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Insights into Structure and Stratigraphy of the Northern Gulf of Mexico from 2D Pre-Stack Depth Migration Imaging of Mega-Regional Onshore to Deep Water, Long-Offset Seismic Data

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ABSTRACT

Mega-regional, 2D, long-offset pre-stack depth migrated (PSDM) data can provide advances to the interpretation of the framework of the northern Gulf of Mexico because the onshore shelf margins and linked deep water systems can be seen in continuous sections with consistent depth processing. The authors present an interpretation of one such seismic line from a new composite survey made up of reprocessed PSDM legacy onshore data from Seismic Exchange, Inc. (SEI) and Geophysical Pursuit, Inc. (GPI), and newly acquired ocean bottom cable (OBC) data and existing marine streamer data from GX Technology. The line extends from onshore east Texas to the deep water of the northwestern Gulf of Mexico and displays distinct, large-scale structural styles and salt remobilization events. Robust shelf sediment loading plus regional tilting drive several phases and scales of linked extensional-contractional geologic elements which are more directly seen in these data than on previous data sets. The Mesozoic to Early Tertiary margins are offset by a series of down-to-basin faults starting at the shelf/slope break positions and form a region dominated by extension and salt withdrawal. Each margin progrades out over its own prodelta shale facies, and lowstand wedge sediments expand into the topography created by this extension and salt withdrawal. Oligo-Miocene translation occurred on a detachment in the base Oligocene section with associated allochthonous salt welds. In addition, modest amounts of Neogene translation are recognized at the autochthonous Louann salt level. Minor shortening is recognized in Paleogene thrusting, as well as the more commonly documented Oligo-Miocene detachment folding in the Perdido fold belt and the folding and thrusting in the Port Isabel fold belt.

INTRODUCTION

It is well established in the northern Gulf of Mexico that substantial deformation in the form of linked proximal extension, salt mobilization and distal contraction is the result of gravity spreading and gliding (Diegel et al., 1995; Peel et al., 1995; Rowan et al., 2004). Indeed the northern Gulf of Mexico Basin is perhaps the archetype example of a progradational passive margin system that induces substantial translation over underlying detachments due to gravitational loading. Despite this recognition, the complexities of the deformation, difficulties in imaging, and shear size of the basin limit the ability to see the whole linked system in one consistent dataset.

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Long-offset data have become critical to serve the growing industry need for regional datasets that overcome imaging limitations of legacy seismic and provide a more complete framework for future exploration. Modern, long-offset, long-recording time, PSDM data can help in the development of new criteria and play ideas for the interpretation of the northern Gulf of Mexico. This study presents an interpretation of a mega-regional line that spans from onshore to ultra-deep water, and is part of a new dataset composed of PSDM, widely-spaced, 2D seismic lines that are composites of several surveys. The land component is existing onshore data from two contributors, Seismic Exchange, Inc. (SEI) and Geophysical Pursuit, Inc. (GPI). These data have been reprocessed and depth imaged by GX Technology. The near shore component is from GX Technology ocean bottom cable (OBC) long-offset, long recording time data, and the deeper water component is GX Technology's long-offset, marine streamer data that was collected and processed in 2004 for the GulfSpan project. On this mega-scale, the deep water stratigraphy can be seen on the same section as landward shelf edges, and the depth-imaged data more properly displays geometric relationships for more accurate stratigraphic and structural interpretation and timings.

MEGA REGIONAL LINE – ONSHORE SHELF TO DEEP WATER

The position of a key seismic line is shown on the basemap in Figure 1 and a stratigraphic and structural interpretation of this line is shown in Figure 2 as it spans over 310 miles (500 km) from onshore east Texas to the ultra-deep water of the northwestern Gulf of Mexico. Highlights of these data include robust development of Mesozoic and Tertiary prograding margins, salt withdrawal affecting the Mesozoic and Early Tertiary, an allochthonous salt weld and associated Eocene-Oligocene detachment, and several phases and scales of linked extension and contraction.

The line in Figure 2 shows a Mesozoic stratigraphic section that starts landward to the northwest at the shelf slope break position of the Cotton Valley. Labeled are the top Cretaceous, Wilcox, top Eocene and Miocene horizons which mark the top of well-developed shelf margins with criteria of downlapping reflections, demonstrating 110 miles of progradation compared to 3 miles of aggradation. These shelf margins prograde basinward over thick lowstand wedges and prodelta to upper slope facies and are seen here to cause significant sediment loading of the substrate.

