sequences (graded bedding characterizes both facies), and single versus multiple clast types.

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Extractable Geothermal Energy in Benue Area, Nigeria

An episodic mobile belt underlies the zone of geothermal springs in the Benue area of Nigeria. The close resemblance between the transverse gravity profiles for the Benue depression and profiles of the central Red Sea depression may indicate a similar origin for the depression. The Benue depression is an expression of a spreading ridge generated from a RRR triple junction which was active in the Early Cretaceous. Separation in the Benue trough ceased in the Late Cretaceous, and the spreading ridge is now defunct and at least partly obscured. In Neogene time, there was predominance of igneous activity in the Cameroon-Adamawa volcanic zone which has many attributes of an embryonic spreading ridge. Many of the Neogene alkaline volcanics in the Benue depression and on the Jos plateau trend northwest-southeast, roughly perpendicular to both the Benue depression and the Cameroon-Adamawa volcanic zone, and may mark the sites of future transform faults.

It is postulated that the geothermal springs in the Benue area are surface expressions of a convective hydrothermal system associated with an embryonic spreading ridge or hot spot. It is also suggested that extraction of energy from this convective hydrothermal system, either for direct heat application or for conversion to electricity in the Benue area, is feasible.

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Late Cenozoic Paleo-oceanography of Norwegian Greenland Sea and Northeast Atlantic: Benthic Foraminiferal Evidence

Analysis of late Cenozoic deep-sea benthic foraminifera from DSDP Legs 12 and 38 was conducted to determine faunal patterns and relate them to the evolution of bottom-water circulation. In the Norwegian Greenland Sea, middle to late Miocene sites from 1,200 to 1,800 m present water depth have an agglutinated benthic foraminiferal assemblage dominated by *Martinottiella communis* and *Spirosigmoilinella* sp.; shallower and deeper sites are barren. A regional unconformity appears to span an interval from within the late Miocene to the early Pliocene. A sparse early Pliocene calcareous assemblage is dominated by *Cassidulina teretis.* Intervals interpreted to represent colder episodes within the late Pliocene-Pleistocene are either barren or contain an assemblage dominated by *Oridorsalis tener.* These alternate with a more diverse assemblage dominated by *Cibicides wuellerstorfi* (> 1,500 m) or *C. teretis, Islandiella norcrossi,* and *Melonis barleeanum* (< 1,500 m) that represent interstadial or interglacial intervals.

North Atlantic sites show higher benthic foraminiferal diversity and better preservation throughout most of the late Cenozoic than the Norwegian Greenland Sea sites. The Norwegian Greenland Sea does not appear to have been a source of North Atlantic deep water during the Miocene to early Pliocene interval because conditions were not conducive to the preservation of calcareous foraminifera. Late Pliocene-Pleistocene assemblage changes in the Norwegian Greenland Sea are interpreted to represent changes in bottom- and surface-water circulation. Episodes of ice cover inhibited bottom-water formation and affected the food supply to the benthos. These intervals alternated with times of more productive ice-free conditions, some of which may have been conducive to bottom-water formation.

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Drilling-Mud Emanometry, a New Technique for Uranium Exploration

Bendix Field Engineering Corp., as a part of the Department of Energy's National Uranium Resource Evaluation (NURE) program, has investigated the feasibility of measuring radon in recirculating drilling mud, and whether the radon variations might be useful for uranium exploration. To implement this program, a prototype instrument was developed and tested. The system works by degassing the drilling mud as it recirculates and by continuously measuring the radon activity of the evolved gas. A record of the relative radon activity, as related to borehole depth, is obtained.

Radon data were obtained at two sites: Sand Wash basin in northwestern Colorado, and the Great Divide basin in south-central Wyoming. At both sites it was found that radon could be measured in the recirculating mud, and the downhole radon profiles paralleled gamma logs obtained from the same drill holes. At the Sand Wash site, the radon content in the mud varied with the lithology encountered. The conglomeratic member of the Browns Park Formation had the highest radon content, twice that of the sand member. The shale of the Mancos Formation had much lower radon levels than either of the other two lithologies. At the Great Divide basin site, the lithology was not as well delineated by the radon profiles.

From this study it was found that radon can be detected in drilling mud and that anomalous radon zones can correspond to uranium concentrations and to variations in lithology. It may also be possible by this method to detect the presence of nearby uranium concentrations.

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Dip-Profile Method of Constructing Structural and Stratigraphic Cross Sections

Dip profiles are graphs that show apparent dip as a function of distance along selected horizontal, vertical, or inclined lines on cross sections. Such profiles not only serve to integrate structural control of all kinds (surface dips, dipmeter dips, and dips derived from contour maps and migrated seismic sections) into a single numerical package, but they also provide a foundation for sophisticated geometric constructions based on the concepts of curvature trajectories and dip isogons. A curvature trajectory is a smooth line that connects points on a cross section where the bedding curvature has a distinctive property not shared by points on either side. (The trace of an axial plane is a familiar example.) Eight kinds of curvature trajectories (of which two relate to dip-slip faults) occur in nature. Each kind is distinguished on dip profiles by a specific, mathematically-defined special point. A dip isogon is a smooth line that connects points of equal apparent dip on those parts of a cross section where the bedding is curved. (The trace of a crestal plane is a familiar example.) Reliable procedures for extrapolating and interpolating curvature trajectories and dip isogons (based on the known or deduced tectonic style) can be used to establish a network of primary and secondary dip profiles—thereby insuring structural and stratigraphic interpretations that are statistically and geometrically consistent with all observed data. The methods described are especially useful for resolving sparse or erratic data and predicting subtle traps and deep structures from shallow control.

