hydrate were recovered at subbottom depths of 238 m (Site 533) and 404 m (Site 568). The principal gaseous components of the gas hydrates were methane, ethane, and CO_2. Residual methane in sediments at both sites usually exceeded 10 ml per liter of wet sediment. Carbon isotopic compositions of methane, CO_2, and ΣCO_2 followed parallel trends with depth, suggesting that methane formed mainly as a result of biologic reduction of oxidized carbon. Salinity of pore waters decreased with depth, a likely result of gas hydrate formation. The small samples of gas hydrates observed visually in cores confirm that gas hydrates are present at these sites, but much of the direct evidence for gas hydrates may be destroyed during the coring and recovery process.

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Benthic Foraminiferal Biofacies in Stevens Sandstone: Relationships to Water-Mass Oxygen Levels in Late Miocene San Joaquin Basin, California

The Stevens sandstone is an extensive and complex sequence of late Miocene turbidite sandstone and mudstone within the Monterey Formation of the San Joaquin basin. To date, the paleoenvironmental analysis of benthic foraminifera in such facies is limited largely to general inferences of paleobathymetry. A different approach uses multivariate analytical methods to classify biofacies and interpret them with respect to modern ecologic concepts derived from studies of Holocene faunas in the southern California borderland. Cluster and factor analysis help define 4 recurrent biofacies in the Coles Levee area: an agglutinated species biofacies (ASB), *Uvigerina subperegrina* biofacies (USB), *Bolivina vaughani* biofacies (BVB), and mixed calcareous biofacies (MCB). Ordination (principal components) plots of environmentally significant species indicate that the biofacies reflect a gradient in oxygen concentration of late Miocene water masses. The BVB and MCB represent the highest oxygen levels, the USB low but not dysaerobic levels, and the ASB the lowest oxygen concentrations. Ordination also shows that downslope transport of faunas and carbonate dissolution are also important in forming Stevens biofacies. Stratigraphic distribution of biofacies defines systematic shifts in oxygen concentration, probably linked to climate. These late Miocene biofacies variations were previously attributed to paleobathymetric changes. The distribution of species not restricted to the defined biofacies, plus the paleoenvironmental analysis presented here, argues against paleobathymetry as a complete explanation. This analytical approach shows the potential for greatly increasing our understanding of foraminiferal biofacies in submarine-fan environments.

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Stratigraphic Significance of Uvigerinid Foraminifers in Western Hemisphere

Uvigerinid foraminifers increasingly are recognized as particularly useful paleobathymetric indices, and current data also provide easily applied bases for their use in biostratigraphic interpretation. Thus, use of many forms of the family Uvigerinidae occurring in the Western Hemisphere can expand utilization of these important forms and provide uniformity in nomenclature and classification.

Uvigerina and related genera illustrate lineage concepts and facilitate paleobathymetric considerations. These biostratigraphic interpretations, based on life ranges of commonly occurring benthonic species, are applicable widely in areas lacking the critical warm-water planktonic organisms normally used in dating.

The genus *Tiptonina* (type species *Siphogenerina nodifera*) and the species *Uvigerina praehubbardi* are proposed as new.

LARSON, DANA C., Mobil Oil, Dallas, TX

Depositional Facies and Diagenetic Fabrics of Falmouth Formation (Upper Pleistocene), Jamaica

The upper Pleistocene Falmouth Formation of Jamaica was deposited in shallow, open-marine environments similar to those on the modern northern shelf. Depositional facies include coralgal boundstones, coral-algal grainstones, foram-algal packstones, echinoid molluscan wackestones, and terrigenous grainstones. Submarine cementation of Falmouth sediments occurred as micritic and/or isopachous bladed rinds composed of magnesian calcite, as well as aragonitic coral overgrowths. The Falmouth limestones were subsequently exposed to meteoric water because of eustatic sea level fall and regional tectonic tilting related to the Cayman shear zone to the north. Isotopic reequilibration and carbonate-mineral stabilization are presently at an intermediate stage. Meteoric and mixing-zone diagenetic processes that have affected this unit include: sparry calcite cementation, aragonite dissolution and inversion, incongruent dissolution of high-magnesian calcite, selective dolomitization, and neomorphism of micritic matrices. Neomorphic fabrics within the Falmouth are spherulitic sparry calcite, microspar, and structure grumuleuse. Isotopic reequilibration coincides with the degree of diagenetic alteration. Carbon and oxygen delta values are lighter in precipitative meteoric cements than in neomorphic constituents. The trend toward negative isotopic composition with increasing age of limestone strata can be shown here to be disguised by exposure to sea spray, organic involvement, and abnormally rapid (nonequilibrium) rates of precipitation. Modern subsurface hydrogeologic environments contain distinctive diagenetic fabrics and isotopic signatures, and are defined by water-flow rate, pore-water chemistry, and rock permeability and porosity.

