

analysis of 250 electric logs in the Sand Wash basin. Lithofacies geometry and relations combined with the interpretation of inferred processes from sedimentary structures were used to develop depositional models.

The Mesaverde Group can be subdivided into wave-dominated deltaic deposits and their flanking sand-rich strand-plain, interdeltic deposits. Deltaic headlands were approximately 20 km wide, while the strand plains extended downdrift for at least 60 km. Near deltaic depositional axes, multiple straight and meandering distributaries replace the upper part of the shoreface sequence. Fluvial plain deposits cap this sequence with point-bar sandstones, splays, overbank mudstones, and coals. In interdeltic areas, progradational shoreface sandstones were deposited and are overlain by coastal plain brackish and freshwater deposits and coals. Marine flooding of the coastal plain was probably due to a combination of subsidence and formation of flanking lows adjacent to depositional axes due to loading.

The progradational shoreface is a coarsening-upward sequence 30 to 120 m thick. The sequence includes a basal bioturbated mudstone which becomes interbedded vertically with hummocky cross-stratified sandstones that are capped by an 18 to 60 m thick sandstone. The base of the thick sandstone contains hummocky cross-bedding that grades vertically into troughs that are capped with very low angle cross-bed sets.

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Mid-Cretaceous Black Shales: A Result of Excessive Fertility or Global Anoxia?

In Holocene marine environments, organic carbon accumulation rates are high in areas of high productivity, rapid deposition, and in anoxic basins. Heavy metal accumulation rates are high in areas of high bulk sedimentation (resulting from the large detrital component), in areas of high fertility (heavy metal enrichment in organic tissue), and in areas of hydrothermal activity. The various environments can be characterized by the relations between their bulk sedimentation rates, amounts and types of organic carbon in the sediment, organic carbon accumulation rates, primary productivity, preservation factors (fraction of organic carbon fixed in the photic zone that becomes buried in the sediment), and accumulation rates of heavy metals (such as Cu, Ni, Zn). Differences in these relations exist, in particular, between areas where sapropel deposition is due to high supply (i.e., high fertility in localized upwelling areas) and where it is due to anoxic deep waters (such as in the Black Sea).

Application of an improved calcareous nannofossil biochronology to compute accumulation rates in various DSDP sections show that the mid-Cretaceous black shales are characterized by substantially higher accumulation rates of heavy metals relative to organic carbon than is observed in Holocene upwelling settings. The implied widespread deep-water anoxia suggests high organic carbon preservation factors and correspondingly low primary productivity for large parts of the mid-Cretaceous oceans.

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Genetic Stratigraphy and Hydrocarbon Potential of a Combination Progradational-Retreating Barrier Island System

Depositional models and consequent stratigraphic "stan-

dards" are among the most valuable tools in scientific hydrocarbon exploration. Such models have been established for barrier-island systems based on extensive study of modern coastal areas. However, concepts of genetic stratigraphy have been developed only for the end members of the barrier-island spectrum, i.e., transgressive barriers (U.S. east coast type) and progradational barriers (Texas Gulf Coast type). Stratigraphic models for these pure types may be inadequate when exploration deals with ancient systems that fall towards the middle of the spectrum. Therefore, a different model must be developed for these intermediate types.

One such intermediate type of barrier-island system along the peninsular Florida west coast has been recognized and modeled by the author. Caladesi and Honeymoon Islands (just north of Clearwater Beach, Florida) formed at the end of the rapid Holocene sea-level rise by upward aggradation of an offshore bar. Subsequent development of the system has been episodic and complex in response to fluctuations in relative rates of sea-level rise and sedimentation. The resulting stratigraphy reflects alternating shoreline progradation (slow sea-level rise) and recession (fast sea-level rise). Laterally adjacent mud and sand environments are repeatedly superimposed on each other, producing an attractive sequence of source and reservoir lithology different from that of previously studied systems.