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Sea-Floor Characteristics and Dynamics Affecting Geotechnical Properties at Shelf-Slope Breaks

Shelf-break geotechnical and sea-floor stability investigations are rare but such studies offer challenging scientific and engineering opportunities in a unique sea-floor environment. The uniqueness stems from the highly variable sea-floor properties, morphology, and dynamic processes. Some characteristics and processes at the break are nonexistent in nearshore environments where most of our understanding and experience exists. The geotechnical properties and stability of submarine deposits are strongly influenced by the nature of the geologic environment, dynamic processes, sediment type, and sea-floor slope. Sediment properties and sea-floor morphology at the break can be highly variable over relatively short horizontal and vertical distances.

The outer shelves and slopes off Cape May, New Jersey, and the Mississippi delta are among the few geotechnically investigated continental margins. Off Cape May, mobile shelf sands contribute to sandy silts overlying the upper slope muds which occasionally exhibit structures and geochemical properties suggesting slope-creep processes. In contrast, the Mississippi delta's shelf-slope break is characterized by clays and silty clays that mobilize as mudflows which encroach upon the upper slope. Geotechnical properties such as shear strength and water content display striking differences between the two areas as a function of regionally differing dynamic processes, sedimentation rate, type, and texture.

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Hatter's Pond Field: Complex Combination Trap in Smackover and Norphlet Formations (Upper Jurassic), Southwest Alabama

The Hatter's Pond field in northern Mobile County, Alabama, has produced 7 million bbl of condensate and 26 Bcf of gas since its discovery in 1974. Production is from the Upper Jurassic Norphlet and Smackover Formations which form a transgressive-regressive package overlying the Jurassic Louann Salt. The Norphlet Formation is a subarkose which was deposited in a coastal dune complex. Subenvironments identified include dune, interdune, wadi, and an upper, massive marine sand lithology which is gradational into the overlying Smackover Formation. The Smackover Formation in the Hatter's Pond field is composed of mudstones, peloidal packstones, oolitic grainstones, and nodular anhydrite deposited in a coastal sabkha complex. The Smackover grades upward into the Buckner Anhydrite Member of the Haynesville Formation. Reservoir development in both the Norphlet and Smackover is facies selective and a product of diagenesis.

Porosity in the Norphlet is most abundant in the massive marine and dune lithlogies and is mesogenetic, secondary porosity formed by the solution of eogenetic carbonate cement and/or solution of grains. Smackover porosity is moldic in the higher energy lithofacies and intercrystalline to vuggy in the finer grained lithologies, with dolomitization and leaching as major factors in porosity evolution. Algal-rich mudstones within the Smackover provide an internal source for the hydrocarbons.

The trapping mechanism in the field is a highly complex, combination structural and stratigraphic trap. The structural component involves salt movement in association with normal faulting. Porosity distribution, and hence reservoir development, is facies selective and is significantly modified by diagenetic alteration. A thorough understanding of facies distribution, diagenetic alteration, and structural relations is necessary for delineation of combination petroleum traps in the Hatter's Pond area.

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Spontaneous Subsurface Combustion of Rocks of Monterey Formation, California

Rocks of the Monterey Formation rich in organic matter have undergone spontaneous subsurface combustion (combustion metamorphism) at many localities, particularly during the Pleistocene. At the best studied locality, the Grimes Canyon area, the burnt-out rock body is 20 km long, 1 to 3 km wide, and at least 400 m thick. The original rocks were mainly mudstones with lesser amounts of diatomites, phosphorites, shales, some cherts, and carbonate rocks. The trace element composition of the parent rocks is that of oil shales; Ba, Cr, Ni, Sb, and Se contents are higher. Rock melting started below 1,000°C. The initial melt (5% of rock volume) is highly differentiated and has a major, minor, and trace element composition indistinguishable from high-calcium granites. These melts intruded to form sills and dikes, and cooled to obsidian-like glasses. As the temperature rose, the melt changed composition and approached the composition of the parent rocks. These melts formed intrusive stocks and cooled to crystalline rocks resembling, in the field, scoriaceous basalt. At the highest temperatures, in excess of 1,650°C, phosphorites were molten; the resulting melt had the composition of apatite and was immiscible with the coexisting silicate melt, with which it formed an emulsion.

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Seismic Detection and Evaluation of Delta and Turbidite Sequences: Their Application to the Exploration for the Subtle Trap

Energy conditions at the seaward edge of deltas allow their division into fluvial-dominated, wave-dominated, and tide-dominated deltas. Each kind of delta has a distinct framework orientation and depositional pattern which results in a characteristic seismic reflection pattern. Fluvial-dominated deltas are characterized by clinoform seismic reflection patterns which include: oblique (tangential), complex oblique (tangential), sigmoid, and complex sigmoid-oblique. Seismic facies analysis can be used to define those facies which contain sand. Wave-dominated deltas are characterized by shingled seismic reflection patterns. Seismic facies analysis of this delta is not effective in identifying those facies which should be sand prone. Shingled reflections may be used in determining the possible location and depositional attitude of strandline sands. Tide-dominated deltas have not yet been identified using