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Significance of Middle Tertiary Large Foraminifera Common to West Africa and Caribbean

The criteria used for the identification of species and genera of Cenozoic large benthic Foraminifera strongly affect interpretations of their geographic distribution. Some researchers contend that migration of large forams between west Africa and the Americas became impossible after the middle Eocene because of increased distance and of ecologic barriers. Thus, the discovery of the Eocene genus *Linderina* in west Africa led them to conclude that the cosmopolitan Tertiary genus *Lepidocyclina* evolved from *Linderina* in the Old World, whereas it evolved separately from *Eulinderina* in the Americas. We find it difficult to accept these conclusions, especially in view of the number of Tertiary species of *Lepidocyclina* and *Miogypsina* which are common to the Mediterranean area, Africa, and the Americas. The discovery of additional large foraminiferal species common to west Africa and the Americas supports our view that many species of Oligocene and Miocene large Foraminifera had much greater paleobiogeographic distribution than has been generally realized.

Carbonate buildups dominated by floods of *Heterostegina* have been widely reported from the upper Oligocene and lower Miocene of the Caribbean–Gulf of Mexico region. We have recently discovered much of the large foraminiferal fauna of these so-called "Het reefs" in the upper Oligocene and lower Miocene of Cameroon (west Africa). Included are such typical Caribbean species as *Leipdocyclina canellei*. The species of *Miogypsinoides* present in the sequence may represent an evolutionary trend different from those in other parts of the world. They appear to be most closely related to the Caribbean species *Miogypsina panamensis*. In addition, we have found *Operculinoides cojimarensis* in the upper Miocene of Gabon. This species occurs abundantly from middle Miocene to lower Pliocene rocks in the Caribbean area and represents the end of the nummulitid evolutionary lineage in that region. Its presence in west Africa is further indication that communication persisted between west Africa and the Caribbean at least as late as the late Miocene.

Moreover, a surprisingly large number of species of smaller benthic Foraminifera is common between west Africa and the Caribbean. The literature records an apparent scarcity of species of large Foraminifera common to both the New and Old Worlds. This apparent scarcity suggests that the parameters used to identify these species are not appropriate and should be reviewed.

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Quantitative Basin Analysis and Evolution of Deep-Marine Shale Basin, Middle Ordovician, Southern Appalachians

A quantitative portrayal of paleobathymetry, rate of sedimentation, age, and crustal subsidence of a deep-marine shale basin not only reveals the timing and magnitude of geologic events but also has potential practical application in petroleum geology, as marine shales commonly are a primary source for hydrocarbons.

A quantitative basin analysis of the Middle Ordovician Sevier Shale basin in east Tennessee was made using: (1) lithofacies interpretation, (2) conodont-graptolite biostratigraphy, (3) paleobathymetry, (4) rate of sediment accumulation, and (5) sediment "backstripping" through time. This analysis indicates three main phases of crustal subsidence: (1) an early tectonic and sediment loading phase with a subsidence rate of 3 to 4 cm/1,000 years; (2) a second tectonic phase with a subsidence rate of 60 to 65 cm/1,000 years; (3) a final sediment-loading phase with a subsidence rate of 4 to 15 cm/1,000 years. Five stages of basin evolution were involved: (1) stable-shelf stage, (2) downwarping stage, (3) starved-basin stage, (4) turbidite-fill stage, and (5) contour-current stage.

On the basis of morphologic, stratigraphic, sedimentologic, and tectonic similarities between DSDP site 262 (Pliocene-Quaternary) in Timor and the Sevier basin, it is proposed that Sevier basin evolution may be considered analogous to foredeep basin development in Timor. This development occurred by concomitant basin subsidence and uplift of adjacent tectonic land owing to basinward migration of a topographic wave.

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Rhythms in Deep-Marine Turbiditic Shales and Fine-Grained Debris Flow

Rhythms in fine-grained sediments have not been studied previously because of their complex depositional cycles and diagenetic changes. Examination of nearly 9,000 layers in outcrops, polished slab samples, and thin sections has led to recognition of rhythms in the Middle Ordovician Whitesburg, Blockhouse, and Sevier formations in eastern Tennessee.

Rhythms have been described in four orders, based on their magnitude. First-order cycles (basin-fill sequences, hundreds of meters thick) are composed of thinning-upward debris-flow sequences and thickening-upward turbiditic shale sequences. Second-order cycles (multiple-sedimentation units, tens of centimeters thick) constitute six types: (1) thinning-upward cycles, (2) symmetrical cycles, (3) thickening-upward cycles, (4) minor multiple cycles, (5) uniform cycles, and (6) dubious cycles. Third-order cycles (single-sedimentation unit, tens of millimeters thick) have thinning-upward and asymmetric types. Fourth-order cycles show the grain-size variations within a single silt layer of the third order.

First-order rhythms were controlled by tectonism, progradation of a deep-sea-fan system, and debris flow. Second- and third-order rhythms were controlled by depositional processes, bottom topography, and sediment source. In the fourth-order rhythms, depositional processes, sediment source, and bioturbation were the dominant controlling factors.

