

AAPG HEDBERG CONFERENCE
"Deepwater Fold and Thrust Belts"
October 4-9, 2009 – Tirrenia, Italy

The Evolution of the Perdido Fold Belt in the Context of Salt Tectonics of the Northwestern Gulf of Mexico – Insights from Numerical Modelling

Sofie Gradmann¹, Christopher Beaumont²

¹Dept. of Earth Sciences, Dalhousie University, Halifax, Canada

²Dept. of Oceanography, Dalhousie University, Halifax, Canada

The Perdido Fold Belt (PFB) is a prominent salt-cored deep-water structure in the northwestern Gulf of Mexico. It is characterized by symmetric, kink-banded folds of a ~4.5 km thick prekinematic layer and by its vicinity to the extensive Sigsbee Salt Canopy. Although its geometry and overall temporal evolution are determined from seismic and borehole data, the factors controlling its evolution and its regional relationship to other salt tectonic structures are not fully understood.

We use 2-D finite element numerical models to study the evolution of the PFB as a gravity-driven fold belt both in a local context and in the context of the larger-scale passive margin, influenced by adjacent allochthonous salt structures. The models comprise a viscous salt layer overlain by frictional-plastic passive margin sediments. Model experiments include sediment progradation, flexural isostasy, sediment compaction, loading by the water column, and effects of pore-fluid pressures in the frictional-plastic sediments.

The PFB shows several unique features that distinguish it from many other deep-water fold belts (Figure 1c and 1d, Trudgill et al., 1999). These include the highly symmetric kink-banded folds extending for 60-100 km, the large 4.5 km thickness of the prekinematic section and the absence of early deformation, the seaward tilt of the entire fold belt, the almost synchronous evolution of its folds within less than 10 Ma during Oligo-Miocene times, and its vicinity to the large allochthonous salt structure of the Sigsbee Canopy.

The PFB is located at the seaward end of the mid Jurassic salt basin. It is partly overlain by the allochthonous salt of the Sigsbee Canopy. Landward of it, an earlier, Eocene paleoceanopy formed, which acted as a detachment surface for another gravity spreading system that formed the shale and salt based Port Isabel Fold Belt. Early Paleogene folding at the mid-basin autochthonous

salt level has recently been suggested (Radovich et al., 2007) but its relation to the later fold belt evolution at the seaward end of the basin is not understood.

Models that address the foldbelt evolution in a local context (Figure 1) consider: the horizontal forces and overburden strength necessary to deform the thick sedimentary layer; the factors controlling the almost synchronous evolution of the fold belt; and the possible effects of different initial salt basin geometries. Analytic calculations of the margin stability show that the PFB can have formed by gravity spreading alone if moderately high pore-fluid pressure ratios of ~ 0.8 developed. We show that parameters such as overburden strength, salt geometry, and/or salt viscosity determine timing, extent, and location of the modeled fold belt.

