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 through submarine canyons incised in the shelf margin, and (3) redeposited carbonate sediment derived from shelf-margin buildups.

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Sea Gullies and Development of Linear Conglomeratic Units

Sea gullies are localized dissections of California borderland upper basin slopes; the gullies form groups, covering distances of 10 to 16 km off points and narrow shelves. Gullies have youthful "V" cross-sectional profiles and relief of less than 100 m; they may extend to basin floors, creating small, coalescing submarine cones.

Gully development is attributed to subaerial stream erosion during eustatic sea-level lowering and outer-shelf exposure. Also, during rapid regional uplift, shelves become narrower and short, steep streams characteristic of immature drainage patterns prograde across shelves, depositing unstable coarse debris near the shelf break. Differential relief, overburden instability, and earthquakes trigger subaqueous mass flows, creating gullies by headward sapping; and at the base of slope, linear aprons of coarse conglomeratic debris accumulate.

Four stages of nearshore basin deposition are recognized in the lower Capistrano Formation (upper Miocene, Mohnian) at Dana Point, California. Basal deposits of fine siltstones, sandstones, and diatomite represent abyssal deposits. These are overlain abruptly by conglomerates interbedded with structureless coarse sandstones, superseded by graded sandstones and siltstones interpreted as mid-submarine-fan deposits.

Basin subsidence, tectonic activity, and increased erosion climaxed during the late Miocene. Conglomeratic debris flows are also associated with sinistral-coiled *Globigerina pachyderma,* indicating the late Miocene N-17 period of glaciation and possible sea-level lowering. Coarse debris accumulated near the shelf break, and gullied submarine slopes developed. Undermining through liquefaction caused debris flow down these gullies; the flows "froze" at the abrupt slope/basin junction, forming linear, composite conglomerate units. Overlying fan sequences reflect basin maturity dominated by canyon point sources.

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Shallow-Water Carbonate and Evaporite Sedimentation Patterns in Lower and Middle Jurassic Rocks of Southern Tunisia

The Lower and Middle Jurassic rocks in southern Tunisia can be divided on the basis of lithology into two distinct regions, the central and northern provinces.

Outcrops in the central province extend in a continuous escarpment south from the Wadi Tatahouine and display a variety of carbonate and sulfate rock types representing very shallow-water deposition. The Lower Jurassic and lower Middle Jurassic Mestaoua Formation is a largely gypsiferous sequence representing deposition in lagoons and on hypersaline shotts. The overlying Bathonian Krachoua Formation displays a range of carbonate lithologies, representing shoreline and tidal-flat environments, and sulfate units, again indicative of gypsiferous lagoons and shotts.

These formations pass northwestward into massive and laminated carbonate strata indicative of deposition on extensive wind-tidal flats. This is the northern province. The lower part of the sequence, the Semoumenia Breccias, is composed of breccias believed to have resulted from evaporite-solution processes. This sequence passes into clastic facies, the Sidi Stout Sandstones (an accumulation of wind-blown sand dunes), toward the Permian outlier of Djebel Tebaga.

Paleogeographic reconstructions show that the area preserves part of the carbonate shoreline sequence which acted as the sill separating a true marine area on the northeast, Tethys, and the Algerian-Tunisian salt basin on the southwest. Periodic marine incursions into the margin of this salt basin are suggested by the presence of extensive storm deposits.

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Devonian Organic-Rich Black Shales in Subsurface Pennsylvania—Stratigraphy and Natural Gas Production

The basal sediments of the Devonian clastic wedge in Pennsylvania consist of a series of black, radioactive, organic-rich shales interbedded with non-black shales and siltstones. Three major black shales are present in the subsurface as indicated by stratigraphic cross sections. These units are the Middle Devonian Marcellus shale facies, and the Upper Devonian Rhinestreet, and Dunkirk shale facies. Mapping of these facies indicates that they are distributed in three generally overlapping belts paralleling the regional strike. The Marcellus facies attains its maximum development in the eastern Appalachian Plateau. This unit, the oldest and deepest of the Devonian black shales, has had numerous shows of gas in wells drilled through it. However, gas has not been produced from it in commercial quantities. The Rhinestreet facies is best developed in the northwest. It is younger and shallower than the Marcellus and has produced commercially from wells in Beaver County. The Dunkirk facies is restricted to the northwestern part of the state where it reaches its greatest accumulation along the margin of Lake Erie. This youngest and shallowest of the major black shale facies has produced commercially since the early 1800s. All three facies have the potential to produce natural gas in commercial quantities. However, owing to drilling economics, the Dunkirk facies appears to have the most immediate potential because of its shallower depths and production history. The Rhinestreet facies is also considered to have immediate potential. The Marcellus facies does not appear to be an attractive primary target at this time because of its great depth, but it could be a good secondary drilling objective.

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Anatomy and Growth History of Holocene Ooid Shoal

Facies anatomy of the Joulters ooid shoal is strikingly