This stratigraphic framework can be recognized in subsurface cores and electric logs. This model can be used to identify position in a subsurface barrier-island system and to lead to hydrocarbon discovery.

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Geochemical and Mineralogical Analyses, Pennsylvanian Kendrick Fauna, Eastern Kentucky

The Kendrick brachiopods of Pennsylvanian age secreted low-Mg calcite shells with average Sr^{2+} content of 1,140 ppm. The crinoids and rugose corals secreted intermediate-Mg calcite skeletons with average Sr^{2+} contents of 2,140 ppm and 1,770 ppm, respectively. Conversely, the Kendrick mollusks secreted aragonite shells which contain less than 1,000 ppm Mg^{2+} . However, the average Sr^{2+} content (4,040 ppm for the cephalopods, 5,210 ppm for the gastropods, and 4,840 ppm for the pelecypods) is higher by a factor of about 2 over the average Sr^{2+} content of their Holocene counterparts.

The brachiopods, gastropods, and pelecypods precipitated calcium carbonate in oxygen (average -4.5 ppt, $\delta^{18}\text{O}$, PDB) and carbon (average $+1.7$ ppt, $\delta^{13}\text{C}$, PDB) isotopic equilibrium with ambient Pennsylvanian seawater. The crinoids and rugose corals are light in both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ by about 5 ppt, relative to isotopic equilibrium values. This isotopic depletion, as in the crinoids' modern counterparts, probably relates to the incorporation of isotopically light metabolic oxygen and carbon at the site of calcification. In contrast, the Kendrick cephalopods apparently precipitated shell aragonite in oxygen isotopic (-4.5 ppt) equilibrium with ambient seawater, whereas their carbon isotopic composition ($+0.5$ to -5.4 ppt) is controlled possibly by kinetic effects.

The Fe^{2+} and Mn^{2+} contents of the fossil allochems and shale suggest that Kendrick seawater was slightly euxinic. In addition, the Na^{2+} content and oxygen isotopic composition indicate a slightly higher water temperature and hyposalinity for Kendrick seawater. Diagenetic alteration is limited to occlusion of pore spaces in the fossils and to compaction and cementation of the shale. This process probably occurred in the marine and/or submarine environment.

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Effects of Arkosic Sandstone Diagenesis on Reservoir Rock Properties

Upper Miocene channel turbidite sandstones of Yowlumne and Rio Viejo fields, southern San Joaquin Valley, California, are clean arkoses buried to depths of 11,000 ft (3,550 m) or more. Petrographic analyses of cored intervals from seven wells show that these medium-grained sandstones have no detrital constituents other than quartz and feldspars (at an approximately 2:1 ratio). The relative abundance of K-feldspar to plagioclase, however, varies among the intervals studied. This variation has given rise to different paths in clay authigenesis, which then control reservoir-rock properties. Nearly all clays, which constitute from a few percent to more than 20% of the rocks, are derived from feldspar alteration.

Sandstones with high K-feldspar relative to plagioclase yield clay assemblages dominated by kaolinite, with minor amounts of illite and vermiculite. Those with high plagioclase content yield abundant expandable clays. Chlorite is practically absent in all intervals studied. Besides detrital composition, abundance and mineralogy of the clays are also affected by depth of burial of the rock.

Feldspar alteration has resulted in porosities in the range of 14 to 20% and permeabilities up to 200 md at depths of 11,000 to 15,000 ft (3,550 to 4,570 m). In contrast, other reservoirs of different composition in the same area have greatly reduced reservoir properties at the same depths. Knowledge of sandstone composition and diagenesis, therefore, is important to exploration.

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Geology of University Waddell Devonian Field, Crane County, Texas

The primary production in the University Waddell field in Crane County, Texas, is obtained from Devonian siliceous carbonates. Since its discovery in 1948, the field has produced 42 million bbl of oil through primary and secondary production.

