The Role of Salt in Cenozoic Gravity Spreading of the Northwestern Gulf of Mexico Basin

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The northwestern Gulf of Mexico Basin is a Mesozoic-Cenozoic passive margin initiated during Late Triassic to Early Jurassic continental rifting. Widespread deposition of the early postrift Louann Salt occurred during the Callovian (late Middle Jurassic) and was immediately followed by oceanic spreading during the Oxfordian (early Late Jurassic). Subsequent thermal subsidence led to a Late Jurassic through Cretaceous transition from shallow- to deep-water carbonates to chalks, marls, and shales in what is presently the offshore portion of the basin. The Cenozoic was dominated by the influx of large volumes of clastics and the progradation of associated deltas. Although some salt-related deformation occurred early in the history of the passive margin, the bulk of tectonic activity was triggered by the Cenozoic clastic deposition. The asymmetric sedimentary load and associated bathymetric relief of the shelf margin set up a gravitational instability that was accommodated by gravity spreading above the salt layer. Updip sedimentation and accompanying extension was balanced downdip by extrusion of allochthonous salt sheets and by contractional folding at the basinward pinchout of the autochthonous Louann Salt. In turn, the allochthonous sheets also accommodated the gravity spreading as they were loaded and evacuated. In this paper, we examine allochthonous salt systems and deep-water fold belts in detail, speculate on the role of rifted basement geometry in controlling the type and distribution of salt tectonics, and comment on various aspects of petroleum exploration in these provinces.

Three different end-member styles of allochthonous salt can be distinguished in the northwestern Gulf of Mexico Basin: salt-tongue, salt-stock, and salt-nappe systems. They are differentiated on the basis of the base-salt geometry, which exerted fundamental control on characteristic evolutionary histories that in turn impacted structural geometries, the amount of extension and contraction, facies development, and fluid flow in both supra- and subsalt environments. All allochthonous salt systems formed by salt extrusion at the sea floor beneath only a thin veneer of condensed sediment. Salt-tongue systems (for example, the inner shelf of Louisiana) are subhorizontal sheets that formed by a single salt tongue or amalgamated salt tongues extruded penecontemporaneously from basinward-leaning feeder diapirs. The base salt has minimal structural relief except for lows in the immediate vicinity of deep feeders and highs along the margins or where separate tongues coalesced. Subsequent sheet evacuation followed two end-member patterns: roho systems, with extension along families of basinward-dipping growth faults that was balanced by further salt extrusion and/or contractional folds; and stepped counter-regional systems, with basinward-leaning secondary diapirs connected by landward-dipping salt welds or faults.

Salt-stock systems (for example, parts of the central Louisiana outer shelf and upper slope) formed by salt spreading radially from bulb-shaped diapirs throughout long periods of time. Amalgamation of salt from multiple feeder diapirs occurred prior to stock collapse in true salt-stock canopies, whereas coalescence occurred as a result of salt evacuation and extrusion in apparent salt-stock canopies; the two scenarios yield different age relationships between supra- and subsalt strata. In either case, deep minibasins replaced the original salt stocks as salt was extruded into sheets and secondary diapirs located over structural highs in the base salt.

Salt-nappe systems (for example, the Sigsbee Nappe along the western Louisiana outer slope) formed by the gradual advance of allochthonous salt such that the base of salt climbed basinward in a series of ramps and flats over a large distance. The nappe was sourced from a series of diapirs located at its landward edge; there were no local feeders beneath the main body of the nappe. Lateral spreading and early loading of the salt resulted in elliptical minibasins separated by a polygonal pattern of reactive diapirs. Subsequent evolutionary patterns are speculative because mature, evacuated equivalents of salt nappes have not yet been documented. The development of different types of allochthonous salt systems was probably controlled in part by the distribution and thickness of the source layer, whether autochthonous or allochthonous, and in part by spatial and temporal variations in sedimentary loading. In the case of the autochthonous (Louann) layer, the salt basin shape and thickness were in turn controlled by the geometry of the underlying rifted basement blocks. In salt sub-basins that were impacted by progradational loading, proximal diapirs grew and extruded as salt-tongue systems, whereas salt nappes formed at the basinward margins. In distal sub-basins unaffected by progradation, salt-stock systems grew in an environment of pelagic sedimentation. When downdip salt extrusion was insufficient to balance updip extension during gravity spreading, contractional structures developed at the basinward margin of the autochthonous salt layer. In the northern Gulf of Mexico, two deep-water, thin-skinned fold belts have been recognized: the Mississippi Fan and Perdido provinces. Each comprises elongate, salt-cored detachment folds, both symmetric and asymmetric, cut by reverse faults on one or both flanks. The timing of deformation in each fold belt is related to the timing of maximum updip depositional loading and resulting extension: primarily Paleogene in the Perdido fold belt and Neogene in the Mississippi Fan fold belt. The two provinces are separated by a region lacking contractional folds, where gravity spreading was accommodated entirely by allochthonous salt extrusion. The various structural styles that resulted from gravity spreading have important ramifications for the two newest and most exciting frontier plays in hydrocarbon exploration of the Texas/Louisiana offshore. First, the success of the subsalt play depends in part on understanding the geometry and evolution of allochthonous salt. Salt-tongue, salt-stock, and salt-nappe systems all have different implications for the nature of subsalt structural traps, the spatial and temporal distribution of reservoir facies, and the timing of source rock maturation and the pathways of hydrocarbon migration and entrapment. For example, salt-tongue and salt-nappe systems may have deflected fluids toward the edges of the salt sheets, whereas salt-stock canopies may have focussed fluid flow into base-salt structural highs that were once the preferred sites for sand transport and deposition. The second frontier play is centered on the large anticlinal closures of the deep-water fold belts. These structures are potential giant fields, with maximum relief and areal closure of up to 2 km and 200 km2, respectively, and multiple targets ranging from Upper Jurassic/ Lower Cretaceous shallow-water carbonates to Tertiary clastics. A secondary possible type of accumulation lies in stratigraphic traps within onlapping synkinematic turbidite sands. The two frontier plays merge where folds extend beneath the allochthonous salt. In all cases, understanding the structural geometry and evolution will be critical in minimizing risk in these expensive plays.