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RECIPROCAL DEPOSITION WITHIN NIAGARAN AND EARLY CAYUGAN (SILURIAN) CARBONATES AND EVAPORITES, NORTHERN MICHIGAN BASIN

Time-stratigraphic relations within Silurian strata of the northern Michigan basin provide a model for reciprocal deposition of carbonates and evaporites. The Niagaran of the basin interior consists of crinoidal hematitic biomicrites. Toward the basin margin the biomicrites thicken and lose their hematitic character. A belt of pinnacle reefs marks the approach to the basin margin. The Niagaran pinnacle reefs have a lower crinoidal zone and an upper coral-algal zone. At the basin margin the Niagaran thickens abruptly into a dolomitized barrier reef complex. The barrier reefs were constructed mainly by corals and massive stromatoporoids which prograded basinward over thick skeletal forereef calcarenites.

Niagaran barrier and pinnacle reef construction was halted in the early Cayugan by an episode of evaporite deposition. Karst features within Niagaran carbonates suggest subaerial exposure of the barrier and pinnacle reefs at this time during a period of lowered sea level. Return of high sea level caused cessation of evaporite deposition and rejuvenation of the pinnacle reefs; also, fringing reefs developed along the margin of the former barrier reef trend. However, the renewed reef development was of a considerably different biotic character. These early Cayugan reefs possess a lower massive encrusting algal zone and an upper laminar stromatoporoid-stromatolite zone. Corals are notably absent. Reef development again was halted by evaporite deposition followed by another episode of carbonate deposition generally devoid of reef rejuvenation.

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HYDROCARBON ACCUMULATIONS IN FOLDED APPALACHIANS OF SOUTH

In the Folded Appalachians of the south most of the petroleum interest and all of the oil and gas production have been within or close to a unique structural feature, the Cumberland overthrust block. This large mass includes parts of Virginia, Kentucky, and Tennessee. Displacement of the block toward the northwest is about 11 mi along its southwest edge in Tennessee and about 4 mi along its northeast edge in Virginia. Rocks of all systems from Cambrian to Pennsylvanian are involved, totaling approximately 20,000 ft in thickness. Oil has been produced from rocks of Ordovician age and gas from rocks of Devonian and Mississippian ages. Other targets exist.

Two reasons are adduced to account for the fact that hydrocarbon accumulations persist in rocks subjected to such extensive displacement. First, gravity sliding rather than tectonic lateral stress seems best to explain the structural relations from surface to basement. Thus, the "overthrust" rocks were under little if any more compressional stress during faulting than before it, and they have not been compacted, recrystallized, or cemented to an extent precluding effective porosity. Second, the Pine Mountain fault, which underlies the block, is a bedding plane fault throughout most of its extent, but locally it ramps upward from one weak zone to another. Four weak zones that favored localization of the fault plane are known. Only at, and northwest of, the ramps are older rocks piled on younger, resulting in abrupt thickening of the sedimentary section.

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STRATIGRAPHY AND PETROGRAPHY OF UPPER SILURIAN WILLIAMSPORT SANDSTONE, WEST VIRGINIA

The Upper Silurian Williamsport Sandstone at the type section in Grant County, West Virginia, is typically composed of very fine-grained green and brown sandstone with some siltstone and shale. A local carbonate member, the Cedar Cliff Limestone Member, is present in the middle of the formation in nearby outcrops in western Maryland. On the north in Pennsylvania, the Williamsport can be traced into the Moyer Ridge Sandstone Member of the Bloomsburg Formation. Eastward, in the eastern panhandle of West Virginia and Maryland, the Williamsport pinches out in the middle of the nonmarine red Bloomsburg facies. Farther south the Williamsport undergoes a facies change into clean well-sorted mature sandstone. The subsurface continuation of this sandstone extends to the Ohio border, where it has been found to be an important reservoir for natural gas.

Sandstones of the Williamsport in the subsurface are very fine to fine grained, subrounded to rounded, well sorted, and texturally mature and supermature. In general, sandstone is most abundant in the upper half of the unit, whereas carbonates become interbedded with sandstone layers in the lower half. Syntaxial quartz overgrowths serve as the primary cement in the upper part of the formation, but dolomite becomes important lower in the section. Gypsum, anhydrite, and barite are minor cements. Intergranular porosity is greatest near the top of the formation.