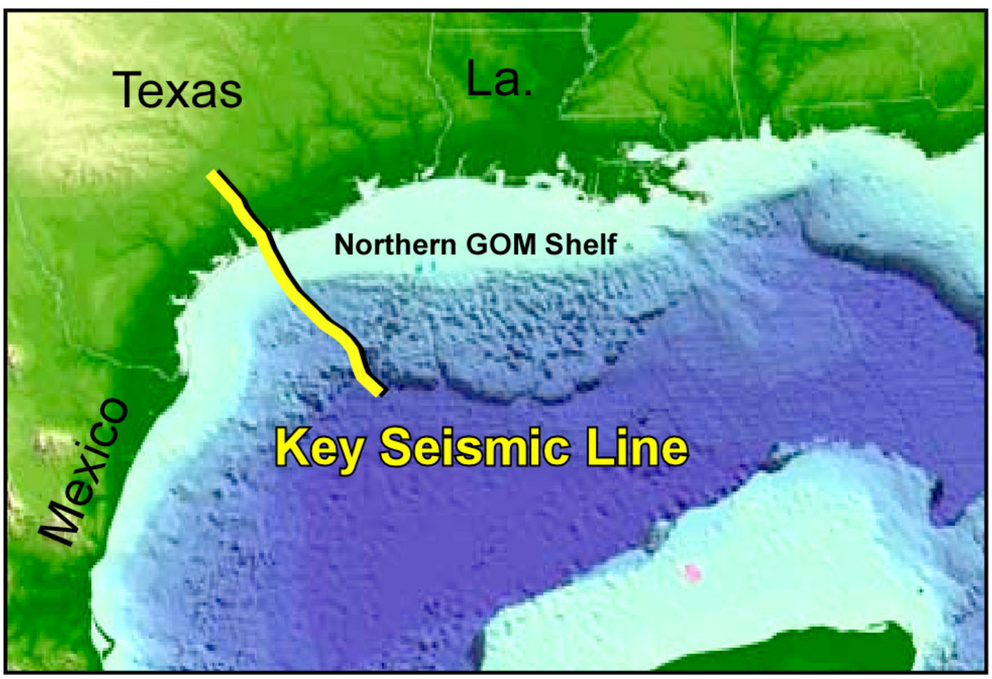

Figure 1. The location of a mega-regional seismic line is shown on a Gulf of Mexico bathymetry map. This line is interpreted in Figure 2 and spans over 310 mi (500 km) from onshore to ultra deep water.

