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Algal Mounds of Upper Cambrian Carbonates of Appalachians, Western Maryland: Examples of Early Patch and Marginal Reefs

The platform carbonates of the Conococheague limestone (Late Cambrian) of the Great Valley, Maryland, carry clotted and digitate mounds from 0.5 to 10 m high, similar to Aitken's (1967) "thrombolites." These mounds are surrounded by cross-bedded oolitic-peloidal grainstones, intraformational conglomerates, and thin-bedded graded dolostones. Internally the mounds are composed of an upward directed network of cm-scale "fingers" of micrite-microspar separated by infills of skeletal packstone-wackestone with abundant remains of gastropods, brachiopods, trilobites, etc. *Renalcids* encrust the edges of the mud fingers and, in the interior, make an irregular, convex lamination which contains filament (?) molds. Stromatactis-like cavities cross-cut the *Renalcid* encrusted mud fingers and the interfinger infills. There observations suggest that the mounds were rigid frameworks constructed by encrusting colonies of algae and forams (?) and inhabited by a diverse marine fauna. The fauna, the association with current-worked sediments, and the position at the base of the shoaling-upward cycles indicate a wave- and current-scoured open subtidal bank environment for these mounds, which we interpret as early algal patch reefs.

In contrast, we find transported blocks of different boundstones to the east in massive off-platform breccias of the equivalent basinal facies of the Frederick Valley, Maryland. These boundstone blocks are composed of masses of *Epiphyton*-encrusted thin micrite plates (platy algae?) and are cut by cavities lined with early marine cements. These boundstones, we believe, were rigid framework algal reefs but were situated along the platform edge as an early Paleozoic marginal reef tract.

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Computer Analysis and Synthesis of Stratigraphy and Petroleum Geology, Upper Cambrian Strata, Morrow County, Ohio

Computer analysis indicates that hydrocarbon accumulations found at the tops of paleogeomorphic features on the Knox unconformity surface of Morrow County, Ohio, are controlled primarily by structural trapping. In the subsurface of Morrow County, the Knox unconformity separates dolomite of the Copper Ridge formation (Cambrian) from the shales, limestones, and dolomites of the Middle Ordovician Chazy formation. A computer-generated three-dimensional plot of the Copper Ridge Dolomite surface reveals a pattern of northwest-southeast trending erosional remnants which exhibit up to 150 ft (46 m) of local relief and resemble a karst topography. The distribution of erosional remnants is believed to be controlled by paleodrainage patterns. The primary reservoir rock is the Copper Ridge Dolomite. The rocks of the overlying Chazy Limestone have buried the erosional remnants and serve as the trap for Copper Ridge Dolomite accumulations.

Trend surface analysis of horizons above and below the Knox unconformity indicates a regional structural dip of 50 to 55 ft/mi (9.5 to 10.4 m/km) toward the east. Negative residuals from the trend surface analysis, which border the eastern edge of production, indicate folding and the existence of a structural trap in Morrow County. Hydrocarbons migrating up structural dip (to the west) were initially caught in the structural trap and then accumulated at the tops of erosional remnants on the Knox unconformity surface.

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Benthic Foraminiferal Response to Glacial/Interglacial Episodes, Deep Gulf of Mexico

Q-mode factor analysis of 55 surface samples and 190 species from water depths beyond 1,500 m in the Gulf of Mexico defined an 8 assemblage model which accounted for 91% of the original information contained in the data matrix. Distributions of these 8 assemblages are related to variations in sediment terrestrial organic carbon content, calcium carbonate content, and water depth. No relationship could be defined for the 8 assemblages and overlying water temperature, salinity, dissolved O_2 concentration, or median grain diameter of the sediment.

Species counts on 58 samples at ~10 cm intervals from the USNS *Kane* core K-129 were completed in order to examine the response of benthic foraminiferal populations to glacial/interglacial episodes in the Gulf. The core is from a site at 3,108 m water depth in the southwestern Gulf (20°56.7′N, 95°05.7′W). It was chosen because it had been previously zoned on the basis of planktonic foraminifers and it spans a relatively long interval of time (~165,000 years).

A 4 factor model of the core, produced by direct factor analysis, accounted for 93% of the original information of the 58 sample by 118 species matrix. An *Eponides turgidus* assemblage was found to dominate high calcium carbonate dissolution intervals through core K-129, whereas an *Epistominella decorata* assemblage dominates intervals of low carbonate dissolution. A *Bulimina translucens* assemblage shows highest factor loadings when surface water temperatures were elevated and continental glacial volumes were reduced. A *Cibicidoides wuellerstorfi* assemblage, which shows highest factor loadings during glacials, demonstrates a highly significant inverse relationship to the development of the *Bulimina translucens* assemblage.

The results of this study suggest that the deep-water benthic foraminifers of the Gulf of Mexico have responded to climatic events of global and regional significance through the late Quaternary. Global climatic effects may be inferred from demonstrated relationships between the foraminiferal assemblages and the planktonic oxygen isotope record, and dissolution history of core K-129. A regional effect is suggested by the relationship defined for the *Cibicidoides wuellerstorfi* assemblage and the distribution of terrestrial organic carbon of the Gulf through time.

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Petroleum Potential of Continental Margin off Southeastern United States

The continental margin off the southeastern United States is underlain by two major basins, the Carolina trough off North Carolina and South Carolina and the Blake Plateau Basin off Florida and Georgia, with the latter basin's landward extension, the Southeast Georgia embayment. The embayment, beneath the continental shelf is the only area in which drilling has taken place. Strata of the landward part of the Blake Plateau Basin including the embayment form a wedge of onlapping marine deposits that might provide stratigraphic traps, such as pinchouts, barrier islands, and channels. Drapes over basement highs might trap petroleum. The seaward part of the Blake Plateau Basin contains a thick (14 km), landward-dipping section, probably composed mainly of carbonate platform deposits. Carbonate banks and an Albian-Aptian rudist reef might provide traps, although the seaward part of the platform has been breached by erosion.