The immature sandstones and siltstones of the Williamsport in northeastern West Virginia probably were deposited on low-energy mud flats in front of the Bloomsburg delta. Sediments were supplied by rivers from source lands farther east in Pennsylvania. The limestones and hematitic beds of the Cedar Cliff Member are interpreted as having been deposited in a lagoon associated with this tidal flat. Farther south, the cleaner, coarser, more mature sandstones were deposited in a barrier island-coastal complex. Regression of the shoreline spread a blanket of sand over the underlying subtidal to intertidal McKenzie Formation. As the shoreline and barrier island complex regressed westward the lagoonal sediments of the Wills Creek Formation were superposed on the clean sand of the Williamsport.

Gas accumulation in the Williamsport is due to a combination of stratigraphic and structural trapping. Salt water is present downdip in all fields, and updip porosity and permeability decrease where the sandstone thins westward. Gas flows in this formation are the greatest recorded in the Appalachian basin, making the Williamsport the most important deep target for drillers in West Virginia. Future exploration should examine the possibility that combination stratigraphic and structural traps exist near the eastern edge of the sand body in central West Virginia and near the southwestern sandstone pinchout in south-central West Virginia.

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SUBSURFACE DATA BEARING ON TECTONIC STYLE OF VALLEY AND RIDGE PROVINCE

Selected seismic lines and well data in the Valley and Ridge province between the Anthracite region, Pennsylvania, and the Pine Mountain region, Virginia-Kentucky, support the hypothesis that the region is characterized by a thin-skinned style of deformation.

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POTENTIAL IMPACT OF OIL DEVELOPMENT ON ECOLOGY AND ENVIRONMENT OF MIDDLE ATLANTIC OFFSHORE AREA

Oil drilling and exploitation have made a calculable impact on the environment in the mid-Atlantic offshore area. Oil pollution is related to the overall polution problem, but there are possibly other direct consequences of oil drilling and exploitation. From actual known oil pollution occurrences, both natural and manmade, it is shown that pollution from natural means has very little impact on ecology. The record also shows that manmade pollution caused by drilling and exploitation in marine areas is, except in local areas, both short lived and not very persistent.

The loss of oil through transport petroleum products produces effects as large as or larger than any exploitation effects; these effects will increase as larger quantities of oil are imported, though they can be lessened by strict enforceable rules.

All interested groups must work together to lessen any possible adverse effects upon the entire economy; they must not take opposite polarized attitudes.

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STRATIGRAPHY AND POTENTIAL PROSPECTS OF DEVONIAN REEFS OF NEW YORK

Reefs are found in the outcrop sections of several Lower and Middle Devonian units in New York State. The most prominent of these occurs in the Edgecliff Member of the Onondaga Limestone.

The Onondaga Limestone was first described and named by James Hall of the New York Geological Survey in 1839. The present fourfold division of the Onondaga, in descending order, Seneca, Moorehouse, Nedrow, and Edgecliff, was proposed by Oliver in the early 1950s. The type section is located in Onondaga County, New York. In the subsurface, the uppermost Seneca Member is a massive limestone and can only by separated from the similar underlying Moorehouse Member by the presence of the Tioga Bentonite Bed, which gives a characteristic peak on the gamma ray log.

The Seneca is absent in the central-southern part of New York, where a pronounced thinning of the Onondaga occurs. The Moorehouse is a massive cherty limestone and is also missing in the extreme central-southern part of New York in the previously mentioned area of thinning. The Nedrow is a shaly cherty limestone and is persistent throughout the state and in the area of thinning, except over known subsurface reefs in the underlying Edgecliff.

The lowermost Onondaga member, the Edgecliff, is a coarse-grained light-gray to grayish-white biostromal limestone, present in an area from northeastern southwestward through central New York.

In eastern and southeastern New York this unit is represented by an argillaceous facies, whereas in far western New York it is highly cherty. The Edgecliff shows a pronounced thinning in central and southern New York and in north-central Pennsylvania, where it is mostly 10 ft or less thick. In the southwestern part of this thin area, three subsurface Edgecliff reefs, all 150-200 ft thick and containing gas, have been discovered since 1967. At least 21 smaller reefs are known in the outcrop section of this member in eastern New York, one in central New York and two in the Buffalo area. The reefs were formed in a clear-water shallow subtidal environment on the Edgecliff platform.

