansas City, MO, and NELSON R. SHAFFER, Indiana Geol. Survey, Bloomington, IN

Sulfur Isotopes Related to Sedimentation Conditions for Metalliferous Black Shales of Pennsylvanian Age

Sulfur isotope compositions were determined for pyrite and sphalerite grains isolated from 8 metalliferous Missourian, Desmoinesian, and Atokan black shales from Missouri, Illinois, Kansas, and Indiana.

The younger Missourian shales from the Forest City and Illinois basins contain consistently light sulfur as expected for euxinic conditions, but sulfides from the older shales show heavier and more erratic sulfur values. These isotope patterns suggest that younger shales accumulated slowly offshore, although older shales may have been deposited more quickly in shallower water. Isotope values, which also correlate with heavy metal patterns (e.g., higher molybdenum values for the easternmost older shales), may therefore reflect gradually deepening conditions for the epicontinental Pennsylvanian seas of the United States Mid-Continent.

COVINGTON, J. MITCHENER, Florida State Univ., Tallahassee, FL

Morphologic Information on Cretaceous Nannofossils from Niobrara Formation

Multiple zones of exceptional preservation within the Niobrara Formation (Upper Cretaceous) have revealed much new morphologic information on coccolithophores. Nine species were found with coccospheres intact, including a species of *Biscutum* with extraordinary cylindrical rather than spherical coccospheres. Cylindrical coccospheres have not been reported from the fossil record, and are rare in modern oceans. An unusual feature of these cylindrical tests is the orderly, repetitive arrange-

ment of the individual coccoliths. Most cylinders are open at both ends, but one specimen illustrated by electron micrographs with one end nearly closed reveals significantly smaller coccoliths at the ends. These smaller, simpler coccoliths probably did not articulate as tightly as those on the rest of the cell and were easily detached. Because of the difference in size and morphology, these terminal coccoliths may have previously been assigned to other taxa. A coccosphere of *Braarudosphaera bigelowi*, not previously illustrated from the fossil record, is also documented in this study.

The stagnant, anoxic benthic environment prevalent during these intervals of Niobrara deposition also fostered the preservation of monospecific coccolith clusters that represent coccospheres formed of nonarticulated coccoliths. These clusters, representing 35 different species, including *Lithraphidites carniolensis, Bolevetelum* sp., *Microrhabdulus belgicus,* and *Rhagodiscus angustus,* provide information on the minimum number of coccoliths originally present on the living cell. Such may prove valuable for determining the total biomass of the living populations based on the abundance of individual coccoliths in the fossil record.

CRANE, R. C., Chevron Overseas Petroleum, Inc., Concord, CA

Arctic Reconstruction from Alaskan Viewpoint

Field, seismic, structural, and stratigraphic data were used to reconstruct the geologic history of the Arctic in 10 m.y. time slices from the present to mid-Jurassic—the time of initial opening of the Arctic Ocean. A basic assumption used for the reconstruction is that Lomonosov Ridge, Alpha Ridge, Mendeleyev Ridge, and Chukchi Plateau are all foundered continental plates.

Opening of the Arctic occurred in 2 stages: Late Jurassic–Cretaceous for the Canada basin, and Neogene for the Eurasian basin. Opening was facilitated by 2 subparallel transform shears: the Arctic (Kaltag-Porcupine) on the east and the Chukchi on the west. Deformation was essentially tensional on the Barents side of the Arctic, and shear-compressional on the Alaska side.

The development of Chukotsk, the North Slope, Brooks, Range, northwestern Canada, Seward Peninsula, and central Alaska can be sequentially related to Arctic opening, modified by impingement of allochthonous terranes (the Pacific plates of Tintina, Denali, Orca, Anadyr, Khatyrka, Kolyma) arriving from the south.

The North Slope of Alaska—a passive, rifted, subsided margin—was aligned with a similar margin on Alpha Ridge. Northeastern Alaska (the Romanzoff Mountain area) lined up opposite the north end of the Sverdrup Rim, near Prince Patrick and Borden Islands.