In the Carolina trough, flow of Jurassic(?) salt has formed diapirs, and withdrawal of salt has caused a large growth fault complex to form along the landward side of the trough. Because the block of sedimentary rock (12 km thick) above the salt is subsiding almost vertically, structures at the fault may include compressional features. The diapirs and faults may provide traps. A large shelf-edge anticline exists more than 150 km long and with a closure of as much as 500 m. Other possible traps might result from stratigraphic features of the onlapping sedimentary wedge landward of the Carolina trough and the eroded and buried paleoslope on the seaward side of the trough.

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North Sea Petroleum Province: A Failed Rift Basin

The North Sea oil and gas province is primarily a Mesozoic failed rift basin developed in response to the break-up of the Pangean supercontinent. The associated tectonism controlled deposition of reservoirs, source, and seals and development of structures and thus was the important factor in the generation, migration, and trapping of hydrocarbons.

The tectonic history of the basin can be divided into three major phases: (1) initiation of subsidence as a broad intracontinental downwarping during Permian, (2) tension induced normal faulting and half graben development from Triassic to Early Cretaceous, and (3) a return to broad basinwide subsidence from Late Cretaceous to the present.

The primary reservoirs include Lower Permian eolian sands, Upper Triassic to Middle Jurassic shallow to marginal marine sands, Upper Jurassic and Paleocene deep marine sands, and Danian and Maestrichtian chalks. Primary source rocks are Middle to Upper Jurassic marine shales and Carboniferous coals. The main structures include buried rotated fault blocks and halokinetic features.

Of the approximate 1,400 exploration wells, 490 have been oil and gas discoveries representing a 1:3.5 success rate. Total proved recoverable reserves are over 32 billion bbl oil equivalent with total potential recoverable reserves estimated at 46 to 70 billion bbl oil equivalent. Nine fields contain more than one billion bbl oil equivalent.

More than 53 billion dollars have been invested in the North Sea since 1965. Average cost to find and totally develop fields is approximately 2 billion dollars. At present, at least 100 million bbl recoverable reserves are usually needed for a field to be economic.

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Facies and Porosity Distribution, Swan Hills Reef Complex, Snipe Lake Oil Field, Alberta, Canada

All of the 11,700 ft (3,566 m) of core in this 130-well limestone reef oil pool was logged for a proposed miscible flood enhanced recovery scheme. The textures, fauna, porosity types, cements, and exposure surfaces are well preserved. Selected examples of each are presented by colored slides.

Nine sedimentary facies and eight porosity types are noted. The porosity is facies selective, but is modified by solution and cementation. Submarine, blocky calcite cement is common. Vadose pendular cement is developed beneath some exposure surfaces.

Twelve lithofacies, based on texture, fauna, color, porosity, and stratigraphic position are recognized. In the lagoons, poorly connected thin beds of porosity are present, whereas the reef flank porosity is relatively thick and contiguous.

Three major depositional cycles, each about 40 ft (12 m) thick, are interpreted. The first terminated with subaerial exposure and local erosional truncation. A few inches of green shale formed in the lagoon. The second cycle began with a major transgression characterized by dense dark brown laminar strom bindstone containing brachiopods, corals, and crinoids. A shallowing-upward gradation to porous massive and branching strom framestone followed. A second exposure surface, capped by discontinuous green shale, marks the termination of this cycle. The third cycle is predominantly biostromal, thickening gradually to the southwest into thin-bedded lagoonal sediments. Local well-washed rudstones suggest beach environments.

Stylolites are common in the lagoonal areas, and less numerous toward the reef front. Fractures are poorly developed and have only sparse porosity. Examples of porous stylolites and fractures from the nearby Goose River reef complex are shown.

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Episodic Sedimentation—How Normal is Average? How Rare is Rare? Does it Matter?

Do sedimentary rocks record mainly average, continuous, day-to-day processes or relatively rare, large-magnitude ones separated by long nondepositional intervals? Subtle legacies from Lyellian uniformitarianism may still impose a subconscious abhorrence of unique events, discontinuities, and large deviations from "average" magnitudes. Where repeated sharp changes of sedimentation are inescapable, periodic cycles are commonly invoked to preserve uniform, orderly variations from some supposed norm. The sedimentary record rarely reflects such uniformity, however, as sedimentologists have gradually realized.

Magnitude versus frequency of processes has long been debated in geomorphology, but has received less attention in sedimentology. *Recurrence interval, recovery time,* and *preservation potential* are critical factors for evaluating significance for the sedimentary record. Large-magnitude processes, which represent positive deviations from the norm and are rare on the human time scale, must be significant over geologic time. But how significant? Could not everyday processes have obliterated much of the evidence? Flood deposits have relatively low preservation potential because they lie above base level. Marine gravel layers dispersed by abnormal waves have greater preservation potential because most ordinary processes are not competent to modify them. Sandy or shelly deposits formed by large waves and displaying either hummocky cross-stratification or graded bedding have a moderate preservation potential, especially if too thick for burrowing animals to homogenize them. Turbidites, which provide exceptional records of episodicity, have excellent preservation potential because they lie well below base level. Many bedding planes are important records of episodicity, too; some are surfaces of erosion, others of nondeposition. These represent negative deviations from average process magnitudes.

The sedimentological importance of rare events is difficult to