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 grainstone buildups. South of the basin center, only a single shoaling-upward sequence is present, with dolomitized, mostly restricted-marine skeletal wackestone to pelletal wackestone or packstone reservoir facies. Nesson anticline, between these 2 areas, contains a single shoaling-upward sequence without an anhydrite cap. In northern Nesson anticline, Mission Canyon reservoir facies are oolitic-pisolitic, intraclastic wackestone or grainstone buildups or open-marine skeletal packstone or grainstone. Both limestones and dolostones are productive in southern Nesson anticline. Limestone reservoir facies are transitional, open to restricted-marine slightly intraclastic, skeletal wackestone or packstone facies. Dolostone reservoir facies are restricted-marine mudstone to skeletal mudstone and pelletal wackestone or packstone.

Northeast of the Nesson anticline, production is from oolitic to pisolitic packstone or grainstone buildups in the Rival (or Nesson) subinterval and from restricted-marine, dolomitized spiculitic mudstone in the Midale subinterval (base of Charles Formation). In the northern Nesson anticline, Rival (Nesson) reservoir facies are offshore open to restricted-marine, skeletal, intraclastic, pelletal wackestone and/or packstones.

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Reservoir Geology of Portion of Sailor Springs Consolidated Field and Its Impact on Primary and Secondary Production

The pool under study is part of the Sailor Springs Consolidated field, Clay County, Illinois. The 23 wells within the pool have produced more than 350,000 bbl of oil from the McClosky limestone (Mississippian-upper Valmayeran) since 1981. The average depth of the wells and the pay zone is 3,000 ft.

The trap is predominantly stratigraphic in nature. Examination of core, thin sections, and geophysical logs indicates that the producing zone is composed of a complex series of oolitic bars. The individual bars are laterally discontinuous, flat bottomed, convex upward, and composed of oolitic skeletal grainstones that grade into dense skeletal wackestones and mudstones that act as reservoir seals. The bars are commonly subtle and easily overlooked. Several wells produce more than 100 BOPD from a zone less than 3 ft thick.

Detailed mapping of total pore volume, total permeability, and facies cementation patterns is essential for successful field development and secondary waterflooding. These parameters have had a direct impact on primary and secondary production performance within the pool. Detailed reservoir mapping also reveals that the pool is subdivided into several reservoirs separated by reentrants that cut across the oolitic bars.

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Beach-Swash Zone: Primary Ooid Factory?

The shore of Long Bay along the southeastern coast of Providenciales Island in the Turks and Caicos Islands, British West Indies, represents a bankward-accreting beach and dune complex of Holocene oolitic grainstone. Offshore, en echelon bars of very low relief consist of skeletal-pelletal grainstones with thin oolitic coatings. Nearshore, the oolitic coatings become more numerous and thicker with the largest and most completely developed ooids found in the beach and swash-zone environments. Adjacent beach and storm-berm sands serve as the source for oolitic particles that have constructed dunes as much as 40 ft high.

This observed relationship between ooids forming in the beach and swash zones, and their subsequent deposition in adjacent beach dunes may provide the most reasonable explanation for the topographically high oolitic dunes of Pleistocene age (some as high as 150 ft) that rim many of the narrow shelf margins of the Bahama Banks. In these settings, little evidence appears for extensive offshore bar development. It is possible, though difficult to prove, that production of oolitic coatings in Bahaman submarine tidal bars and banks (Cat Cay, Schooner Cays, south end of the Tongue of the Ocean) primarily occurs during periods of low tide in a beachlike environment rather than during periods of movement associated with strong tidal currents.

This swash-zone method of oolite formation provides an alternative model to the traditional bar mechanism for the formation of elongate oolite sand accumulations. Such a mechanism might also explain extensive ancient oolitic sand sheets that may have grown through lateral accretion of the oolite-forming beach facies, or as a basal transgressive beach facies deposited during a relative sea level rise.

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Carbonate Structural and Stratigraphic Trap with a Diagenetic Twist: West Purt Field, East Texas

The Rodessa Limestone (Aptian) produces from structural and combination traps in the East Texas basin. West Purt field, in northeastern Anderson County, is a Rodessa combination trap where porosity and permeability have been affected by hydrocarbon alteration, adding an additional complexity to the reservoir.

In West Purt field, porous skeletal grainstones successively pinch out obliquely across the crest of a northwest-plunging structural nose. The structure is cut by a eastward-dipping fault that forms the eastern boundary of the field. The reservoir grainstones have been subdivided into 3 facies. Two of these facies are fine-grained to cobble-size, poorly sorted coral-skeletal rudstone, cyclicly interbedded with fine-grained, well-sorted mollusk-echinoid grainstone and packstone. The third facies is the overlying fine to coarse-grained mollusk-peloid grainstone, commonly laminated or graded. The overall sequence is interpreted as a prograding shoreface and foreshore deposit.

Among the more significant aspects of diagenesis are the early formation of moldic porosity that is partially filled with phreatic isopachous and equant calcite spar cements. Later compaction and minor cementation by saddle dolomite and anhydrite had a minimal effect on porosity. The final stage of cementation was the precipitation of solid bitumen. This bitumen causes a moderate decrease in core-measured porosity, but a significant decrease in permeability by plugging pore throats. The presence and distribution of solid bitumen are not discernible on logs owing to the lack of significant density contrast between crude oil and bitumen. Solid bitumen occurs only in wells adjacent to the eastern boundary fault, regardless of structural elevation. Geochemical analyses of bitumen samples suggest that secondary gas from an underlying source (migrating up the eastern boundary fault) caused the precipitation of solid bitumen by deasphalting the in-place oil.

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Oil-Productive Miocene Algal and Sea Grass Carbonate Mudbanks, South Sumatra, Indonesia

Ramba and Tanjung Laban oil fields, located about 70 km northwest of Palembang in southern Sumatra, produce from wackestones and packstones in the lower Miocene Batu Raja Formation. Reservoir rocks are part of relatively small, undolomitized, low-relief carbonate buildups that accumulated on a widespread platform facies. Rocks in the platform facies are dominantly shaly nodular wackestones, whereas rocks in the buildup are dominantly nonshaly wackestones and packstones. The regional setting, the abundance of micrite in the buildups, the absence of both coralline algae and marine cements, and the geometry of the buildups suggest that noncalcareous algae and/or sea grasses were the dominant organisms responsible for forming these mudbanks.

The absence of shale in the mudbanks has been important in forming the secondary porosity that yields most of the oil. Vugs and molds form as much as 30% of the rock in the best reservoir zones. Fractures formed by dissolution and collapse greatly enhance reservoir quality in many places. Another type of porosity, microintercrystalline, occurs within "chalky" micrites scattered through the upper part of the buildups. Porosity in these micrites reaches 25%, but permeability is very low.

The recent discovery of oil in these low-energy carbonate mudbanks of the Batu Raja Formation has opened a new exploration play in the South Sumatra basin. Many similar buildups will likely be found as exploration continues and the basin's paleogeography becomes better understood.

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Southern Appalachian Thrust Model