Upper Ordovician (Cincinnatian) strata in Ohio, Indiana, and Kentucky were deposited as cyclic sequences. Three types of cycles are represented: thin, graded storm cycles, moderately thick megacycles (carbonate to shale sequences), and thick shoaling-upward cycles (shale-rich, grainstone-poor facies that grade upward into shale-poor, grainstone-rich facies).

Cincinnatian strata were deposited on a gently sloping, shallow-marine carbonate ramp. Sedimentation was episodic; periods of in-situ carbonate accumulation were frequently interrupted by storm events. Tropical storms affected sedimentation and benthic ecology in seven ways by: (1) eroding sediments; (2) transporting allochthonous clays and silts onto a carbonate ramp; (3) winnowing, transporting, and redistributing carbonate sediments; (4) generating downslope gravity flows; (5) mixing benthic fauna from different communities; (6) periodically interrupting the process of community succession; and (7) creating favorable conditions for the evolution and success of opportunistic species.

Because of the excellent preservation of episodic storm events and their influence on sedimentation and paleoecology, the Cincinnatian Series is recognized as an example of an ancient storm-dominated, carbonate ramp. The following characteristics are diagnostic of storm domination in the rock record: (1) abundant storm sequences occur in all facies; (2) storm sequences are variable; (3) inner shelf facies have thin, discontinuous bedding; (4) rudites dominate in inner shelf facies; (5) fine grainstones are concentrated in outer-shelf facies; (6) textural inversions are common; (7) carbonate rock types are widely variable; (8) storm-generated structures occur in all facies; (9) in-situ faunal communities are rare; and (10) most beds contain a mixture of fossil-preservational states.

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Reservoir Development in Ellenburger Group of West Texas—a Diagenetic Jambalaya

Porosity and permeability in the Ellenburger Group of west Texas result from a complex interaction of early to late diagenetic processes. Porosity formation occurred in at least seven stages: (1) early marine phreatic calcite cementation, (2) fabric-selective (mixing-zone?) dolomitization, which created intercrystalline porosity, (3) episodic subaerial exposure and karstification, which created vuggy, cavern, solution-channel, moldic, fenestral, breccia, and fracture porosity, (4) mineralogy-selective meteoric phreatic or mixing-zone silicification, which preserved existing porosity by preventing further carbonate cementation, (5) deep-burial xenotopic dolomite recrystallization, which destroyed nearly all of the precursor intercrystalline porosity, (6) deep-burial dolomite, calcite, and anhydrite cementation of some vugs and fractures, and (7) late-stage tectonic fracturing, which created most of the reservoir permeability.

The Ellenburger Group consists of numerous vertically stacked subaerial exposure cycles 1-20 ft thick. Porosity within each cycle is laterally discontinuous and patchy. The complete cycle is composed of four zones (from top to bottom): (1) glauconitic shale, which is interpreted to be a paleosoil horizon, (2) brecciated dolomite, cherty dolomite, or chert, which formed from solution collapse, (3) nonbrecciated dolomite containing abundant dissolution-generated porosity, and (4) nonporous dolomite, which was largely unaffected by karstification. Zones 1 and 4 are nonporous with very low permeability; zones 2 and 3 have high porosity and permeability. The presence of subaerial exposure cycles throughout the Ellenburger Group has resulted in numerous vertical permeability barriers, which may be the cause of reservoir stratification in some fields.

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Diagenesis of Miocene Gas Sands in Pattani Basin, Gulf of Thailand