Rhythm analyses of fine-grained sediments are significant in understanding (1) major events related to tecto-

nism, (2) deep-sea environments, and (3) frequency and dynamics of depositional events.

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Regional Aspect of Sediment Distribution Across Middle East During Middle Triassic Time

Middle Triassic rocks across the Middle East provide information on regional paleogeography based on the distribution of different depositional facies that are clearly related to the structural history of the region. Several structural provinces have been recognized: the Arabian-Nubian massif, the Middle East platform, and the Tethyan trough.

Except for the central part of interior Syria and central and northeastern Iran, the Middle Triassic rocks of the Middle East represent shelf sediments consisting of three major depositional systems. A belt of mixed clastic-carbonate rocks with evaporite deposits of nonmarine, supratidal, tidal-flat, and lagoonal origin is present in the central part of Saudi Arabia. This belt grades into carbonate-evaporite facies of the Arabian Peninsula, southwestern Iran, northern Iraq, and the area of the Syrian-Turkish border. The carbonate-evaporite facies grades into strata which are predominantly open-marine carbonate rock of the Tethyan sea shelf facies over most of Iran, northern Iraq, most of Syria, probably Lebanon, Jordan, Palestine, and the Sinai Peninsula. Several positive and negative areas are within this platform: the Jawf-Rutbah-Mardin high, the Central Arabian embayment, and the Southeastern Saudi Arabia uplift.

The basinal marine sediments of the Tethyan trough facies include Alpine-Mediterranean deposits in central Syria and a terrigenous flyschlike sequence in central and northeastern Iran. The northeastern to northwestern part of central Saudi Arabia holds promise for new petroleum exploration because of a possible great thickness of Permian-Triassic rocks of the carbonate-shelf facies capped by Middle-Late Triassic evaporites.

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Post-Middle Cretaceous Seismic Stratigraphy and Geologic History of Deep Gulf of Mexico Basin

A seismic stratigraphic analysis of 5,000 n. mi of regional multifold reflection data allows an interpretation of the post-middle Cretaceous geologic history of the deep Gulf of Mexico basin. Five horizons that are major unconformities along the southern margin of the basin were mapped throughout the deep Gulf and used to define five depositional sequences (seismic units). Ages for the two youngest horizons were obtained by direct correlation with DSDP holes—Pliocene-Pleistocene and late Miocene. The other horizons are tentatively correlated with proposed major global unconformities and eustatic sea-level changes—middle Oligocene, early Tertiary, and middle Cenomanian. The middle Cenomanian horizon is the most prominent subbottom reflector in the deep Gulf. It represents a striking unconformity on the seismic data along the base of the Campeche and Florida Scarps against which the younger sequences thin, onlap, and pinch out. Isopach maps of the units indicate a combined maximum thickness of 7 to 8 km for the post-middle Cretaceous sediments in the central basin. Variations in individual unit thicknesses and seismic facies reflect regional changes in depositional patterns through time: during the Late Cretaceous through middle Tertiary the main sediment source was in the west, and deposition consisted mainly of homogeneous, probably fine-grained sediments changing upward to alternating sand and mud; in the middle Tertiary there was a major influx of sand and mud from both the north and west; following a late Miocene–Pliocene starved-basin interval, fine-grained turbidites from a northern source built the thick Pleistocene-Holocene Mississippi fan.

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Future Exploration Opportunities in Gulf of Mexico

Those directly responsible for evaluating recent lease sales in the Gulf of Mexico are painfully aware that the quality of prospects and amount of potential reserves are significantly reduced from what they were several years ago. We believe, however, that this may not be an irreversible situation, in that significant reserves may lie in the undrilled structures of the continental shelf, slope, and abyssal plain of the Gulf of Mexico.

Portions of the South Florida basin and deep waters of offshore Louisiana and Texas are specific areas in the Gulf of Mexico that we feel warrant further investigations by industry.

Subsurface facies and structure maps constructed from available well control, regional CDP seismic, gravity, and magnetic coverages indicate favorable conditions exist in these frontier areas for the entrapment and generation of hydrocarbons. The testing and development of these deep-water and/or deep-drilling objectives will require advanced drilling and production technology.

The most economic means by which to initiate the evaluation of these frontier areas is through stratigraphic-test programs (i.e., COST-type wells). Through the use of stratigraphic tests, better "direct" scientific knowledge can be obtained that would supply the needed exploration incentives and business inducements for industry to invest capital dollars in what may now appear to be prohibitive, high-risk areas. If successful, it would also give industry the lead time required to develop and refine technologies needed to operate in these less than favorable environments.

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Exploration in East Malaysia over Past Decade

In the past decade two large oil fields and several large gas fields have been discovered on the continental shelf of East Malaysia together with some smaller oil and gas fields. Geologically, the shelf contains most of the postgeosynclinal younger Tertiary sediments of the