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Geologic Mapping and Studies of Modern Geologic Processes of Continental Slope Off New Jersey—Observations by Midrange Sidescan Sonar and Research Submersible

To assess surficial geologic conditions of importance to exploration and development of the continental slope off New Jersey, the U.S. Geological Survey has mapped the area between Lindenkohl and South Toms Canyons (including blocks to be leased in Sale No. 59). A dense network of high-resolution seismic reflection profiles and more than 65 piston cores shows a complex bathymetric surface underlain by Pleistocene sediments on the upper slope and midslope. Tertiary sediment crops out on the lower slope. The seismic profiles, piston cores, and observations from several submersible dives on the uppermost slope suggest that the slope, now generally blanketed by a thin layer of fine-grained Holocene sediment, is relatively quiescent, but was geomorphically more active during the late Pleistocene or early Holocene. In contrast, more recently acquired images from a deep-towed midrange sidescan-sonar system (5 km swath) show geomorphic details of gullied canyon walls, differential erosion of truncated strata, several small slope failures, and apparent amphitheatric headward erosion of lower slope valleys. An area of the upper continental rise is covered by blocky debris which may have been transported down South Toms Canyon. The "crispness," shapes, and locations of such features detailed by the sidescan-sonar images suggest that some of these features may be recent. Additional observations to investigate the nature and age of these features on the midslope and lower slope were conducted from the deep-diving submersible *Alvin* during July 1981.

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Crustal Structure and Stratigraphy of Continental Margin Off Northeastern United States

Geophysical studies and deep drill-hole data define the major structural elements and seismic stratigraphy for the U.S. Atlantic margin north of Cape Hatteras. Two basins, the Baltimore Canyon Trough (BCT) and Georges Bank Basin (GBB), and three adjacent platforms (the Long Island, Carolina, and La Have platforms) were formed during rifting of Africa from North America in the Early Jurassic. Postrift sediments, that is, those deposited after sea-floor spreading began, can commonly be distinguished from prerift and synrift sediments by a conspicuous "breakup" unconformity. Postrift sediments are as thick as 7 km in GBB and 13 km in the BCT. Prerift and synrift sediments within grabens are 5 to 9 km thick and are characterized by tilted reflection sequences and diffractions.

The East Coast magnetic anomaly (ECMA) marks the landward edge of oceanic crust and a distinctive hinge zone in crystalline basement separates the continental platforms from the major basins. This hinge zone is mirrored by an abrupt shallowing seaward in the depth to the Moho; a further shoaling in depth to Moho also coincides with the ECMA. The rift-stage crust underlying the marginal basins is 12 km thick in BCT and 25 km thick in GBB.

The synrift sequence includes red beds and evaporites (including salt); the postrift sequence grades upward from massive Jurassic dolomites, limestones, and anhydrites into shale and clastic facies of Cretaceous and Tertiary age. Approximately 70% of the postrift sediment was deposited in the Jurassic during a period of rapid thermal subsidence and sediment loading.

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Phenomena of Pulsation Tectonics Related to Early Rifting of Eastern North American Continental Margin

New data from the recent IPOD drilling of DSDP Site 534 in the Blake-Bahama Basin give a definitive age for the spreading-center shift involved in the early rifting of the North American Atlantic margin. A basal Callovian age (~ 155 m.y.) is determined for the Blake Spur magnetic anomaly marking this spreading-center shift that signals the birth of the modern North Atlantic Ocean. This is some 20 m.y. younger than previously thought. One implication of this surprising result is that this spreading-center shift starting North Atlantic rifting is now of an age which could be assigned to the spreading-center shift needed to end the rifting in the Gulf of Mexico. It is suggested that this might be one and the same event. Another implication of this surprisingly young age for the Blake Spur event is that very high spreading rates are now required for the Jurassic outer magnetic quiet zone along the North American margin. This association of a high spreading rate with a magnetic quiet zone is similar to that for the middle Cretaceous and implies a link between the processes controlling plate spreading, which are in the upper mantle, and the processes controlling the magnetic field, which are in the outer core. A theory of pulsation tectonics involving the cyclic eruption of plumes of hot mantle material from the lowermost mantle could explain the correlation. Plumes carrying the heat away from the core/mantle boundary later reach the asthenosphere and lithosphere to induce faster spreading. The pulse of fast spreading in the Jurassic apparently caused the rifting of the North Atlantic. Other pulses of fast spreading appear to correlate with major ocean openings on various parts of the globe, implying that this may be a consistent process. Rifting of passive margins may be controlled by the more fundamental global processes described by the theory of pulsation tectonics.

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Stratigraphy and Structure of Atlantic Continental Margin in Bahama Platform Area

Approximately 2,100 km of 24-fold multichannel seismic reflection data reveal the subsurface geology of a large part of the continental margin in the Bahamas region. Discordance between the westward-dipping prebreakup sediments and the eastward-sloping basement along the edge of the Blake Plateau is interpreted as an effect of a splinter of continental margin derived from the African plate by a spreading-center jump in Middle Jurassic. Early rifting centered under the main part of the Blake Plateau became inactive, as a spreading-center jump shifted the active rift to east of the present Blake Escarpment along the Blake Spur magnetic anomaly.

In the northern Florida Straits the data reveal that the prebreakup unconformity, underlain by Triassic-Upper Jurassic(?) arkosic volcaniclastics, extends from southern Florida to the western Bahama Banks. These volcaniclastics are associated with the intermediate nature rift-crust formed just prior to and during breakup of the North American and African continental plates.