Diagenesis of early Miocene sandstones in the Pattani basin resulted in rapid cementation and degradation of reservoir quality with increasing depth of burial. These subquartzose sandstones provide an example of accelerated burial diagenesis in an area of unusually high geothermal gradient. Burial compaction, progressive cementation by quartz overgrowths, and development of authigenic kaolinite and illite have substantially reduced porosity and impaired permeability at depth. Abundance of quartz overgrowths increases with depth, indicating continuous or episodic silica cementation. Kaolinite occurs as a pore-filling cement between depths of 4,500 and 10,000 ft (1,375-3,050 m). Illite is common as pore-linings and also bridges pores in deeper zones (8,000-10,000 ft or 2,450-3,050 m). Minor cements include calcite, dolomite, siderite, pyrite, mixed-layer illite-smectite, and chlorite. Feldspars display textures that indicate progressive dissolution with increasing burial depth. Large intergranular pores are present in permeable sandstones between 3,000 and 7,500 ft (925-2,275 m). In low-permeability sandstones from deeper zones (7,500-10,000 ft or 2,275-3,050 m), porosity is largely restricted to voids within detrital feldspar grains. Many of these secondary pores are partly filled by authigenic kaolinite and illite, and their pore apertures are usually smaller (1-15 μm diameter) than intergranular pore apertures (10-75 μm diameter). Good reservoir properties in the Pattani basin are generally restricted to sandstones above 7,500 ft (2,275 m) that contain large intergranular pores. Abundant secondary porosity below 7,500 ft (2,275 m) is generally associated with poor reservoir properties; however, favorable reservoir properties may occur locally where large feldspars have been leached from coarse-grained sands.

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Origin and Diagenesis of Beachrock, Discovery Bay, Jamaica

From in-situ pore water and rock analyses of a lithified Holocene beach deposit in Jamaica (1,240 ± 50 yr B. P. at 22 cm depth, 670 ± 50 yr B. P. at 14 cm depth, 0 yr B. P. at surface), we propose a geochemical model for intertidal carbonate cementation. The beachrock unit is laterally and vertically discontinuous with unconsolidated beach sands surrounding it. The unit dips seaward at an angle of 10° and contains localized open orthogonal fractures that are oriented parallel and normal to the shore line. Three distinct cement types are found in Jamaican beachrock: (1) equant and bladed high-Mg calcite (12-29 mole % $MgCO_3$), (2) low-strontium fibrous aragonite (1,700-3,100 ppm SrO), and (3) micritic high-Mg calcite envelopes. These cements vary both laterally and with depth in the unit, and accurately reflect the changes in time and space of the chemistry of the interstitial water; the cements are produced in stoichiometric equilibrium with the pore-water chemistry. The high-Mg calcite cements are precipitated when CO_2 degases ($P_{CO_2} = 10^{-5.1}$) through agitation in the surf and consequently raises the pH to a maximum of 8.4 during the higher tides. During these times, the pore waters are saturated with respect to the precipitating Mg calcite containing 15-29 mole % $MgCO_3$. During low tide, when the agitation of the surf is minimal, the CO_2 does not degas, increasing the P_{CO_2} to a maximum of $10^{-4.0}$. Continued precipitation aids in the increase in CO_2 levels, the decrease in pH to a minimum of 7.9 and the lowering of saturation states of Mg calcites. Phreatic fresh water flows seaward during low tide, preferentially through the open fractures, lowering strontium levels and saturation states in the pore waters. Thus, at low tide, lower Mg calcites of 12-15 mole % $MgCO_3$ are precipitated where fresh water has not invaded (maximum Cl = 22‰). Models of Sr partitioning show low-strontium aragonite is produced from the neomorphism of high-Mg calcites near the open fractures in mixed meteoric and marine interstitial waters (Cl = 11.05-13.48‰). Our data suggest that P_{CO_2} is the master variable and that beachrock cements are not static but ever-changing in mineralogy and chemistry.

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Fluid Inclusions and Porosity Development in Arun Gas Field, Indonesia

The Arun gas and condensate field in northern Sumatra is a large Miocene coral-algal reef complex. The Arun limestone is rich in lime mud throughout the section, and low to moderate-energy paleoenvironments are indicated. The reservoir facies are strongly affected by diagenesis and display several secondary porosity types, including moldic, vuggy, breccia, and fracture porosities. Without the diagenetic alteration of otherwise tight muddy limestones, reservoir facies would not have developed at Arun. To put constraints on the timing of porosity development in Arun field, fluid inclusions were examined in coarse calcite cements which partially or completely filled some of the secondary pores. The fluid within the inclusions is brackish with an equivalent of 2.5 wt. % NaCl.