LEMONS, DAVID, Baylor Univ., Waco, TX

Geomorphic Indicators of Deeper Seated Structure on the Southern Margin, East Texas Basin

Surface geomorphic features are frequently difficult to relate to potential productive structures, but in the East Texas basin there appears to be a significant correlation between surface features and oil fields.

The surface topography overlying the East Texas basin gives little indication of subsurface structure. However, conspicuous to southeastern Houston County on the southern margin of the East Texas basin, and to a large part of the entire basin, is a series of northwest- and northeast-trending stream and topographic alignments. These mappable linear geomorphic features (termed lineaments) may indicate fracturing, faulting, and jointing, and thus may be a clue to subsurface structure.

The lineaments of southeastern Houston County were mapped and analyzed on a local scale, and those of Houston, Cherokee, Trinity, and Angelina Counties were mapped and analyzed on a more regional scale. Both the local and regional scale lineament analyses indicated preferential orientations of north 30° west and north 30° east. These lineaments are thought to reflect fracturing and faulting although field reconnaissance could not confirm this.

It is suggested that gravity slide of the East Texas basin gulfward from the updip edge of the Louann Salt provided the tensional forces necessary for major lineament formation. However on a more local scale there is a correlation between lineaments and productive fields.

Areas of minimum lineament density on the lineament-density contour maps represent subtle subsurface structural highs and, conversely, areas of maximum lineament density on the lineament density contour maps represent subtle subsurface structural lows. Therefore, petroleum potential is generally limited to areas of minimum lineament density.

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Processes Involved in Salt-Dome Development I: Dynamic Effects

In a study of the dynamical interplay of salt and sediment using buoyancy pressure as the driving force, we find that (a) salt cannot become buoyant until a critical depth of sediment is reached corresponding to a porosity of 25-30%, (b) viscosity plays virtually no role in the development of diapiric salt structures on a geologic time scale, (c) both overpressure and the lateral cohesive strength of overlying sediments retard the development of a dome by delaying the initiation of diapirism and suppressing the later growth of the salt structure, (d) the formation of a "mushroom cap" on a diapiric structure can be caused both by differential impedance provided by the sediments and by differential buoyancy of salt, although relative importance of the 2 mechanisms is unknown at present, and (e) the draping of sediments over a diapiric structure and rim synclinal development can be modeled easily provided that the sediments

are of low cohesive strength. The influence of sediment strength and previous sediment faulting on the development of draped sediments and rim synclinal structures remain outstanding concerns.

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Processes Involved in Salt-Dome Development II: Thermal, Gravitational, and Chemical Effects

The quantitative investigation of processes involved in salt dome development include thermal, gravitational, and chemical effects of uprising salt domes. We find that (a) there must be a positive-temperature anomaly occurring around the upper flanks of a salt dome but that organic maturation is typically so low that the resulting enhanced maturation is still insignificant for hydrocarbon generation, (b) there must be a negative temperature anomaly occurring around the lower flanks of a salt dome that significantly inhibits overmaturation of hydrocarbons and so enlarges the hydrocarbon window, (c) the magnitude of the negative gravity anomaly associated with a salt dome, that is predicted by an equilibrium model of gravitational instability is much smaller than the observed values, implying that salt domes are inhibited in their development either by lateral sediment strength, undercompaction of the overlying or surrounding sediments, or by the available supply of salt, (d) the 4 major current suggestions for cap-rock formation discussed in the literature have serious deficiencies; none of them is capable of supplying enough anhydrite for the observed thicknesses of cap rocks. Permeability enhancement by 2 orders of magnitude is required for any of these processes to be viable. A method for producing such an enhancement is based on fluid characteristics in a generalized sandstone and shale section.

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Sources and Distribution of Upper Pleistocene Sand, Eastern United States Atlantic Shelf

A 2-yr study of the sources and distribution of upper Pleistocene and Holocene sand on the eastern United States shelf between the Bay of Fundy and Cape Hatteras reveals that 3 sand types are found on this shelf: (1) glacially transported, very angular sands, (2) fluvially transported, well-rounded sands derived from unlithified coastal plain deposits, and (3) fluvially transported, moderately angular sands derived from lithified sedimentary and crystalline rocks of the Appalachian and New England areas. For the most part, the distribution of these sand types reflects the late Pleistocene paleogeography of this shelf. Glacial sands are found in the areas of upper Pleistocene till, moraine, and outwash-plain deposits east and northeast of the Hudson Canyon; the 2 fluvial sands are found in coast-normal stripes that correspond to the ancestral paths of the many rivers that traversed this shelf during the late Pleistocene. The preservation of relict paleogeographic patterns of these sorts are an indication of diffusive transport of sand through most of this shelf. The exceptions to this are found in the shallow waters of Nantucket Shoals and Georges Bank, where glacial sands are presently being advected to the southwest by the strong tidal currents that prevail.

