work controlled by plate morphology helps localize later diagenetic events, which ultimately produce a well-connected, predominantly large-pore network. This provides for large initial production rates and relatively high recovery factors, which are very desirable reservoir attributes from an economic standpoint.

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CYCLES IN GASPERIAN (MISSISSIPPIAN) BASIN-EDGE SEDIMENTS OF INDIANA

Basin-edge sediments of the Gasperian Stage (Upper Mississippian) in southwestern Indiana consist of four limestone formations that alternate rhythmically with three terrigenous formations. Each formation exhibits an aggregate of supratidal to subtidal lithofacies having characteristic fossil assemblages and diagnostic parameters of depositional turbulence. Areal distribution patterns of lithofacies for each widely correlative stratigraphic unit have analogs in known lithotope patterns of modern inner shelf sediments. Certain Gasperian patterns were influenced by antecedent topography. Lithofacies succeed one another in predictable sequences representing distinctive regressive and transgressive lithotopes of seven principal cyclothems. Two successive, homotaxial cyclothems are represented wholly by carbonate facies. Other cyclothems maintain greater individuality and are partly or entirely terrigenous. Lithofacies of all but one cyclothem are arranged asymmetrically with either prolonged transgressive or prolonged regressive phases. Sudden lithotope shifts are discernible. Local influxes of terrigenous sediments coupled with progressive changes in strike of the contemporaneous shoreline from N25° W to N5° W effected disappearance of three cyclothems toward the north.

Although Gasperian formations maintain essentially the same sequential order throughout the Illinois basin, those exposed in Indiana differ fundamentally from equivalent strata near the structural axis of the basin in thicknesses, proportion of carbonates, strike of sedimentary bodies with respect to paleoslope, and magnitude of shoreline migrations. Gasperian sediments in Indiana accumulated in a relatively stable coastal region influenced by shoreline processes. This area differs from the basin center which other authors have shown to be the locus of terrigenous deposition in an unstable deltaic regime.

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STRATIGRAPHIC CORRELATION AND RESERVOIR DISTRIBUTION IN MID-ATLANTIC PART OF ATLANTIC COASTAL PLAIN–CONTINENTAL SHELF GEOSYNCLINE

Analyses of stratigraphic correlation, reservoir distribution, and facies change in Mesozoic and Cenozoic sediments in the subsurface of the Salisbury embayment can be used as a model for stratigraphic projection into the submerged part of the geosyncline. The sediments studied are unlithified with a thickness greater than 7,700 ft near the coast. Onshore Cretaceous marine and nonmarine sand and clay correlate with a published geophysically identified semiconsolidated sediment unit as thick as 14,000 ft. Paleocene, Eocene, and Miocene sediments project into a zone of up to 5,000 ft of unconsolidated sediment. A thin veneer of Quaternary marine and nonmarine sediments covers almost the entire coastal plain-shelf area. Limited onshore evidence suggests that lithified Triassic or Jurassic sediments comprise a significant deeper part of the offshore basin.

Correlations range from simple, long-range correlations of widespread, uniform, marine units to difficult, short-distance correlations where abrupt facies changes in marine and nonmarine sediments take place. Identification of the Upper-Lower Cretaceous boundary is in doubt and previously has been placed at different levels within a stratigraphic interval 3,000 ft thick. The diversified and complex terminology applied to sediments on the northwest geosynclinal flank demonstrates the complexity of correlation in this area of abrupt facies change. Detailed geophysical log correlations also suggest the presence in the subsurface of this area of abrupt facies changes in marine and nonmarine stratigraphic units. Local minor unconformities may be common in the margin of the geosyncline.

A salt-water wedge protrudes to within 20 mi of the basin edge and commonly is found at depths greater than 1,000 ft. Excellent reservoir conditions occur throughout the onshore stratigraphic section.

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RECOGNITION OF PRE-PLEISTOCENE GLACIAL ENVIRONMENTS

Pleistocene glacial deposits are identified easily; however, the existence of pre-Pleistocene glacial deposits has been challenged for several reasons. Recognition of earlier widespread glacial deposits is associated by many workers with continental drift, a process that complicates paleomagnetic and paleoclimatic reconstruction. In addition, pre-Pleistocene glacial deposits can be interpreted environmentally in several ways. Alleged tillites containing poorly sorted clasts, striated rock fragments, and rock flour are similar to deposits formed by subaerial and subaqueous mass movements. Few criteria alone are decisive; therefore many environmental criteria must be sought.

Among the more important physical characteristics of glacial deposits are ultramicroscopic markings on the surfaces of quartz sand grains; massive, nonsorted debris with abundant rock flour, silt, sand, and blocks; striated stones; deflection and penetration of laminae by stones; stone shape; presence of erratics; extraordinarily large boulders; ice-molded structures; striated and polished pavements; and thickness and extent of stratigraphic units.

The more important chemical criteria include comparisons of chemical and mineralogical composition of clasts and matrix, differing mineralogy of the stones, and oxygen-isotope ratios of fossil shell material.

Biological criteria include fossil invertebrates and vertebrates capable of existing in cold climates; and the identification of fossil floras which may be characteristic of cold climates.