Homogenization temperatures, after pressure correction, suggest that the cementation began close to the maximum burial depth and as recently as 5 Ma. Since the cement postdates the formation of secondary pores, it is conceivable that secondary porosity could have developed not only in the shallow subsurface (i. e., the vadose zone), but also in moderate to deep burial conditions. Shales surrounding the Arun reef are overpressured as a result of dewatering during smectite-illite conversion and have expelled water into the Arun limestone. This process may contribute to pervasive secondary porosity as well as remobilization of materia. for localized late-stage cements.

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Facies Architecture and Production Characteristics of Wave-Dominated Deltaic Reservoir, Big Wells Field, Southern Texas

The Big Wells (San Miguel) oil field in Dimmit and Zavala Counties, southern Texas, produces from a broadly lenticular, wave-dominated deltaic sandstone encased in prodelta and shelf mudstones. An updip porosity pinch-out coincides with a gentle undulation on an otherwise smooth, gulfward-dipping monocline, resulting in a combination stratigraphic and structural trap. The reservoir is relatively tight with average porosity of 10% and permeability of 7 md; wells require fracing to stimulate production. Ultimate recovery is projected to be 30% of the 180 million bbl field.

The reservoir is subdivided into a nonproductive, transgressive upper sandstone and a productive but intensely bioturbated, predominantly deltaic lower sandstone. The tight upper sandstone provides the reservoir seal. Internal architecture of the reservoir is complex, consisting of strike-elongate beach-ridge deposits that merge north into a dip-elongate, digitate channel-sandstone system representing the deltaic entrant into the basin. SP-log facies display mostly strike-parallel orientations; however, resistivity-log facies are more complex and varied, reflecting a high degree of reservoir heterogeneity.

Early production is uninfluenced by the sedimentary fabric of the reservoir. Initial isoproductivity maps display peaks that correspond with faults, proximity to the gas cap, and to a lesser extent, local sandstone thicks. However, during subsequent production, internal architecture strongly influences reservoir yields as the depositionally complex northern half of the field displays lower recoveries than the beach-ridge deposits to the south.

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Textural Evidence for Origin of Salt Dome Anhydrite Cap Rocks, Winnfield Dome, Louisiana

Textures within anhydrite cap rock are products of repeated cycles of halite dissolution and residual anhydrite accretion at tops of salt stocks. Quarrying operations at Winnfield dome have exposed extensive portions of the anhydrite cap rock zone. This zone is composed primarily of unoriented, xenoblastic anhydrite crystals in laminae less than 1 mm to several centimeters thick. Laminations are defined by thin, dark sulfide accumulations and pressure solution of anhydrite. Deformed, banded anhydrite clasts are contained locally within laminae. Multiple-laminated, concave downward anhydrite mounds occur along some horizons. They may contain anhydrite breccia fragments or sulfides. Coarsely crystalline salt mounds, containing disseminated idioblastic anhydrite also occur along horizons. Mound morphologies vary from tall and thin to broad and squat; maximum dimensions range from less than 0.5 m to about 2.0 m. These moundlike structures are related spatially and genetically.

Moundlike structures are believed to form from salt spines along the salt-anhydrite contact. As the spine dissolves through several cycles of dissolution and accretion, a laminated anhydrite mound is preserved; if the spine becomes isolated from dissolution, then a salt inclusion is preserved. Anhydrite beds within the Louann Salt, deformed during diapirism, are preserved as deformed anhydrite clasts. Steeply dipping, bedded anhydrite zones within the salt stock may produce brecciated anhydrite mounds when incorporated into the cap rock. Sulfides record the movement of metalliferous fluids through the salt-anhydrite contact. Cores from other Gulf Coast domes indicate that these textures and interpreted processes are common.

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Reexamination of Bengal Fan Model for Turbidites of Frontal Ouachitas

The lower member of the Pennsylvanian Atoka Formation outcrops within the frontal Ouachitas of Arkansas. Strata are comprised of turbidites and related deep-marine deposits, which locally exceed 5.5 km (18,000 ft) in structural thickness. Several previous workers have drawn analogies between Ouachita turbidites (or flysch) and the present-day Bengal Fan, located in the eastern Indian Ocean. As a first-order approximation, this model is basically correct, especially in terms of overall tectonic setting. Yet, when examined in detail, there are striking dissimilarities between the frontal Ouachitas and the Bengal Fan.

