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.

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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 of the island arc suggest that these fracture zones have existed throughout the Tertiary history of the region.

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Lithostratigraphy and Chronostratigraphy of Catskill-Pocono Delta, Upper Devonian-Lower Mississippian, Northern West Virginia

In the central Appalachian basin, sandstones of the Catskill-Pocono delta have produced commercial oil and gas for over a century. In northern West Virginia, spatial and temporal relationships in this sequence (Chemung, Hampshire, and Pocono Formations) are poorly defined and understood.

Correlation using base-lined (relative method) gamma-ray logs, supplemented by lithologic logs and outcrop study, elucidates detailed lithostratigraphic and chronostratigraphic interrelationships including: (1) development of a stratigraphic and sedimentologic "framework" for these strata, (2) illustration of "true" thickness variations of subsurface rock units, (3) determination of distribution and position of "clean" sandstone and red-bed lithofacies, (4) identification of persistent sandstone trends through time, (5) positioning of time lines, which pass through apexes of maximum onlap and offlap, and (6) recognition of an angular unconformity as the upper sequence boundary.

Resultant cross sections illustrate subtle stratigraphic relationships including intertonguing lithofacies, updip and downdip pinch-outs of shallow marine sandstones, and probable cross-slope channel and lobe deposits of turbiditic origin. In addition, subsurface-to-outcrop correlation resulted in identification and description of various gas-bearing sandstones on outcrop, and in correlation of subsurface lithostratigraphic units to outcrop lithofacies.

A similar methodology is recommended for subsequent studies to determine "true" and/or net thickness of a particular facies (i.e., organic-rich shale, "clean" sandstone, or "tight" sandstone). The same approach may be used in other basins where: (1) adequate numbers of gamma-ray logs are available, (2) a consistent shale base line may be determined, and (3) a "clean" sandstone lithofacies or uniform carbonate section is present for determination of a clean sandstone or minimum deflection base line.

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Diffusion of Low Molecular Weight Hydrocarbons Through Pore Space of Sedimentary Rocks: Its Recognition, Quantitation, and Geologic Significance

Based on theoretical considerations, diffusion of low molecular weight hydrocarbons through the water-saturated pore system of sedimentary rocks can be expected as a common and ubiquitous process in the subsurface. Wherever concentration gradients develop (e.g., with the onset of hydrocarbon generation near the contact between organic-rich and organic-lean strata) diffusion of mobile components should occur. Diffusion processes play a dual role in the subsurface: as an initial step for transportation of hydrocarbons from source rocks toward carrier rocks, and at a later stage, when a reservoir accumulation has formed, as a destructive process by light hydrocarbon dissipation through the cap rock.

Geochemical evidence to illustrate the role and the effects of diffusion in both processes generally is represented by characteristic relationships between concentration depth trends and the molecular size and structure of the various hydrocarbon species in the transported mixture. Also, shale cap rocks of productive reservoir hydrocarbon accumulations are permeable, and diffusive loss of light hydrocarbons is significant. For individual light hydrocarbons, diffusive halos can be recognized in the cap rock above the reservoir accumulation.

Based on newly determined effective diffusion coefficients, model calculations have been made for quantitation of the outlined observations. In this way it was possible to demonstrate that molecular diffusion through the water-saturated pore space of shale source rocks represents an effective process for primary migration of gas and can account for transportation of such.

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Maturity Anomalies, Fluid Flow, and Permeability Preservation in Frio and Anahuac Formations, Upper Texas Gulf Coast

The Pleasant Bayou geopressured-geothermal test wells in Brazoria County, Texas, display a prominent thermal maturity anomaly in the Oligocene Anahuac and Frio Formations. Highly geopressured, more-mature shales are interbedded with hydropressured to moderately geopressured sandstones in the upper Frio and Anahuac. In contrast, shales and sandstones in the lower Frio, including the Andrau geopressure-geothermal production zone, are highly geopressured and exhibit lower thermal maturities.

In the deeper lower maturity sandstones, porosity is dominantly secondary. These sandstones are more permeable by an order of magnitude than the more-mature shallower sandstones. The intense dissolution of grains in the highly geopressured lower Frio Formation is directly related to the increasing solubility of CO_2 (released during the maturation of organic matter) with increasing pore pressure.

Maturity data at Pleasant Bayou indicates that the upper Frio was subjected to an extended period of upwelling basinal-fluid flow that caused the thermal anomaly. Updip flow of hot basinal fluids was largely arrested in the lower Frio by the high geopressure. Consequently, the maturity of the lower Frio was not increased.

Late-state porosity and permeability destruction by carbonate cementation seen elsewhere in the Gulf Coast was inhibited in the deeper Frio by the low influx of Ca^{2+} ions contained in the fluids. These Ca^{2+} ions were released from albitization of feldspars at more-mature, deeper levels.

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Fluid and Rock Interaction in Permeable Volcanic Rock

Four types of interrelated changes—geochemical, mineralogic, isotopic, and physical—occur in Oligocene volcanic units of the Mogollon-Datil volcanic field, New Mexico. These changes resulted from the operation of a geothermal system that, through fluid-rock interaction, affected 5 rhyolite ash-flow tuffs and an intercalated basaltic andesite lava flow causing a potassium metasomatism type of alteration. (1) Previous studies have shown enrichment of rocks in K_2O as much as 130% of their original values at the expense of Na_2O and CaO with an accompanying increase in Rb and decreases in MgO and Sr. (2) X-ray diffraction results of this study show that phenocrystic plagioclase and groundmass feldspar have been replaced with pure potassium feldspar and quartz in altered rock. Phenocrystic potassium feldspar, biotite, and quartz are unaffected. Pyroxene in basaltic andesite is replaced by iron oxide. (3) $\delta^{18}O$ increases for rhyolitic units from values of 8-10 permil, typical of unaltered rock, to 13-15 permil, typical of altered rock. Basaltic andesite, however, shows opposite behavior with a $\delta^{18}O$ of 9 permil in unaltered rock and 6 permil in altered. (4) Alteration results in a density decrease. SEM revealed that replacement of plagioclase by fine-grained quartz and potassium feldspar is not a volume for volume replacement. Secondary porosity is created in the volcanics by the chaotic arrangement of secondary crystals.

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Madison Group (Mississippian) Reservoir Facies of Williston Basin, North Dakota

Twenty-seven oil fields producing from the Mission Canyon Limestone and Charles Formation (middle and upper Madison Group) were studied: (1) along the eastern basin margin (Bluell, Sherwood, Mohall, Glenburn, Haas, and Chola fields), (2) northeast of Nesson anticline (Foothills, North Black Slough, South Black Slough, Rival, Lignite, and Flaxton), (3) along Nesson anticline (North Tioga, Tioga, Beaver Lodge, Capa, Hoffland, Charlson, Hawkeye, Blue Buttes, Antelope, and Clear Creek), and (4) south of the basin center (Lone Butte, Little Knife, Big Stick, Fryburg, and Medora).

Mission Canyon reservoirs along the eastern margin are in several shoaling-upward carbonate to anhydrite cycles of pisolitic packstone or