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SUBMARINE LITHIFICATION OF JAMAICAN REEFS

Widespread lithification of recent reef framework is occurring just below the reef-water interface in all zones of the reef to depths of at least 70 m on the north coast of Jamaica. Several different frameworkbinding processes appear to be involved: (1) crusts of organic origin, commonly concentrically layered deposits of red algae, Foraminifera, and Bryozoa, and (2) thick, laminated, lithified, micrite crusts with a smooth to nodular surface, preferentially accreted upward and not clearly associated with any calcareous taxa. The organic crusts commonly occur just under the reef surface, whereas the hard concretionary crusts are common deeper within the reef, lining the numerous channels and cavities that permeate the framework.

Many of the reef pores (both the primary inter- and intra-framework pores and also cavities produced secondarily by boring organisms such as *Cliona*) are filled with lithified sand, micrite, or acicular crystalline cement. Just beneath the reef surface is extensive lithification of poorly sorted micritic sediments between and within the framework. Sand trapped in inter-framework cavities is consolidated by drusy cements. In many places, the lithified material is bored by *Cliona* and the resulting cavities are refilled and relithified, indicating that these processes occur at a rapid rate.

Similar features are recognized in Pleistocene reefs on the north coast of Jamaica. This observation suggests that the lithification processes are common in time as well as in space.

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Paleozoic Carbonate Facies of Central Appalachian Shelf

The central Appalachian shelf, which received sediments discontinuously throughout the Paleozoic, is bounded on the north by the Precambrian crystalline rocks of the Adirondacks, on the west by the Cincinnati arch and on the east by geosynclinal basins. Major carbonate sequences were deposited during the Late Cambrian-Early Ordovician (Conococheague, Beekmantown), Middle Ordovician (Black River, Trenton), Middle Silurian (Lockport), Late Silurian-Early Devonian (Tonoloway, Keyser, Helderberg), and Middle Devonian (Onondaga). Minor, but equally interesting, carbonate units were deposited during the Middle Devonian (several thin limestones within the Hamilton) and Late Devonian (Tully).

Recent environmental stratigraphic studies of these carbonate rocks show a great variety of lithofacies and biofacies. Despite this great diversity, four major facies complexes can be characterized.

Tidal flat deposits, consisting of laminated, dolomitic, mud-cracked, intraclastic rocks with low faunal diversity and algal structures, are well developed in the older carbonate units (Conococheague, Beekmantown, Black River, upper Lockport, Tonoloway, Keyser, and lower Helderberg). These rocks were formed in supratidal and intertidal environments.

Shallow subtidal deposits, consisting of biomicrite (generally well burrowed), biosparite (in many places current stratified), and some oösparite with relatively diverse and abundant biotas, are particularly common in the middle part of the Cambrian-Devonian carbonate sequence (upper Black River, Trenton, middle Lockport, Keyser, Helderberg, and Onondaga). These rocks record restricted- to open-marine environments above, or slightly below, effective wave base.

Deeper subtidal deposits, consisting of well-burrowed impure biomicrite with less abundant and less diverse biotas, are more typical of the younger part of this interval (Onondaga, Portland Point, and Tully). These strata formed in open-marine environments below effective wave base.

Carbonate buildups are found throughout the Cambrian-Devonian either as small algal mounds (Conococheague, Beekmantown, Lockport), tabulate or stromatoporoid biostromes (Black River, Lockport, Keyser, Helderberg, Tully), or as bioherms dominated by rugose and tabulate corals (middle Lockport, Helderberg, and lower Onondaga). Fossil diversity and abundance are greatest within the biostromes and bioherms.

As might be expected, the temporal distribution of these broad facies complexes parallels the Paleozoic tectonic history of the central Appalachians. Thus, during times of tectonic stability carbonate tidal-flat and shallow subtidal deposits were abundant. As tectonism increased in the eastern geosynclinal terranes, the nearshore areas of these environments were flooded by land-derived terrigenous clastics. Greater subsidence of the shelf areas also seems to have been general, with the result that deeper water carbonate became more common. Carbonate buildups seem to occur in a wider variety of environmental situations. Although related to the general tectonic regime, they also were dependent on good marine circulation and local paleogeography.

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Markov Forecasting Techniques in Exploration

When preceding events influence succeeding events, a certain probability can be calculated for the process, which is said to possess the Markov property. An increasing number of geologic processes have been described that demonstrate this property, and the behavior of exploration geologists frequently is no exception. Markov methods allow a reasonably limited number of exploration factors to be considered together on a probability basis. A particular advantage is that factors having different dimensions, such as barrels of oil, the density of seismic coverage, or the cost of drilling, can be evaluated together for forecasting purposes.

Small Markov studies can be undertaken without a computer, but for larger models it is both simple and desirable to use a computer. A forecasting model should include consideration of environmental conditions (the historical events), the alternative choices (the possible outcomes from which the optimum forecast may be derived), and the weight attached to each factor.

Forecasts can be made for two general areas. Within a company, the exploration environment conducive to success is worthy of investigation, as is the efficiency of the exploration process. From a competitive viewpoint, the behavior of other companies is of interest as advantage can be taken of any known Markov tendencies in their exploration policies. Geologists should use Markov methods to reduce the uncertainty of decision making to finite probability. This will result in an increased success ratio.

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Practical Computer Usage for Subsurface Geologists

Techniques for proper utilization of the computer need to be developed by experienced subsurface geologists thoroughly familiar with the computer programs used in solving exploration problems. Output from the computer is not the end result, but is the beginning point for the exploration geologist. The "geology" of