CREANEY, S., Esso Resources Canada, Limited, Calgary, Alberta, Canada

Reaction of Organic Material to Progressive Geologic Heating

The generation of oil is a process that begins to occur at some point during the burial history of a source rock. This "onset of maturation" is dictated largely by temperature and residence time. However, the nature of the source rock itself also influences the hydrocarbon product being expelled from the source rock. The vast majority of the world's oil can be ascribed to source rocks of the following types. (1) Marine mudrocks deposited in anoxic conditions and dominated by phytoplankton organisms; this type of source rock can have a carbonate or clay inorganic matrix and total organic carbon values from 1 to 30% (commonly 4 to 10% when immature). Examples of this classical oil source rock would be the source rocks of western Canada, the Middle East, and the North Sea. (2) Specific coal facies such as torbanites and cannel coals, which contain a mixture of hydrogen-rich plant detritus (e.g., spores, pollen, cuticle, resin, and algae); deposition was probably in open-water areas of an overall coal-swamp environment. Examples of hydrocarbons from this type of source include the Gippsland basin, Canadian Beaufort Sea, and Southeast Asia. (3) Lacustrine organic-rich deposits, rich in freshwater algae, which ultimately result in high-wax crude oils. Examples are relatively rare, but include major source rocks in the Uinta basin and China.

The effect of increasing maturity on marine mudrocks of the Devonian Duvernay Formation of Alberta illustrates oil generation from this type of source rock. The data base in this unit consists of 40 conventional cores, ranging from immature to completely overmature, and 80 oils from separate accumulations sourced from the Duvernay. An illustration of oil generation in a coaly source rock is provided by a single core from the Lower Cretaceous of the Beaufort-Mackenzie basin plus many of the oils and condensates reservoired in that area.

CULVER, STEPHEN J., and ANTHONY C. GARY*, Old Dominion Univ., Norfolk, VA, and MARTIN A. BUZAS, Smithsonian Inst., Washington, D.C.

Benthic Foraminiferal Morphology: New Approach to Paleodepth Interpretations in Northern Gulf of Mexico

Variation in benthic foraminiferal morphology is a potentially powerful tool in paleoenvironmental and paleobathymetric interpretations. Recognition of distribution patterns of particular morphologic characters in modern Gulf of Mexico taxa will enable these distributions to be applied to bathymetric interpretations of Tertiary core samples.

The morphology of the 295 most commonly recorded benthic foraminiferal species in the northern Gulf of Mexico was scored into 68 categories describing test shape, chamber shape, chamber arrangement, apertural characteristics, and surface sculpture. Cluster analyses of these data at 300 localities resulted in maps showing the distribution of particular sets of morphologic features. Many of these "morphologic biofacies" are depth relatable. Canonical variate analysis was used to determine which morphologic variables were most important in distinguishing the various biofacies.

This approach to paleobathymetric interpretations should be applicable throughout the Cenozoic and perhaps into the Mesozoic, as morphology can be considered as an adaptive response to environmental factors. Even though different taxa are involved throughout the Cenozoic, similar morphologic characters can indicate adaptations to similar environments. Hence, this modern data set can be applied to determine paleobathymetry in older samples.

CURIALE, JOSEPH A., STEPHEN R. LARTER, ROBERT E. SWEENEY, and BRUCE W. BROMLEY, Union Oil Co. California, Brea, CA

Molecular Thermal Maturity Indicators in Oil and Gas Source Rocks

Detailed chemical parameters have been proposed as indicators of thermal maturity in oil and gas source rocks. Certain classical maturity parameters involving carbon preference indices and compound class ratios such as HC/EOM and EOM/TOC are infrequently used today, having been largely replaced by detailed molecular parameters. Among these parameters, the molecular distributions of metalloporphyrins, cyclic hydrocarbons, low molecular weight hydrocarbons, and gases are most commonly used. Recent instrumental advances have allowed the measurement of detailed molecular ratios in geochemical organic matter, stimulating the development of biologic markers, such as steranes, hopanes, and metallated tetrapyrroles, as thermal maturity indicators. Increased chromatographic resolution of source rock hydrocarbons has also promoted the use of low molecular weight hydrocarbons, methylphenanthrenes, and aromatized steranes as maturity indicators.

The future use of molecular thermal maturity indicators in source rocks is expected to increase significantly. In addition to further advances in understanding the significance of biologic marker hydrocarbons, metalloporphyrins, and thermally generated light hydrocarbons, the use of other nonhydrocarbons as maturity determinants will probably develop.

DANFORD, J. MICHAEL, Carolina Power and Light Co., Southport, NC

Paleoecology of Foraminifera of Lower Castle Hayne in Southeastern North Carolina

Foraminiferal fauna present in the lower Castle Hayne biomicrudite exposure northeast of Wilmington, North Carolina, suggests a depositional environment in a transitional zone between the open-marine outer continental shelf and the upper continental slope. Evidence that supports