

ends of alternating left and right segments. The segments curve toward one end of the organism, terminating distally in spines. Individual segments exhibit longitudinal ornamentation, and grooves separating adjacent segments indicate articulation.

Data from the USSR, Africa, and South Australia suggest that *Pteridium* lived in a shallow water, near-shore, high-energy environment. However, the CSB examples are preserved in an essentially bedding-parallel position in deep-water flysch, suggesting transportation from nearshore into deep water.

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#### Multiple Depositional Cycles in Bashi and Hatchetigbee Formations (Lower Eocene), Alabama

The marine Bashi Formation and its updip facies equivalent, the Hatchetigbee Formation, may represent the most complete earliest Eocene shallow-marine section in the world. These two coeval formations contain as many as 4 transgressive-regressive cycles, probably reflecting several significant sea level changes during the first 2 million yr of the Eocene. The most transgressive, deepest water marine deposits, which suggest inner to middle neritic depths, are at or very near the base of each cycle, and consist of abundantly fossiliferous glauconitic sand, silt, and clay. The uppermost sediments in each cycle usually consist of clay containing brackish to freshwater palynomorph assemblages. This upward transition in each cycle from neritic to freshwater environments within less than 6 m (20 ft) of section can most reasonably be explained by rapid changes in relative sea level rather than by progradation.

*Discoaster diastypus*, *Tribrachiatus bramlettei*, or *Tribrachiatus contortus* occur in the lower 3 cycles. First occurrence of these 3 species has been used to define the base of calcareous nannofossil Zone NP10 of Martini or the *Discoaster diastypus* Zone of Bukry, both considered to mark the base of the Eocene. In central Alabama, strata above a scour surface at the top of the third cycle do not contain *T. bramlettei* or *T. contortus*, which become extinct at or near the top of Zone NP10, or *Discoaster lodoensis*, which first occurs in Zone NP12; they do have *Tribrachiatus orthostylus*, which first occurs in upper Zone NP10. We tentatively have placed within Zone NP11 these sediments which probably represent a fourth cycle.

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#### Hydrocarbon Entrapment in Alberta Deep Basin

Entrapment of hydrocarbon accumulations in the deepest region of the Alberta sedimentary basin is linked to certain principles of subsurface fluid flow behavior in generally tight sandstones, and to active hydrocarbon generation in adjacent source beds. Similar geologic conditions and associated deep-basin-type hydrocarbon accumulations no doubt exist in the deeper portions of other sedimentary basins.

Conventional concepts of subsurface hydrocarbon accumulation do not apply to the deep basin form of entrapment, yet both mechanisms conform to certain important physical principles of fluid flow behavior. The conventional entrapment idea, based on many case histories and sound physical principles, entails downdip hydrocarbon-over-water contacts, initial reservoir pressures greater than formation water pressures at the same position (the so-called "capillary displacement pressures"), updip reservoir seals, and accumulations that are essentially in static equilibrium.

Deep-basin concepts of hydrocarbon entrapment, on the other hand, are opposed to conventional ideas. Hydrocarbon-bearing sands in deep basin regions grade laterally updip into permeable water-bearing sands without reservoir barriers to segregate the fluids. Water-over-hydrocarbon contacts appear at the updip limits of the accumulations and generally are absent downdip. Original hydrocarbon accumulation pressures are usually less than projected formation-water pressures at common depth points. Deep-basin accumulations fed by active downdip source rocks may be in a dynamic state of slow, updip hydrocarbon migration. Hydrocarbons lost across the updip water/gas contact are replaced by new hydrocarbon influx from downdip source rocks. Prolonged hydrocarbon flux through deep-basin reservoirs may result in

exceptionally low residual water saturations and favorable hydrocarbon relative permeabilities in tight sandstones.

These unusual physical principles of the Alberta deep-basin hydrocarbon accumulations are illustrated by Elmworth field examples and by physical fluid flow models.

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#### Dipmeter Advisor—An Artificial Intelligence Interpretation Program

The Dipmeter Advisor program is an application of Artificial Intelligence and Expert System techniques to the problem of dipmeter interpretation. Development of the rule-based program, which attempts to emulate human dipmeter analysis performance, began in 1978 and has now progressed to the field-test stage.

The program currently contains 90 rules which were obtained from a knowledge engineer's observation of one expert over a period of eighteen months. The program, which is designed to interact with the user and the geologist, divides the process of dipmeter interpretation into 11 successive phases. The sequence progresses from initial examination through validity checks, structural dip determination, structural dip deletion, missing-section analysis, depositional environment analysis, and stratigraphic analysis.