Biostromal facies and reefing are also present on the outcrop in several zones in the Middle Devonian Hamilton Formation, which overlies the Onondaga. Most important of these zones are in the Ludlowville Member of the Hamilton in the Syracuse area of central New York. Two of these zones, the Joshua and Staghorn Point, occur over areas of 40 and 120 sq mi, respectively, according to Oliver. No reef buildup in these zones has been encountered in drilling as yet, but no systematic search has been made for reefs in the subsurface.

Several smaller reefs are known from outcrops of the Coeymans Formation of the Helderberg Group in central New York and northwestern New Jersey.

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GROWTH FAULTS IN UPPER CAMBRIAN AND LOWER ORDOVICIAN ROCKS OF WESTERN PENNSYLVANIA

The Upper Cambrian Gatesburg Formation of northwestern Pennsylvania (Erie, Crawford, Mercer Counties) is almost 1,000 ft thick and consists of oolitic sandy dolomite; two 100- to 150-ft thick sandstone units, previously called "Upper Sandy and Lower Sandy members," occur at the top and middle of the formation. One hundred twenty-five miles southeast at outcrop in central Pennsylvania, the Gatesburg is 1,500 ft thick and is similar in lithology to the northwestern Pennsylvania strata. Recent drilling between these two areas indicates that the Gatesburg thickens to more than 1,900 ft and is of different lithology in the intermediate area. The two sandstone units of northwestern Pennsylvania are replaced by dolomite, and a sandstone body, 200-350 ft thick, occurs stratigraphically below the position of the sandstone units of northwestern Pennsylvania. Apparently no strata represent this thick sandstone in northwestern Pennsylvania. The additional thickening and the different lithologic sequence of the Gatesburg strata in this intermediate area are the result of deposition in a northeast-trending basin whose western edge is interpreted to be a growth fault.

Lower Ordovician (Beekmantown) dolomites and limestones thicken from zero in northwestern Pennsylvania to more than 3,500 ft in central Pennsylvania. The thickening also results from a growth fault which trends northeast and lies east of the fault in the Upper Cambrian rocks.

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TECTONIC FRAMEWORK OF SOUTHERN APPALACHIANS—EVIDENCE FROM GRAVITY AND MAGNETIC DATA

A plate tectonics model comprised of three major subduction zones explains many major geophysical anomalies and geologic structures observed in the southern Appalachians. The Brevard zone is thought to mark the southeastern boundary of a major Caledonian subduction zone. Many thrust faults of the Blue Ridge and eastern Smoky Mountains are thought to root in this zone. A subduction zone extending along the western margin of the Blue Ridge in Virginia and Smoky Mountains in Tennessee is thought to be an *en échelon* extension of the Brevard zone. A minimum of 55 km crustal shortening has been calculated for the Brevard zone in western North Carolina. Minor subduction occurred along the Blue Ridge-Smoky Mountain zone during the Hercynian orogeny. The main locus of the Hercynian subduction is thought to have been the Knoxville zone, so named because the basement subcrop of the zone passes beneath Knoxville, Tennessee. Most thrust faults along the Cumberland Plateau-Valley and Ridge boundary are thought to root in this zone. The amount of subduction seems to have been less than that of the Caledonian orogeny. Each inferred subduction zone coincides with northeast-southwest linear gravity lows and parallel discontinuities in the magnetic field. Basement anticlines occur northwest of the Brevard and Knoxville zones.

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PREDICTIONS OF FUTURE EXPLORATORY TRENDS IN APPALACHIAN BASIN

Exploration activity within the Appalachian basin has shown a marked upswing within the past year. Current massive lease acquisition programs and saturation seismic activity have far exceeded past cyclic pulsations of exploratory activity.

Proximity to eastern gas and oil markets and higher gas prices are important factors, but cooperation of major gas and pipeline companies with major oil companies and large independent producers, and the recognition by these operators that the Appalachian basin is a vast, untested, geologic frontier with "major company" reserves to be probed for and developed, have added appreciably to the present exploration momentum.

The principal areas to be prospected with geophysical methods and the drill are: