of the general principles without ignoring the complexity of the gas versus oil problem.

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Authigenic Illites in Sandstone Reservoirs

Authigenic illites have been found in pores of many sandstones which are known to be hydrocarbon reservoirs. Typical samples are from the Norphlet Formation in southern Mississippi, the Wilcox Formation in south Texas, and the Lance Formation in Wyoming. Illites in these sandstones are mainly in the form of laths with perfectly developed morphologies. Laths have widths of 0.1 to $0.3\mu$ and lengths ranging up to $30\mu$. Scanning electron (SEM) images show that these "hair like" illites fill many of the pores of these sandstones, and cause a serious reduction in permeability. Elemental analysis of the laths with EDAX energy dispersive X-ray analyzer shows that Si, Al, and K are the major constituents and Mg is the minor constituent in the chemical composition of the laths. Transmission electron images show that illite laths have grown from an amorphous core which is rather similar to an irregular smectite aggregate. X-ray diffraction patterns display the coexistence of discrete illite (9.9Å) with an illite/smectite mixed layer with a distinct reflection varying from 10.5 to 11.0Å. In the sample from the Wilcox Formation the laths form regular arrangements which lead to the development of platelets.

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Geological Significance of LANDSAT Data on Some Known Giant Fields

No abstract available.

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Pore Types in Sunniland Limestone (Lower Cretaceous)

The Sunniland Limestone of south Florida produces hydrocarbons from five types of porosity in carbonate reservoirs. (1) Primary interparticle pores are volumetrically most abundant. Secondary pores after dissolution of aragonite are common but less abundant than primary pores and occur both as (2) matrix porosity and (3) vuggy porosity. (4) Fracture porosity is important in one reservoir and occurs at several localities in the lower Sunniland Limestone. (5) Intercrystalline pore space in dolomite occurs in thin intervals in several reservoirs. Any one reservoir contains two or more of the pore types.

Three types of dolomite are present in the Sunniland Limestone. A presumed early tidal-flat (sabkha) dolomite is composed of 1-to-10 $\mu$m crystals that are strontium- and calcium-rich and iron-poor compared with other dolomite from the unit. The dolomite is enriched in $C^{13}$ and $0^{18}$ relative to PDB-1 standard. It is associated with tidal-flat sedimentary structures and is nonporous. A second dolomite, composed of crystals up to 500 $\mu$m along an edge, is porous, iron-rich and strontium-poor relative to earlier dolomite, enriched in $C^{13}$ but depleted in $0^{18}$, and is considered to be a later replacement. A rare third type of dolomite is petrographically distinct as pore-filling crystals up to 1 mm in width with markedly undulose extinction ("baroque" dolomite).

Cementation by a thin calcite fringe around grains and a later blocky calcite cement is present locally. The latter cement precipitated in part during or after compactional grain fracture. Sunniland carbonate rocks contain less than 100 ppm manganese, and a manganese/iron value below 0.06. These low values are believed responsible for a lack of cathodoluminescence in Sunniland limestones and dolomites.

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Porosity Preservation and Early Freshwater Diagenesis of Marine Carbonate Sands

Observations from Holocene and Pleistocene limestones of south Florida and the Bahamas provide the basis for a general outline of freshwater alteration of marine, primarily aragonitic, sands. Porosity and mineralogic data suggest that metastable carbonate recrystallization takes place before significant porosity loss. The outline proposes the following main points: (1) porosity is only slightly modified during mineralogic stabilization and early cementation; (2) secondary porosity development during early cementation preserves overall porosity; (3) early cements formed during metastable-phase recrystallization are almost entirely autochthonous on a reservoir scale. The time of stabilization may be as short as $10^4$ years but may be slowed for long periods (e.g., by salt water intrusion, dry vadose conditions, stagnant water). Major porosity reduction occurs after stabilization and takes longer periods of time $>10^6$ years (e.g., extended period of subaerial exposure, burial diagenesis). Our observations of the effects of early freshwater diagenesis underscore the importance of later diagenetic events in porosity reduction of limestones.

This outline suggests that reservoir limestones developed through early freshwater diagenesis of aragonitic sands should be characterized by high porosity, most of which is secondary. Conversely, high-porosity reservoirs with considerable amounts of primary pore space have either escaped pervasive freshwater diagenesis or are developed in sediments that were originally calcite.

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Hummocky Cross-Stratification—Indicator of Storm-Dominated Shallow-Marine Environments

Hummocky cross-stratification (HCS), as formally defined by Harms and others in SEPM Short Course 2, is the preferred term for very distinctive, low-angle (2 to 15°), curved to undulating laminae which are broadly concave and/or broadly convex upward ("hummocky"). The swales commonly cut each other, giving rise to very low-angle, curved intersections of laminae. Laminae are broadly parallel over hummocks and swales, in sets 2 to 20 m thick. Wavelengths range from about 1 to 5 m, and heights range from about 10 to 40 cm. HCS is not a form of trough cross-bedding—dips are too low, stratification is as commonly arched upward as downward, and the hummocks and swales are elliptical to almost circular.

HCS occurs both in thick (several meters) beds and in sharp-based thinner beds (tens of centimeters) interbedded with shales. In the latter, oriented sole marks commonly are present on the sandstone bases that indicate regional paleoslope. Shales between sandstones are bioturbated, but the HCS itself is not.

Harms and others interpreted HCS as formed by storm waves, but below fair-weather wave base. Several other authors have defined similar stratification and have argued for a similar interpretation, but the widespread geologic occurrence and significance of HCS have been hidden by the multiplicity of different names. Our examples from the Fernie-Kootenay (Jurassic-Cretaceous) transition and from the Cretaceous Cardium Formation (both in southern Alberta) suggest by stratigraphic context with other facies that the HCS was formed below fair-weather wave base. Specifically, we suggest that water piled onshore during major storms returns seaward as a sediment-laden density current (as in Hurricane Carla, Texas Coast, 1961). The density current forms oriented sole marks but, instead of depositing a Bouma sequence, the current deposits sediment onto a seafloor still under the influence of storm waves—forming HCS instead.

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## Exploration Potential of Pennsylvanian-Permian Carbonate-Shelf Margins and Deltaic Sandstones, Palo Duro Basin, Texas

Potential hydrocarbon reservoirs occur in Pennsylvanian and Lower Permian (Wolfcampian) carbonate-shelf margins, fan-delta arkosic sandstones, and deltaic sandstones in the Palo Duro basin. Thick basinal shales, which are stratigraphically equivalent to shelf carbonate rocks and sandstones, may have served as hydrocarbon source beds, although present thermal gradients are inadequate for liquid hydrocarbon generation.

During the Pennsylvanian, a carbonate-shelf-margin complex with 200 to 400 ft (60 to 120 m) of depositional relief developed around a narrow embayment that opened southward into the Midland basin. The position of local shelf margins shifted through time. Following initial construction, shelf margins retreated shelfward throughout Pennsylvanian and earliest Permian time. During later Wolfcampian, shelves prograded westward and southward into the basin, filling it by late Wolfcampian time.

Potential hydrocarbon reservoirs are thick zones of secondary porous dolomite within the shelf-margin complex. Dolomite porosity is commonly greater than 10%. The distribution of porous dolomite along shelf margins may indicate dolomitization was related to (1) early postdepositional, mixing-zone diagenesis in islands present along the shelf margin, or (2) dewatering of basinal shale, leading to montmorillonite-illite conversion and release of magnesium during burial diagenesis.

Pennsylvanian and Permian fan-delta deposits of arkosic sandstone (granite wash) shed off the Amarillo uplift are potential clastic reservoirs. Production occurs from stratigraphically equivalent, granite wash deposits on the northern side of the uplift in the Anadarko basin. Porosity in granite wash sandstones averages 15%.

Pennsylvanian quartzose sandstones are also interbedded with thick sequences of basinal shale, suggesting that the sand entered the basin through passes in the shelf margin. Geometry of sandstone bodies suggests deposition as distributary-mouth-bar fingers of high-constructive elongate deltas. Porosity in these sandstones reaches 18%.

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## Lower Permian Facies Tracts and Evolution of Carbonate-Shelf Margins, Palo Duro Basin, Texas Panhandle

Lower Permian (Wolfcampian) strata of the Palo Duro basin consist of 1,000 to 2,000 ft (300 to 600 m) of terrigenous clastic and carbonate sediments which were deposited in basin, slope, shelf-margin, shelf, and deltaic environments. Lateral and vertical sequences of facies throughout the basin indicate that these strata are regressive and document the first episodes of Permian marine retreat from the Panhandle region of Texas.

Terrigenous clastic sediment was derived from highlands which surrounded part of the Palo Duro basin. Exposed Precambrian granite in the Amarillo uplift, Sierra Grande uplift, and Bravo dome yielded large quantities of arkosic sand (granite wash) to fan-delta systems which emptied into shallow-marine environments in the northern part of the basin. Along the basin's southeastern margin, high-constructive deltas prograded westward from the Wichita Mountains depositing quartz-rich sand and mud across the shelf.

Seaward of the clastic-facies belt, an arcuate, carbonate-shelf-margin complex, averaging 1,000 to 1,200 ft (300 to 360 m) in thickness and facing south toward the Midland basin, dominated Wolfcampian deposition. The western shelf margin consists of a superposed sequence of carbonate strata exhibiting limited basinward progradation. In contrast, the eastern shelf margin is composed of several superposed, progradational carbonate sequences, individually averaging several hundred feet in thickness. During early to middle Wolfcampian time, the eastern shelf margin prograded westward 10 to 30 mi (16 to 48 km) but the western margin remained stationary. Shelf margins shifted in response to deposition of slope sediments in front of the shelf, creating a foundation for subsequent carbonate buildups. Slope deposits consist of (1) hemipelagic mud, (2) fine-grained clastic sediments transported downslope