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