3D Seismic Geomorphology and Sequence Stratigraphy of the Northern Delaware Basin Bone Spring Formation: Constraint from Deepwater Bipartite Petrophysical Motifs

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The Leonardian Bone Spring Formation contributes in no small part to making the Permian a Super Basin, but the subsurface determination and correlation of its petroleum system criticals owing to its mixed carbonate clastic composition is problematic. We provide helpful insight into some of these problems with our recent ~400 sq mile core and petrophysically constrained 3D seismic geomorphology and sequence study in the Northern Delaware Basin through the incorporation of deepwater bipartite petrophysical motifs.

Borehole gamma ray logs, if dominated by the ^{40}K response, can be viewed as an empirical proxy for depositional process energy. Therefore, when the deepwater clastic factory is dominating, an upward decrease in gamma ray radioactivity indicates an increase in process energy, an upward increase in gamma ray radioactivity reveals a decrease in process energy, and no change in gamma ray implies process energy stasis. By contrast, in a reciprocal sedimentation setting where deepwater carbonates respond to a clastic influx when the shelf is exposed, the inverse motif applies as an upward gamma ray increase implies clastic dilution and process energy. Conversely, an upward decrease in gamma ray radioactivity reveals a decrease in process energy, and no change in gamma ray a process energy stasis. If these trends are regionally pervasive, they are generally indicative of vertical allocyclic accommodation changes (relative sea level rise vs fall) but instead if local are indicative of horizontal autocyclic accommodation changes (progradation vs retrogradation). When confirmed by core in a deepwater reciprocal sedimentation scenario, application of this deepwater bipartite motif scheme to corresponding trends in regional base lap termination directions on seismic allows further discrimination and calibration of the process energy trends and associated parasequence sets.

Incorporation of this deepwater bipartite methodology yields the following process-response sequence stratigraphic synthesis. During Leonardian time the major marine inlets to the Delaware Basin from the Panthalassia Ocean were from the Hovie to the Southwest and or Apache/Diablo Channels to the West. Although the overall regional tectonic subsidence owing to crustal flexure and stretching deepened the basin and affected the magnitudes of observed sea level change, the changes are largely synchronous with the global sea level curve. Indeed, detailed borehole-constrained calibrated seismic chronostratigraphy and relative sea level curve generation from our 3D seismic volumes reveal the Bone Spring Formation subsurface members to not only correspond but also to record eight general cycles (L1-L8) with four imbedded parasequence sets: High Stand (HST), Regressive (RST), Low Stand (LST), and Transgressive Systems Tracts (TST).

Geomorphologically the allocyclic sedimentation trends viewed in the 3D seismic volume exhibit persistent systems tract geometries. Shelf progradation, stasis and retreat of the Victoria Peak reef margin and associated periplatform slopes of the third order cycles yielded angles which recorded episodes of deposition, erosion, slumping, and whether of carbonate or clastic makeup: The HST's associated with an active carbonate shelf factory exhibit aggradation slopes up to 28º. With sea level fall, the shelf is incised and an ensuing thin RST with carbonate mass transport complexes and associated slumping provide angles which increase up to 36º. The LST's reveal a decreasing angle on the backstepping shelf slope with fine grain clastic input. The ensuing clastic TST 's generally exhibit the lowest slopes with angles approaching 19º. Recognition of these parasequence sets is critical to mapping spatial variations in reservoir quality with the complication of autocyclic changes in fan geometries.

These dramatic 3D seismic observed reciprocal relationships to relative sea level changes with shelf platform derived carbonates during high stands and clastics during lowstands are confirmed by petrophysics and cores. While the Bone Springs basin sediment gravity flow deposits are composed of pelagites, varying density calciturbidites, and high density turbidites, the two-end member spectrum of lithologic change affects frackability and source rock richness. In addition, the 3D imaging of compensational stacking that results from each successive lowstand channeling into the continually shifting apron basin fans allows delineation of fairways of heightened pore volume and storage capacities. Our outcrop studies show that with sea level rise and fall an additional complication results from alternating bathymetric zones of anoxia and source rock richness and, interestingly, associated rock strength.

As one proceeds farther out into the basin from the shelf edge, the Bone Spring deepwater system third order cycles are correlatable irrespective of lithologic and associated seismic amplitude change if reflector phase is taken into account. For the fourth and higher order cycles dominated by autocyclic processes, correlation becomes problematic owing to fan lobe switching, channeling, and slumping. However, by calibrating the high resolution deepwater bipartite sequence stratigraphy of the wells to the interpreted seismic sequence framework, an effective lithofacies prediction and depositional system analysis still may be made. For deepwater reciprocal petroleum system analysis and pragmatic exploration, the sequence integration of the two methods is not only appropriate, but critical.

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