Back-reef platform deposits of limestones, dolomites, and evaporites of Late Jurassic to Albian age extend from the Blake-Bahama Escarpment under Florida. These covered what once was a huge megabank extending over a wider area than the present smaller isolated Bahama Banks. The formation of the modern Florida Straits and Bahama channels occurred in the Cenomanian transgression when the overall area deepened. Only on the present Bahama Banks and Florida platform did shallow-water carbonate deposition persist to maintain the shallow-bank environments.

Evidence of recurring scour by current erosion is found in the Florida Straits. Erosional events apparently occurred in middle Cenomanian, middle Paleocene, early-middle Eocene, and middle Oligocene, which are times of lower eustatic sea level. This evidence of Florida current scour indicates that the current was present as far back as the Cenomanian.

A carbonate bank margin and reef complex has been present along the Bahama Escarpment since Middle Jurassic. Apparently these organic buildups seeded on structural relief on oceanic basement created during the spreading-center jump along the Blake Spur anomaly. The bank margin apparently has retreated at least 15 km below the A^u unconformity.

Active faulting at least through the Late Cretaceous and perhaps into the Tertiary, occurred along the Great Abaco fracture zone. These relatively young tectonic events, along with the post-Albian faults in Providence Channel, indicate interactions between the Atlantic and Caribbean plates and extensions of faulting far to the northeast of Cuba and the greater Antilles.

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Importance of Regional and Local Structure to Devonian Shale Gas Production from Appalachian Basin

Over 1 Tcf of high-quality natural gas has been produced from Devonian shales during the past 100 years. The shale is its own source, seal, and reservoir; natural features within the shale form the reservoir. Organic shale is the prime requisite for production, but productivity relates to the presence of open fractures so that one can presume that abnormally productive trends correspond to open fracture zones. This presumption is supported by the direct association of linear zones of high production with linear basement structure detailed in three fields studied. The blanketlike nature of the lower production ubiquitous in southern West Virginia and eastern Kentucky probably relates to a fracture facies developed within the shale and controlled by shale lithology and Appalachian tectonics.

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Depositional Environment of Albian Sandstone, Baltimore Canyon Trough, Mid-Atlantic OCS

The Albian sandstone, found throughout the Baltimore Canyon Trough, was studied using data from well logs, cores, and cuttings from COST and exploration wells from common-depth-point seismic lines. The sandstone is 300 m at the thickest point and covers at least 10,000 sq km; its top is at depths of 1,600 m to 2,900 m. Although the sandstone is mostly Albian in age, in some wells its top is about middle Cenomanian and in others the sandstone is partly in the Aptian. The sandstone overlies a shale and grades upward from silt to a medium to coarse sandstone with interbedded shales. At the top of the Albian sandstone is a well-sorted coarse- to medium-grained sandstone averaging 24 m thick that can be correlated in all the wells studied. Grain-size analyses of the uppermost sand were done on the cuttings using an automated rapid sediment analyzer; results indicate deposition in an environment intermediate between beach and fluvial environments. The top of the Albian sandstone is marked by an unconformity with overlying marine shales. During a time of global sea-level rise, sediments continued to accumulate near the shelf edge creating the thick sand sequence in the center of the Baltimore Canyon Trough. A major sea-level drop, and subsequent rise, during the Cenomanian coincided with the end of sand deposition.

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Geochemical Framework and Source-Rock Evaluation of Mid-Atlantic OCS

Geochemical analysis of exploration and deep stratigraphic test wells has provided new information on organic richness, thermal history, and type of source material in much of the Baltimore Canyon Trough. The total organic carbon content and concentrations of light-gas through high-molecular-weight hydrocarbons in Jurassic, Cretaceous, and Tertiary samples define zones of marginal to excellent richness. Levels of thermal maturation, primarily determined by thermal alteration index and vitrinite reflectance data, indicate that burial below 3,500 m is generally required for petroleum generation. Microscopic analysis of kerogen also delimits oil-prone and gas-prone organic facies.

Measured parameters when mapped by a computer contouring program show geochemical trends in strata of different ages. In addition, some geochemical zones of exploratory interest that were originally observed in the COST wells can be extended to oil company wells. Cretaceous and Cenozoic rocks have little petroleum potential in this area because of their thermal immaturity. However, organic-rich units in Jurassic strata may have generated significant quantities of natural gas or oil in some parts of the basin.

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Thermal and Mechanical Evolution of U.S. Atlantic Continental Margin

The postrifting tectonic subsidence of the U.S. Atlantic continental margin appears to be due to thermal contraction following continental breakup. This subsidence is greatly increased by the effect of sediment loading. Models for the response of the lithosphere to loads show that the rigidity of the lithosphere is a strong function of temperature. Hence the flexural rigidity at the U.S. margin should vary in both space and time. The thermal structure and subsidence of the margin has been modelled using a two-dimensional extension model where the amount of extension has been allowed to vary across the margin and lateral conduction of heat has been included. The equivalent elastic thickness of the lithosphere has been approximated as the depth to an isotherm. Thermoelastic effects of the cooling lithosphere, as well as the flexural loading of the sediments, have been included. The lateral flow of heat and flexure have contrasting effects. The lateral heat flow tends to cause uplift of the coastal plain region landward of the hinge zone and to increase the subsidence rate in the regions of the transitional crust. In addition, the effects of lateral heat flow modify the thermal history of the sediments and heat flow. Flexure, on the other hand, causes subsidence of the coastal plain and decreases the sediment accumulation beneath the transition zone. The stratigraphy of the U.S. margin is seen to be the result of the complex interaction of these effects as their contributions vary through the history of the margin.

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