The dimensions of the Bengal Fan are staggering, it measures roughly 1,000 km (620 mi) by 3,000 km (1,860 mi). The main feeder channel is 13 km (8 mi) across and 850 m (2,790 ft) deep. Channels within the mid-fan region are up to 2-3 km (1.2-1.9 mi) in width and 100 m (330 ft) in depth, and some channels maintain continuity for well over 2,000 km (1,240 mi). Rates of vertical sediment accumulation are no more than 75 m/m.y., with isopach data showing only 3.5 km (11,500 ft) of post-Eocene accumulation. Limited sampling also shows rather low sand-mud ratios over much of the fan.

Lithofacies data and depositional cycles within the lower Atoka Formation are suggestive of middle-fan, outer-fan, and basin-plain environments. If Atoka channels were as large as those of the Bengal Fan, they certainly remain unrecognized in the rock record. Instead, the entire length of the outcrop belt in Arkansas is less than 250 km (155 mi), and facies changes define a clear east-to-west transition from middle fan to basin plain. Significantly, Atoka sedimentation rates were approximately 10 times higher than Bengal rates. It is evident that the Atoka fan system was much more confined than the Bengal Fan; it probably formed within a narrow, rapidly filling, remnant ocean basin rather than on an unrestricted abyssal floor.

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Biostratigraphy and Paleoenvironment of Morrowan (Zone 2) Brachiopoda, Bird Spring Group, Arrow Canyon, Clark County, Nevada

Comprehensive study of the Morrowan brachiopod faunas of the Bird Spring Group at Arrow Canyon, Clark County, Nevada, is important because the section has been suggested as a stratotype for the base and top of the Pennsylvanian Subsystem and for the Atoka Series. Twenty-three species of brachiopods belonging to 17 genera occur in zone 20 at Arrow Canyon. Many of these also occur in described Morrowan faunas in Wyoming, Colorado, Utah, and New Mexico; but similarities with the Mid-Continent and Appalachian assemblages are less. However, no striking regional differences are evident, and it appears that the North American Morrowan fauna is more or less homogeneous. In contrast to the exotic South American and Arctic elements known from Atokan, Missourian, and Virgilian rocks at Arrow Canyon, no foreign taxa have been noted in zone 20. Microfacies and faunal associations indicate four distinct brachiopod-bearing environments: (1) relatively deep water below turbulence with few brachiopods on a soft substrate; (2) somewhat shallower, more turbulent water with many species, of which only a few are represented by large populations, living on a more firm substrate; (3) environments just below the zone of turbulence in which many species of brachiopods are represented by substantial populations on a calcarenitic substrate; and (4) crinoidal bars in the zone of turbulence with a few species represented by relatively few individuals.

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New Developments in Microphotometry of Kerogen and Bitumen at Various Stages of Thermal Maturity and Applications to Hydrocarbon Exploration

Microphotometry is the computerized microscopic measurement of reflectance, fluorescence, and transmittance of organic matter in sedimentary rocks. Microphotometric data are an indispensable tool in exploration of hydrocarbons.

The chromaticity of kerogen particles in fluorescence and transmitted light is derived from spectral analysis and provides new scales for thermal maturity: the Fluorescence Color Index and Transmittance Color Index. The TCI could substitute for the inaccurate TAI. Generation of crude oil within thermally mature kerogen particles shows characteristic fluorescence phenomena when microscopically observed and measured.

Spectral data and chromaticity values provide an improved method for determining the thermal maturity of petroleum source rocks, in particular when vitrinite reflectance data are unreliable or unavailable. The "oil floor" in a basin is marked by the disappearance of the fluorescence of fossil alginite, exinite, amorphous organic matter, and most bitumen. This method provides a better mapping of thermally mature petroleum source rocks.