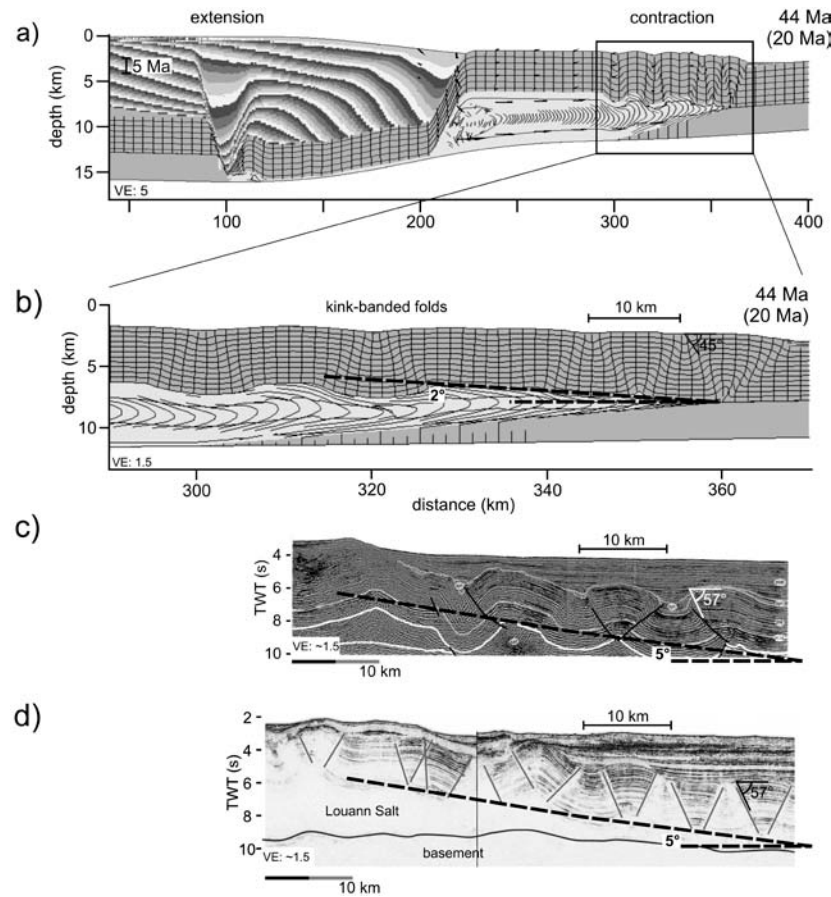


Figure 1: Comparison of numerical model results with seismic sections from the Perdido Fold Belt. a) Reference model after 44 Ma model run time (age in brackets denotes time since onset of gravity spreading). The gray scale shows the chronostratigraphy in 5 Ma major bands, each divided into 1 Ma subbands. b)

Close-up of numerical model showing the fold belt with highly symmetric kink-banded folds of ~10 km wavelength. c) Seismic sections of PFB from Rowan et al. (2000). d) Seismic section of PFB from Camerlo and Benson (2006, AAPG©2006, reprinted by permission of the AAPG whose permission is required for further use).

When constructing model experiments that address the evolution of the fold belt from a regional perspective we work backwards in time. First we address the related and possibly coeval Miocene evolution of the Sigsbee Salt Canopy and the PFB, then the preceding evolution of the landward located, Oligo-Miocene gravity spreading system above allochthonous salt, and finally the evolution of this shallower, mid-basin detachment layer, the Eocene salt canopy. Three different conceptual models for canopy evolution are tested (Figure 2).

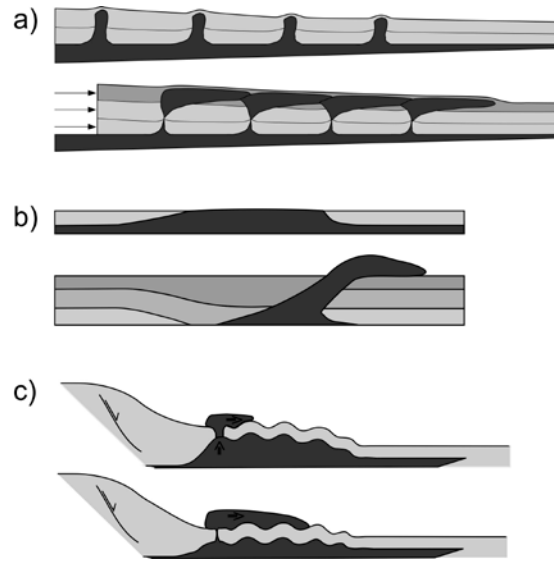


Figure 2: Conceptual models of three types of salt canopy evolution. a) Salt expulsion through shortening of early diapirs. b) Canopy formation through expulsion rollover, requiring no failure of overburden due to regional shortening or extension. c) Salt expulsion through breached anticlines requiring strong overall shortening.