LEVIE, DONALD S., JR., Phillips Oil Co., Houston, TX

Deep-Water Hydrocarbon Potential of Georges Bank Trough

Characterization of the petroleum potential for Georges Bank Trough has been based primarily on limited organic geochemical data that indicate the area of recent drilling activity behind the paleoshelf edge to be poor in organic carbon and $C_{15}+$ extract values, with predominantly terrestrial kerogen types. Maturation data also suggest an inadequate thermal history for hydrocarbon generation in the area. It is possible that the effects of heat flow from the New England Seamount Chain may contribute to hydrocarbon generation in the Georges Bank Trough—a relationship that may also exist between the Newfoundland Seamount Chain and the Hibernia area of the Grand Banks. Also, comparisons can be drawn between the Atlantis Fracture Zone bordering the Georges Bank Trough and the Romanche-St. Paul Fracture Zone off the Ivory Coast. In the latter region, restricted anoxic environments with sediments rich in marine kerogen types have been identified, as have both structural and stratigraphic trapping mechanisms. Within this rhombochasm configuration, reservoir lithologies of sandstone and carbonate turbidites, fractured deep-water chalks, and reefal limestones should occur.

The relationships of seamount to fracture zone, as applied to the rhombochasm model for the Georges Bank Trough, should enhance the hydrocarbon potential of the lower Mesozoic sediments seaward of the paleoshelf edge and thus classify this area as a future major hydrocarbon province.

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Major Discoveries in Eolian Sandstone: Facies Distribution and Stratigraphy of Jurassic Norphlet Sandstone, Mobile Bay, Alabama

Recent exploratory and development drilling in Mobile Bay, southwest Alabama, has proven prolific gas production from the Norphlet sandstone at depths greater than 20,000 ft with individual well tests of 10-27 MMCFGD. Excellent reservoir qualities are a function of preserved primary porosity and permeability developed in an eolian setting.

In Mobile Bay, thick eolian sediments (200-600 ft) lie directly on Pine Hill or Louann evaporites. Three facies of the Norphlet have been recognized: (1) a thin (20-30 ft) basal wet sand flat or sabkha facies, (2) a massive dune facies, and (3) a thin (30-40 ft) upper marine reworked facies.

The wet sand flat or sabkha facies is characterized by irregular to wavy horizontally bedded sandstone associated with adhesion ripples. It is probably sporadically developed in response to localized wet lows during earliest Norphlet deposition.

The majority of the Norphlet section is characterized by massive wedge-planar and tabular-planar cross-stratified sandstone, interpreted to be stacked dune and dry interdune deposits. Individual dune sets range in height from a few feet to 90 ft. Cross-bed sets exhibit internal stratification patterns similar to large- and small-scale dunes described by G. Kocurek and R. Dott, Jr.

The marine reworked facies is characterized by structureless to diffuse or wavy laminated sandstone that reflects a reworking of the dune deposits by the ensuing Smackover transgression.

Reservoir quality is affected by textural properties determined by depositional processes associated with these various facies. Diagenetic patterns further reducing reservoir quality occur in the depositionally less-porous sediments. Dune facies sediments exhibit the best reservoir qualities. Variations of reservoir quality within the dune facies are related to dune height and dune versus interdune accumulations.

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New Evidence Suggesting Segmentation of Cocos Plate

Compilation and analysis of geophysical and geological data indicate that the Cocos plate consists of three segments that have individual poles of rotation and independent motion vectors.

Contoured heat-flow and gravity maps of the region delineate the boundaries of the segments within the Cocos plate. These segments have different focal-plane solutions along the Middle America Trench and different sedimentary-basin configurations within the Central America–Mexico island arc. Recent studies of seismic data from the region also have suggested that the subducted Cocos plate consists of three segments.

The proposed northern and central segments are separated by the northeast-trending Siqueros–Tehuantepec Ridge fracture zone. The proposed central and southern segments are separated by the northeast-trending Costa Rica fracture zone that is located just northwest of the Cocos Ridge and extends from the Galapagos rift to the central valley of Costa Rica. Poles of rotation and relative motion vectors have been calculated with respect to the Caribbean plate for each segment. The northern segment is moving N75°E, oblique to the trench; the central segment is moving N50°E, perpendicular to the trench; the southern segment is moving north, perpendicular to the trench.

The Siqueros-Tehuantepec and Costa Rica fracture zones appear to join with "tectonized" zones that dissect the Central America–Mexico island arc and extend across the Caribbean plate, suggesting that it too is segmented. Structural and stratigraphic data from the sedimentary basins