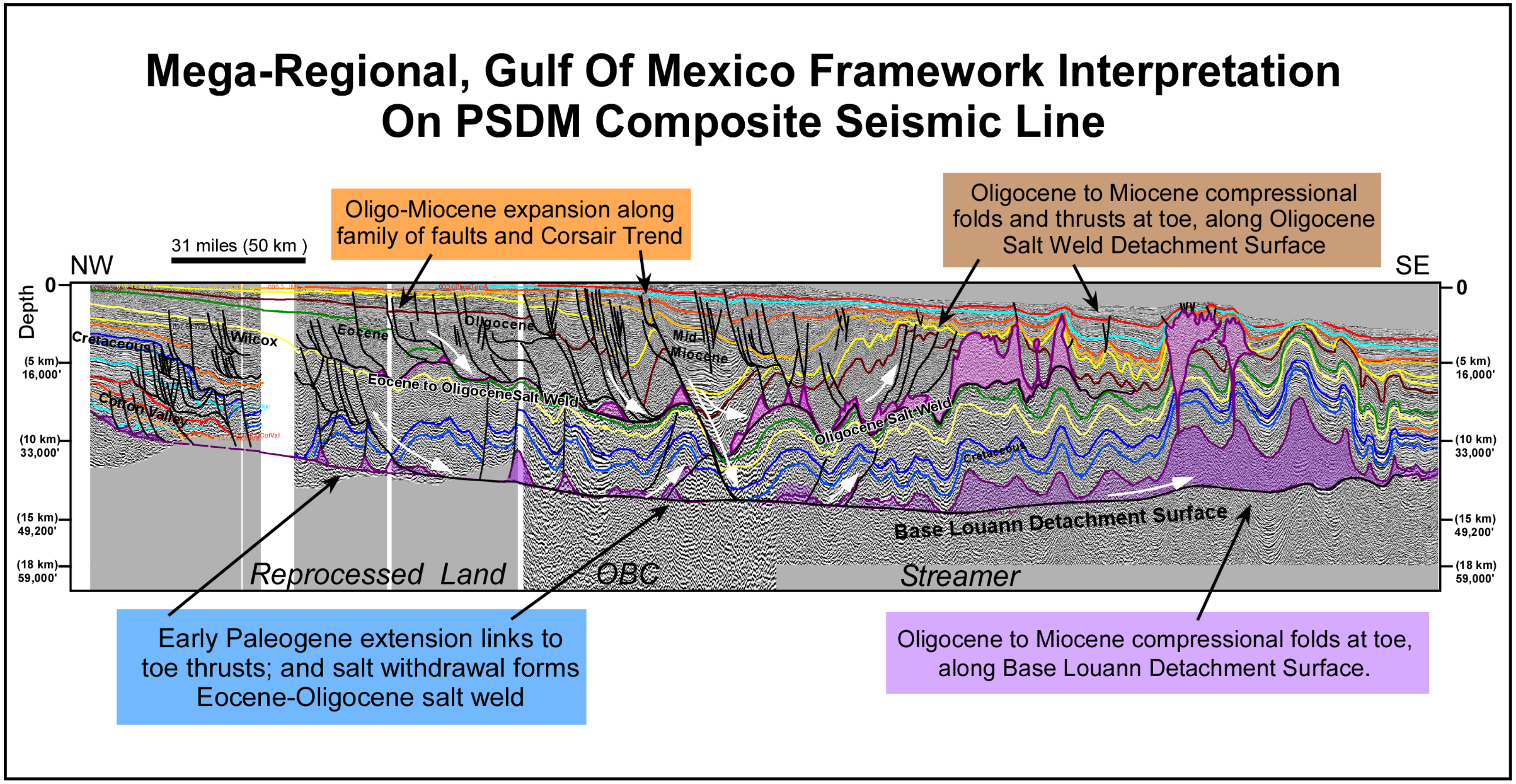

Figure 2. The stratigraphic and structural framework interpretation is shown on a mega-regional PSDM seismic line composite of land, ocean bottom cable, and streamer data. The highlights of this interpretation include extension and salt withdrawal in the early Paleogene, robust Paleogene shelf edges, a semi-regional Eocene-Oligocene salt weld, and a major expansion of the Oligo-Miocene sediments linked to compressional features forming on detachment surfaces at the base Louann and at the Oligocene allochthonous salt weld. The land data is reprocessed by GX Technology and licensed through Seismic Exchange, Inc. (SEI). The OBC and streamer data are acquired and processed by GX Technology. The data is part of the GulfSpan project and shown courtesy of GXT and SEI. The vertical exaggeration is 6:1.

The Cretaceous shelf edge is highly faulted by down-to-basin faults and salt withdrawal features and the Wilcox section fills this accommodation space with thick sediments. In an outboard position, the Mesozoic section is interpreted as undergoing salt evacuation and shows a systematic, counter-regional, tilted fault block style described in Rowan and Inman (2005) in their interpretation of PSDM 2004 streamer data from the GulfSpan project. These Mesozoic fault blocks are capped by a pervasive feature that is interpreted as an allochthonous salt weld at the base Oligocene in the northwestern Gulf of Mexico area (Rowan et al. (2005). The pervasive nature of this weld is shown in Figure 2 and additional criteria for this feature as a true salt weld are recognized by McDonnell et al. (2007). The weld criteria include high to low angle disconformities in seismic reflections across a common surface, in addition to high amplitude and low frequency seismic reflections. These reflections are interpreted as remnant salt bodies and condensed sections that have been deposited at the top of salt and have been left behind at the weld surface. This weld could be a regional sealing surface in some areas rather than a window for hydrocarbon migration.

The interpretation presented here highlights gravity forces that have affected the section at different times. These forces act in concert with robust margin progradation onto an inclined, subsiding basement, and with the development of several levels of detachment surfaces to form a series of mega-regional, linked extension and contractional structural elements. In this figure, detachment surfaces are interpreted at the Oligocene allochthonous salt weld (Diegel et al., 1995), and secondarily at the Louann level.