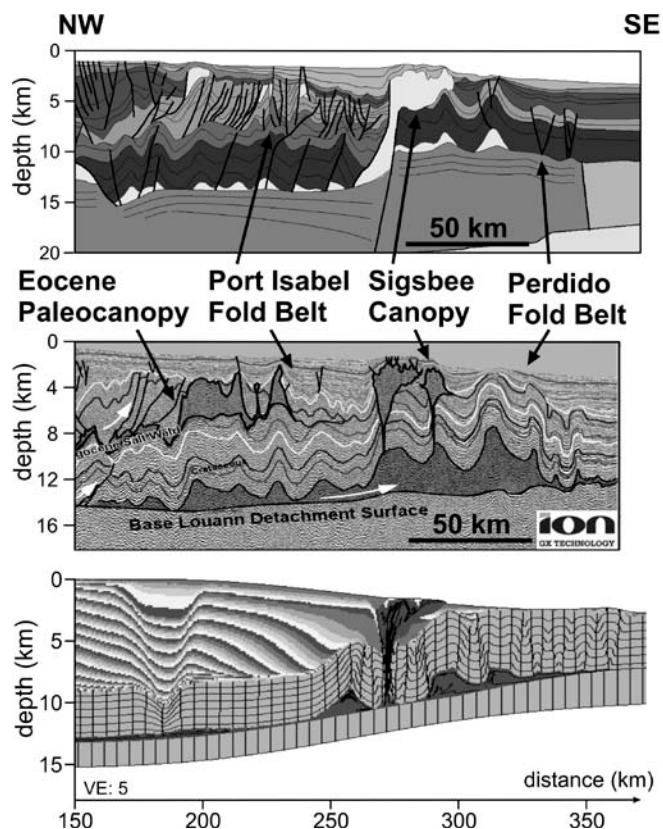


Figure 3: Comparison of cross sections of the PFB region with numerical model results. a) Line drawing of PFB region showing the Sigsbee Canopy and fold belts at allochthonous and autochthonous salt level (F. Peel, personal communication, 2007, after Peel et al., 1995). b) Seismic section and line drawing from Radovich et al. (2007) (published with permission of ION/GXT and SEI). c) Numerical model results of allochthonous salt structure above fold belt.

The simplified models of the Gulf of Mexico show that toe-of-slope folding is a viable mechanism to develop diapirs in the deep salt basin and, together with breaching of anticlines, to develop allochthonous salt structures. This could account for the evolution of the Sigsbee Salt Canopy overlying the PFB (Figure 3). In this scenario, the PFB likely represents the terminal folding of a much larger, diachronously formed fold belt system. The presence of a mid-basin allochthonous salt sheet in the models and subsequent shallower-level gravity spreading modifies the stratigraphy and structure showing higher resemblance to the sediment structures observed in the northwestern Gulf of Mexico. Furthermore, the shallow level detachment buffers the deformation induced by margin instability before it steps down onto the autochthonous level as it is also suggested for the PFB region (Rowan et al., 2005).

The evolution of a mid-basin canopy by breaching anticlines (Figure 2c) is compared to the results from models testing two other hypothesis of canopy evolution. In the first scenario, a canopy forms as pre-existing diapirs are squeezed, requiring early extension or quiescence for diapir growth followed by subsequent shortening (Figure 2a). In the second scenario, salt is expelled from its basin by a large expulsion rollover (Figure 2b). This scenario requires no regional stress regime or failure of the overburden (Ge et al., 1997, Rowan and Inman, 2005).

This work aims to explain the first-order structures of the PFB and the northwestern Gulf of Mexico in a dynamical context by comparing its evolution with those of a series of finite element model experiments. The modelling is designed to place quantitative constraints on the conditions under which the PFB may have evolved (overburden strength and geometry, sedimentation rates, salt thickness, salt geometry and salt viscosity), to test whether the system was driven by gravity alone, and to enhance the general understanding of the evolution of gravity-driven deep-water fold belts.

References:

- Camerlo, R. H., and E. F. Benson (2006), Geometric and seismic interpretation of the Perdido Fold Belt: Northwestern deep-water Gulf of Mexico, *AAPG Bull.*, 90(3), 363 – 386.
- Ge, H., M. P. A. Jackson, and B. C. Vendeville (1997), Kinematics and dynamics of salt tectonics driven by progradation, *AAPG Bull.*, 81(3), 398 – 423.
- Radovich, B., J. Moon, C. Connors, and D. Bird (2007), 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, *Trans. Gulf Coast Assoc. Geol. Soc.*, 57, 633 – 637.
- Rowan, M. G., and K. F. Inman (2005), Counterregional-style deformation in the deep shelf of the northern Gulf of Mexico, *Trans. Gulf Coast Assoc. Geol. Soc.*, 55, 716 – 724.
- Rowan, M. G., B. D. Trudgill, and J. C. Fiduk (2000), Deep-water, salt-cored foldbelts: Lessons from the Mississippi Fan and Perdido Foldbelts, northern Gulf of Mexico, in *Atlantic Rifts and Continental Margins*, *Geophys. Monogr. Ser.*, vol. 115, edited by W. Mohriak and M. Talwani, pp. 173 – 191, AGU, Washington, D. C.
- Rowan, M. G., K. F. Inman, and J. C. Fiduk (2005), Oligo-Miocene extension at the Louann level in the northern Gulf of Mexico: Kinematic models and examples, *Trans. Gulf Coast Assoc. Geol. Soc.*, 55, 725 – 732.
- Trudgill, B. D., M. G. Rowan, J. C. Fiduk, P. Weimer, P. E. Gale, B. E. Korn, R. L. Phair, W. T. Gafford, G. R. Roberts, and S. W. Dobbs (1999), The Perdido Fold Belt, northwestern deep Gulf of Mexico; part 1, Structural geometry, evolution and regional implications, *AAPG Bull.*, 83(1), 88 – 113.