During the interpretation process the program asks the user for information about missing sections and depositional environments. If requested inputs are not available, the program then utilizes structural dip changes as missing-section indicators, and dip scatter plus shale resistivity (in some areas) as environmental indicators. After locating any structural dip changes, the program searches above the point of change for a megared dip pattern. If such a pattern is found, the vertical extent and azimuth of the pattern are used to determine the type of fault (growth, late) and the fault-plane orientation.

Stratigraphic interpretations are performed by comparing, with the rule base, the lithology, dip patterns, and menu of depositional features found within any given environment.

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#### Coral Content of Quaternary Reef Limestones

The coral content of Quaternary reef limestones provides a useful calibration of the preserved record of modern reefs. Estimates of the percentage of corals in outcrops range from 32 to 46% for the Key Largo limestones of south Florida; 18 to 46% for Pleistocene limestones of the Kenya coast; and up to 60% for Pleistocene reef limestones of Barbados. Core borings from the Great Barrier Reef have an even wider range in the percentage of coral, with only localized areas of more than one-third massive or branched coral.

Simulated core borings made on photographs of outcrops call attention to the wide range of variations to be expected. The average standard deviation of coral percentages in simulated core borings is  $\pm 13\%$  as compared with percentages of their respective outcrops.

These results further support the view that percentage of coral in Quaternary reef limestones is highly variable and is often less than one-third of the total biomass. Furthermore, they give a useful baseline for comparing Quaternary and more ancient reef limestones.

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#### Paleogene Sedimentation and Deformation Along Svalbard's Sheared Margin

The northern part of the Svalbard-Barents margin was a shear margin from 58 Ma to 36 Ma. The strike-slip effects on Spitsbergen are evident in (a) the Central Basin, (b) the fold-and-thrust belt of western Spitsbergen, and (c) Forlandsundet Graben.

An early mid-Paleocene transtensional regime is suggested by about

500 m (1,640 ft) of deltaic deposits dispersed westward into the Central basin. These overlapped the basin margins in response to initial high rates of subsidence along the flank of the shear zone. Late Paleocene uplift and increasing transpression along the shear zone is recorded by a drainage reversal and about 2 km (1 mi) of easterly offlapping deltaic deposits.

In western Spitsbergen, deformation of late Paleocene through Eocene age represents the culmination of transpression and is characterized by thrusts, asymmetric folds, and steeply-dipping reverse faults producing approximately 10-15 km (6-9 mi) of crustal shortening.

Farther west, the Eocene to early Oligocene Forlandsundet Graben, and probably other smaller basins, originated after the climax of transpression, possibly during collapse of the uplifted axis of the orogenic belt. Although the Forlandsundet Graben contains a true vertical thickness less than 3 km (2 mi) of fan-delta to submarine fan deposits, its apparent thickness greater than 5 km (3 mi) suggests basin migration during increasing transtensional conditions. Extensional deformation of the graben sequence heralded the transition of the Svalbard margin from a sheared to a rifted regime. From 36 Ma, Spitsbergen was uplifted, and deep (> 5 km, 3 mi) rift basins developed along the new continental margin.

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#### Interactive Geologic Modeling

Improved success in finding hydrocarbons and minerals depends on developing geologic models from seismic, gravity, and magnetic data that most closely approximate real-world settings. Although data processing remains the chore of mainframe and minicomputers, interpretations and modeling of geologic and geophysical information now are best accomplished on personal computers because these computers afford the explorationist maximum freedom to shape and fine tune geophysical evaluations. Three case histories use the GEOSIM geophysical modeling systems to delineate exploration targets.

The first example is Silurian Niagaran reef trends in the Michigan basin. Here, differences in seismic reef anomalies result from variations in carbonate-evaporite stratigraphy encasing the reefs, reef geometry, and reef reservoir parameters. These variations which influence real seismic-response differences can be successfully matched using appropriate geologic models in generating synthetic seismic reef anomalies.

The second example applies gravity and magnetic data to seismic modeling of a Wyoming coal field. Detailed seismic stratigraphy helps locate those portions of the field having multiple seams, although it does not resolve individual economic zones. Gravity data do identify pinchout margins of multiseam zones and pinchouts between principal coals. Magnetic data are then used to delineate the burn (clinker) margin.

