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Understanding the Effects of Antecedent Topography and Differential Compaction on the Development of Play Trends in the Permian Basin: An Example from Means Field, Andrews County, West Texas

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Two important controls on Leonardian and Guadalupian platform carbonate play trends in the Permian Basin are (1) antecedent topography, and (2) differential compaction of progradational platforms across antecedent aggradational margins or basement structures. Antecedent topography provides depositional relief for differentiation of depth-dependent platform vs. slope facies, focuses wave and tidal energy to localize grain-dominated carbonate reservoir facies, and determines the location of tidal flat development and subaerial exposure and related diagenesis. Antecedent topography is a primary syndepositional control on margin development and orientation, progradation/aggradation ratio, and depositional style, and thus on the distribution of ramp/shelf crest carbonate reservoir facies. Differential compaction is an important, though commonly underestimated process in carbonate platforms undergoing burial. In the Permian Basin, differential compaction occurred most prominently in 3rd-order Leonardian and Guadalupian highstand sequence sets that prograded over antecedent aggradational and/or erosional platform margins and wedge-shaped packages of compactible basin facies. Documented outcrop and subsurface examples of this are from the Leonardian 1 ("Abo"), Leonardian 4-6 ("Upper Clear Fork-Glorieta"), and Guadalupian 8-10 ("Upper San Andres") sequences. Differential compaction can potentially modify the structure and preserved stratal geometry of a carbonate platform via progressive down-to-the-basin rotation of the prograded platform top across an underlying "compaction hinge". This progressive rotation causes the development of basin-facing monoclines, tilted topset strata, apparently oversteepened outer shelf and slope clinoform geometries, and fractured and/or faulted platform strata across the compaction hinge. The development of these features can begin shortly after burial, provided the proper setting, and progress for several million years until compaction processes have terminated. Differential compaction is proposed to be a principal mechanism responsible for the development of 15 major San Andres and Grayburg structures and associated reservoirs of the Central Basin Platform.

Means Field provides a well-documented example of how antecedent topography and differential compaction controlled San Andres-Grayburg play elements. Means Field is located on the eastern, windward margin of the Central Basin Platform. The field is approximately nine miles long (north-south, parallel to the platform margin) and 3 miles wide (east-west). The structural configuration of the San Andres Formation is that of an asymmetric, north-trending anticline with approximately 230 ft of closure on the western updip side and over 1200 ft of relief on the eastern downdip side. The eastern margin of the field parallels a 400 ft down-to-the-east, fault-bounded scarp or flexure at the top of the Lower Ordovician Ellenburger Formation. This flexure was a persistent feature that localized the Strawn, Canyon, Cisco, Lower Wolfcampian and Middle Wolfcampian shelf margins. Following the Middle Wolfcampian 2nd-order highstand, the Upper Wolfcampian platform margin backstepped to the northwestern corner of the Means Field area. Subsequent L1-L5 Leonardian margins prograded eastward and southeastward from the Upper Wolfcampian platform core. During deposition of the Leonardian 6-8 sequences, the platform margin prograded eastward in the northern part of the field and aggraded in the southern part. The Upper Wolfcampian and Leonardian platform sequences (~3000 ft thick) are remarkable for their associated thick (~3000 ft thick), siliciclastic-rich basinal equivalents. The Guadalupian 1-4 sequences of the Middle San Andres Formation were dominantly aggradational and confined to the platform updip of the Leonardian 8 margin. Ramp crest carbonate reservoir facies developed broadly over the area defined by the underlying Leonardian 5 platform. Following deposition of the basin-confined Brushy Canyon Formation siliciclastics (Guadalupian 5-7 sequences), the Guadalupian 8-10 sequences prograded progressively basinward of the underlying Leonardian 8 shelf margin. Each of these sequences becomes expanded in thickness as it crosses this underlying compaction hinge. Several faults cut the San Andres and Grayburg along this hingezone, and analysis of water and CO_2 breakthrough trends suggests a zone of enhanced fracture-controlled permeability is coincident with the hingezone as well. The Guadalupian 10 terminal shelf margin lies up to 1600 ft below its highest equivalent shelf crest strata.

These observations suggest that differential compaction of Upper Wolfcampian-Leonardian basinal strata relative to equivalent platform strata was accelerated during deposition of the Upper San Andres sequences in response to rapid progradation. This differential compaction continued until at least the end of the Permian, as suggested by thickness variations in the Grayburg-Rustler interval. These thickness variations suggest that Upper Wolfcampian-Leonardian basinal strata compacted 40-45% more than their platform equivalents by the end of the Permian. In summary, San Andres shelf crest reservoir facies are localized by a Leonardian platform margin trend, which in turn was inherited from a Lower Ordovician flexure. The structure of the Means San Andres reservoir began to form by differential compaction shortly after deposition of the Middle San Andres Guadalupian 4 sequence, and was subsequently amplified during the remainder of the Permian. Hydrocarbon trapping was due to permeability pinchout to the west and northwest, where San Andres reservoir facies grade into anhydritic mud-rich tidal flat deposits, and 4-way structural closure. Major implications of the differential compaction model include early post-depositional structural trap formation, fracture and fault development along the compaction hinge, presence of basinward tilted and onlapping reservoir facies along the eastern limb of the structure, and improved understanding of the "basinal" stratigraphy east of Means Field, which includes progradational Upper San Andres 4th-order highstand platform units that could easily be misinterpreted as prograding lowstand wedges.