The field's structure is an asymmetric anticline created by the upthrown side of a reverse fault. The anticline dips steeply into the fault on the west side of the crest and dips gently away from it on the east. The seal and source rock for the field is the Woodford Shale (Devonian), a black pelagic shale. Updip migration from the Woodford provided the source for the three productive zones in the reservoir rock. Production is directly related to fracture porosity (7 to 12%) in beds with abundant replacement chert. Permeability through the productive zones is discontinuous and generally low (less than 5 md). The fractures in the Devonian siliceous limestones developed as a response to Pennsylvanian compression that created the reservoir structure.

The siliceous lithologies make up 60% of the Devonian sequence. The cherts are black, white, or gray and occur in brecciated or massive beds. Associated limestones are light-gray bioclastic packstones.

The chert is thought to be of secondary origin. The silica was derived from in-situ spiculites, locally reprecipitated as chert. A basinal environment is interpreted for the Devonian siliceous limestone and carbonate units. The Devonian carbonates deposited after the Silurian pelagic shales indicate a period of shallowing in the basin.

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Geometry of Tertiary Coal Seams as a Response to Changes in Structural Framework

Diminished subsidence of the Williston basin at the end of the Cretaceous was followed by accumulation of thick lignite seams in the Ravenscrag Formation (Paleocene). The formation of seven coal fields in southern Saskatchewan was also influenced by contemporaneous subsidence structures that originated as collapse of overlying strata above areas of salt leaching from the buried Devonian Elk Point evaporite basin. Lignite seams, up to 10 m thick, accumulated in successively younger coal fields that prograded to the southeast across southern Saskatchewan toward the cratonic depocenter in western North Dakota. The shape of the older coal basins conformed to the areas of salt solution activity and both the coal fields and component beds accumulated as circular forms. Salt-solution collapse effects diminished upsection with more pronounced cratonic influence that originated with intermittent movements between Precambrian crustal blocks forming the Williston basin. The thicker areas of coal seams in the middle of the 300-m coal-bearing section accumulated parallel with the cratonic lineaments but oblique to the coal-basin forms that retained a geometric relation to the salt solution. The uppermost coal basins were almost completely dominated by cratonic influence with thick coal bed areas parallel with cratonic lineaments and dispersed in a reticulate pattern. Younger coal fields distant from the cratonic depocenter were elongated parallel with lineaments oriented toward the cratonic depocenter, whereas coal fields next to the center of the Williston basin accumulated as arcuate forms along the strike of the basin. The activity of salt-solution subsidence structures during the formation of the uppermost coal fields was sufficiently weak to favor greater regional bed thickness but not affect lateral basin form.

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Breccias, Mudflows, Turbidites, Fossil Soils, or Transposition Structures? A Case Study from Eocene Green River Formation, Wyoming

Sedimentary structures in carbonate micrite sediments of the Green River Formation (Eocene) have been interpreted as breccias, mudflows, turbidites, or fossil soils. After careful study of these sediments and their vertical and lateral associations, they are actually seen to be transposition structures that result from intrastratal viscous or hydroplastic flow.

Some of the features that are associated with the soft-sediment deformation include microfaults, microfolding, flair structures, ball-and-pillow type structures, lense- and tear-shaped intraclasts, lineated intraclasts, unusually shaped intraclasts, "roof-pendant" intraclasts, and "fluidized" sediment.

When deformed units are traced laterally for even small distances (< 1 m) they may grade into undeformed units. Many units form boudinage structures and completely disappear laterally for short distances. Discontinuous "breccias" can be traced laterally or vertically in many instances to intact, undisturbed sedimentary units. Vertical associations are large-scale arcuate or fold structures (wavelengths 3 to 4 m), soft-sediment injection features, and mudcracks up to 2 m deep.

This case study points out the necessity of caution when interpreting carbonate micrite sediments that contain intraclasts that may at first appear diagnostic of primary breccias, mudflows, turbidites, or fossil soils.

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