Seismic modeling of subtle stratigraphic traps is the broader area of exploration interest contained in the first 2 examples. In the third, successfully modeled and tested examples of lateral changes in deltaic facies and of faulted, unconformity-bounded continent-margin sequences are shown to be successful guides to reinterpretation of seismic data.

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#### Foraminiferal Biostratigraphy and Paleoenvironments of Eastover Formation (Late Miocene), Virginia

Foraminifera from 50 samples taken from the Eastover Formation (Miocene) in Virginia are used in a study of biostratigraphy and paleoecology. The Eastover Formation contains two members: the lower Claremont Manor Member, a clayey, silty, poorly sorted, fine-grained sand which contains abundant foraminifera; and the upper Cobham Bay Member, a well-sorted, shelly, fine-grained sand that contains less abundant foraminifera.

Planktonic species are used to establish a biochronology of the Eastover, while benthic species are used to interpret paleoecology, using the distribution of modern foraminifera as a basis. Evidence of changes in environments through time and varying sea margins is searched for by examination of samples taken from vertical sections and samples taken from different geographic locations within the study area. Additional evidence of paleoenvironments is gained by a grain size analysis of sediments from the formation. Synthesis of this information allows for reconstruction

of the geologic history of the Eastover Formation in terms of environments changing through time and space.

Cluster analysis and canonical variate analysis are used to clarify differences in foraminiferal content between and within the two members and to identify the taxa which cause such differences. Analysis of this type is helpful in revealing any foraminiferal assemblage zones present as well as quantifying data derived from the study.

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#### Heat Flow as an Indicator of Regional Ground-Water Migration in Great Plains

Heat-flow and temperature-gradient measurements indicate a correlation between subsurface structures, regional ground-water flow, and heat flow in the Great Plains. Throughout the province, thick Cretaceous shales act as confining layers to aquifers, e.g., the Dakota (Cretaceous) and the Madison (Mississippian), which flow generally eastward in accord with the declivity of the plains. The vertical component of ground-water flow on the margins of the Denver, Kennedy, and Williston basins evidently exceeds the thermal diffusion rate in the confining layers overlying the aquifers, and causes significant disturbances in the surface heat flow. Heat flow along the eastern margin of the Denver basin in Nebraska may be about 50% higher than normal due to the water flow; the effect in the Kennedy basin in South Dakota and Nebraska may have doubled the surface heat flow. The Williston basin has anomalous heat flow on its eastern margin and may also show effects of intrabasin structures such as the Nesson anticline. These ground-water systems constitute a significant low-temperature geothermal resource that is estimated to exceed  $20 \times 10^{18}$  J of energy. Recognition of this geothermal resource and accurate estimation of the amount of available energy is best achieved by heat-flow studies. For example, estimates of geothermal resources in Nebraska based on heat-flow data and bottom-hole temperature data differ by 80%.

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#### Three-Dimensional Seismic Monitoring of Enhanced Oil Recovery Project

The 3-D seismic survey technique has been used to monitor the progress of an enhanced oil-recovery project in which production is stimulated by in-situ combustion driven by injected gas. A baseline 3-D data volume was recorded previous to the initiation of the combustion program. After combustion had been allowed to proceed for some time, the 3-D survey was repeated. Since the basis for tracking the effects of the combustion process is comparison, great care was taken to duplicate field geometry, recording parameters, and data processing. VSP data were also recorded to locate precisely the target sand reflection time and character.

Previous to the analysis of the 3-D data, synthetic traces were generated from well log data modified in several ways to simulate the effects of the combustion process. The target sand is characterized seismically by an impedance contrast due to low density. The predicted changes in reflection character are primarily due to changes in density caused by increased gas saturation. Complex trace attributes were computed to examine amplitude and other waveform changes. Comparison of preburn to postburn data shows differences that can be explained by increased gas saturation.

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#### Depositional Environment and Reservoir Characteristics of an Upper Devonian Sandstone in the Appalachian Basin, Cherryhill Field, Indiana County, West-Central Pennsylvania

The Appalachian basin is referred to as the birthplace of the oil and gas industry. Drilling has occurred since the Drake discovery well in Titusville, Pennsylvania, in 1859. Applying new tricks in an old basin is one way to help meet tomorrow's energy needs.

An isopach map, cross sections, genetic increment strata (GIS) map, core studies, and subsurface well logs suggest a gas-productive turbidite