As labeled on Figure 2, the Early Paleogene time is the oldest, linked extension and contractional element. The interpretation here sees this as mainly driven by robust margin progradation. Mesozoic to Paleogene offset and translation takes place along sets of low angle, down-to-basin faults that sole out onto the base Louann salt weld. The Mesozoic to Wilcox section exhibits diagnostic rollover into the down-to-basin fault surfaces, but this rollover is broken-up by salt-withdrawal features and the regional seismic line advances the recognition of this criteria. A thick Wilcox section fills the accommodation space created by this extension. In Figure 2, the onshore extension results in an offshore contractional thrust belt that shows small, but clearly imaged thrusts involving the Mesozoic and Paleogene section. On most lines in the survey, salt evacuation seems to account for most of the shortening required by this extension and these older thrusts are interpreted in only a few places, but where present on the OBC data they seem compelling, and represent to our knowledge a newly recognized contractional response to Early Tertiary translation in the northwestern Gulf of Mexico.

The Oligo-Miocene extension is accommodated as translation along the allochthonous salt weld at the base Oligocene discussed above, a recognized major detachment surface in the northwestern Gulf of Mexico (Diegel et al., 1995; Peel et al., 1995). This is well imaged in these mega-regional lines (e.g., Fig. 2) where the geometry of the structures above the detachment clearly does not coincide with those in the pre-Oligocene section below. The corresponding linked contraction can be seen in the toe in the Oligocene to Early Miocene Port Isabel fold belt as well as a canopy and some small folds outboard (Peel et al., 1995) (Fig. 2). In addition, modest amounts of Neogene translation are recognized at the autochthonous Louann salt level to account for shortening in the Perdido fold belt (Peel et al., 1995; Trudgill et al., 1999; Rowan et al., 2005). The question of how this translation is transferred down to the Louann level is a challenge as there is no unambiguous place in the seismic data where this occurs, but it seems to be related to the Corsair trend and its associated faults as this is the only possible deeper fault system and has a growth history (Early to Middle Miocene) that corresponds to the growth in the Perdido region (Fig. 2). Peel et al. (1995) showed a cross section (their Line 5) that shows the Corsair fault soling out in a Louann detachment. Rowan et al. (2005) discussed the possibility that a widening diaper below the Corsair that could, at least in places, accommodate some of the deeper extension. The wide spacing of the lines on these data shows variations in how this slip is transferred to the deeper detachment level. On the line in Figure 2 is shown a Corsair fault that soles into the Louann detachment; however, variations along strike do occur, as discussed by Rowan et al. (2005). It may be that the Paleocene thrust faults just updip of the Corsair at this location required transfer to the lower level to occur just outboard of these thrusts as this was not an effective detachment in the Paleocene either. On lines to the southwest a fault system directly behind the Corsair seems to be the fundamental fault that steps down to the Louann level. There Paleocene thrust faults are not evident.

CONCLUSIONS

As one examines the entire seismic line, the mega-geologic scale enhances an understanding of the interaction of the stratigraphy, extension faults, salt events, and contractional features and timings. The Mesozoic and

Cenozoic shelf margin progradation of 110 miles in the northwestern Gulf of Mexico can be seen with this deep imaging. Early Mesozoic, Early Paleogene extension occurred at a series of down-to-basin faults. Wilcox sedimentation develops with vigorous progradation and high sedimentation rates fills the accommodation space. Minor thrusting of the same age is recognized in places at a deep detachment in the Louann. Thick Oligocene to Miocene sediment expansion forms into a family of faults including the Corsair trend as they follow robust shelf slope break positions moving basinwards. These listric faults connect to down-to-basin faults and sole out mainly in an allochthonous salt weld at the base Oligocene. The corresponding linked contraction can be seen in the toe in the Oligocene to Early Miocene Port Isabel fold belt as well as a canopy and some small folds outboard. Minor amounts of translation are transferred to the deeper Louann detachment along the Corsair trend allowing for minor shortening in the Perdido fold belt in the Early to Middle Miocene.

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The authors acknowledge that the interpretation was built upon the original 2004 GulfSpan horizon and fault framework performed by Mark Rowan and Kerry Inman as a starting point. Mark Rowan established an initial structural framework for the interpretation shown here by providing some salt horizons and faults. Discussions with Martin Jackson and Mike Hudec were valuable in providing insight into salt interpretation styles and issues of structural timing. However, the final interpretation is the responsibility of B. Radovich, J. Moon, and C. Connors.

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