Integrating 3D seismic data with structural restorations to elucidate the evolution of a stepped counter-regional salt system, Eastern Louisiana Shelf, Northern Gulf of Mexico

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Abstract: By integrating 3D and 2D seismic interpretation with structural restorations we have reconstructed the evolution of a complex, composite stepped counter-regional salt system in the West Delta/South Pass (WDSP) area of the northern Gulf of Mexico. Biostratigraphically calibrated well data allow the last 10 Ma of the evolution of the salt system to be divided into six stages: (1) sea-floor extrusion of isolated salt tongues fed from the Jurassic Louann salt through northward dipping feeders prior to 7.5 Ma; (2) amalgamation of the salt tongues to form a salt-tongue canopy between 7.5 and 6.4 Ma; (3) counter-regional evacuation of the salt-tongue canopy as a result of enhanced sediment loading due to progradation of the shelf margin between 6.4 and 5.0 Ma; (4) evacuation of salt into a series of salt walls linking salt domes between 5.00 and 2.55 Ma; (5) evacuation of the salt walls to form counter-regional fault welds between 1.95 and 0.5 Ma; and (6) final evacuation of most of the salt from deeper levels leaving a series of isolated salt domes connected by counter-regional fault welds. The counter-regional evacuation of the WDSP salt systems illustrates the value and limitations of published 2D models for allochthonous salt, and the reconstructed evolution yields insights into the complex interactions between salt deformation and sedimentation. The results also suggest that the WDSP salt systems significantly affected sediment transport pathways, trap geometries and possibly late stage petroleum migration across evacuating salt welds.

It is now well established that the offshore northern Gulf of Mexico is characterized by a complex pattern of salt structures, many of which are allochthonous bodies, detached from their original Jurassic source layer (e.g. McGuinness & Hossack 1993; Diegel *et al.* 1995; Fletcher *et al.* 1995). This is most apparent at the Sigsbee Escarpment where shallow allochthonous salt has overridden deep basin strata for tens of kilometres. In contrast to this large tabular salt canopy, the eastern Louisiana shelf area comprises a series of isolated salt domes, linked by both basinward and landward (counter-regional) dipping faults (Fig. 1). In the West Delta and South Pass (WDSP) southern addition protraction areas, these isolated salt domes are particularly well defined (Fig. 2) and are associated with significant petroleum accumulations, e.g. the South Pass 89 field and the West Delta 133 field. The South Pass 89 field has been highly productive since its discovery in 1969. To date, 55 801 MBO, 46.15 BCF, and 2115 MBO condensate have been produced from Lower Pliocene/Upper Miocene reservoirs (Marathon production figures, pers. comm. 2000). The trap is a complex stratigraphic/structural trap along the steep to overturned eastern flank of the South Pass 89 salt dome (Dome B in Fig. 2). Adjacent salt domes are linked by a series of landward dipping, counter-regional faults (or fault welds), that show a large degree of expansion in their hangingwalls (Schuster 1995). These shallow salt bodies overlie a deeper, discontinuous system of allochthonous salt welds (evacuated salt bodies) and remnant salt (Schuster 1995).

The main aims of this paper are to examine how the deep-level salt systems evolved into the shallower salt dome geometries (in 3D and through time) and how this complex evolution may have influenced reservoir development, trap formation and petroleum migration from the underlying source rocks (see also Bland *et al.* 2000).

Several different end-members for the evolution of allochthonous salt have been proposed and documented in the northern Gulf of Mexico, including stepped counter-regional and roho systems (Schuster 1995; Diegel *et al.* 1995) and salt-stock canopies (Rowan *et al.* 1994; Rowan 1995). The basic components of these systems are salt tongues and bulb-shaped salt stocks, respectively (Rowan 1997; Rowan *et al.* 1999). Ultimately, the only difference between these elements is the symmetry or asymmetry of salt extrusion: salt tongues are extruded basinward from basinward-leaning feeder stocks; whereas bulb-shaped salt stocks spread radially from vertical feeders.

In the WDSP area the dominant salt style is that of stepped-counter regional salt systems. The 2D geometry and evolution of these salt systems as determined by Schuster (1995) has come to represent the type example of a stepped counter-regional salt system (Fig. 3) within the northern Gulf of Mexico basin.

In this paper, we aim to build on Schuster's (1995) landmark publication by focusing on the three-dimensional geometry of the salt systems, and then use both 2D and 3D structural restorations to illustrate the changing salt geometry during its emplacement and subsequent evacuation. Finally, we use the restorations and isopach maps to illustrate the history of interaction between salt movement and sedimentary loading. The results of this study should be useful both to researchers who are investigating the processes of salt system evolution and to industry geoscientists who are exploring for petroleum around salt structures in stepped counter-regional salt systems worldwide.

Seismic and well database

Two different seismic datasets were merged and interpreted (Fig. 4) for this study. The primary dataset used was a 1993 Western Geophysical, time-migrated 3D survey, with acquisition bin dimensions of 25 × 40 m. We also interpreted a 1990 3.2 km × 3.2 km grid of time-migrated 2D seismic data to extend our interpretations and tie some of the nearby wells.

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