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The structure of the Offshore Niger Delta

C. D. CONNORS[1*], B. RADOVICH[2], A. DANFORTH[3] AND S. VENKATRAMAN[4]

[1]*Dept. of Geology, Washington and Lee University, Lexington, VA, USA.*

[2]*ION/GX Technology and Dynamic Global Advisors, Houston, TX, USA.*

[3]*Independent Consultant, Houston, TX, USA.*

[4]*ION/GX Technology, Houston, TX, USA.*

e-mail: connorsc@wlu.edu

Abstract: We present a new analysis of the linked gravity-driven deformation in the Tertiary Niger Delta. On the shelf, the fundamental detachment surface sits at over 11 km subsea and shallows to 7 km in the toe of the delta. The inner slope is both translating and accommodating shortening from updip extension, and exhibits a ductile and complex shale response. The deepwater contractional toe of the delta is primarily a brittle fold-and-thrust belt of imbricate fault-bend, fault-propagation folds, and shear fault-bend folds. Growth commenced in the late Oligocene, and continues to the present day on some structures.

Keywords: Niger Delta, gravity spreading, toe thrust, fault-related folding, mobile shale.

It has long been recognized that the prograding Niger Delta causes extensive gravity spreading with the offshore manifestation of this gravity-driven deformation consisting of substantial extension on the shelf and inner slope, and contractional folding and thrusting in the outer slope and basin floor (Lehner and De Ruiter, 1977; Evamy *et al.*, 1978; Doust and Omatsola, 1990; Damuth, 1993; Rowan *et al.*, 2004; Corredor *et al.*, 2005). The depth of deformation and complexity of some of the structures has limited the ability of previous work to fully constrain the detachment depths, structural styles, timing of deformation, and influence of the basement. We present here a regional analysis of the structure and stratigraphy of the offshore Niger Delta from an interpretation of the new regional 2D seismic survey that clarifies much of these previous uncertainties.

Methods

We interpreted over 4800 line-km of 2D marine seismic reflection data from the NigeriaSpan survey, acquired and processed by GX Technology in 2005 and 2006. The survey extends from the shelf to basin floor and covers most of the deformed regions of the delta depicted in figure 1 except for a minor portion of the eastern and southeastern part of the delta. The seismic data have optimal characteristics (long offset, long recording time, prestack depth migrated) that provide advanced imaging of previously enigmatic mobile shale structures, as well as deep imaging of the prodelta stratigraphy, and detachment levels.

We interpreted several sequence boundaries, the top of ocean crust and the Moho throughout the data set. Our interpretation incorporated published well data to provide ties to sequence

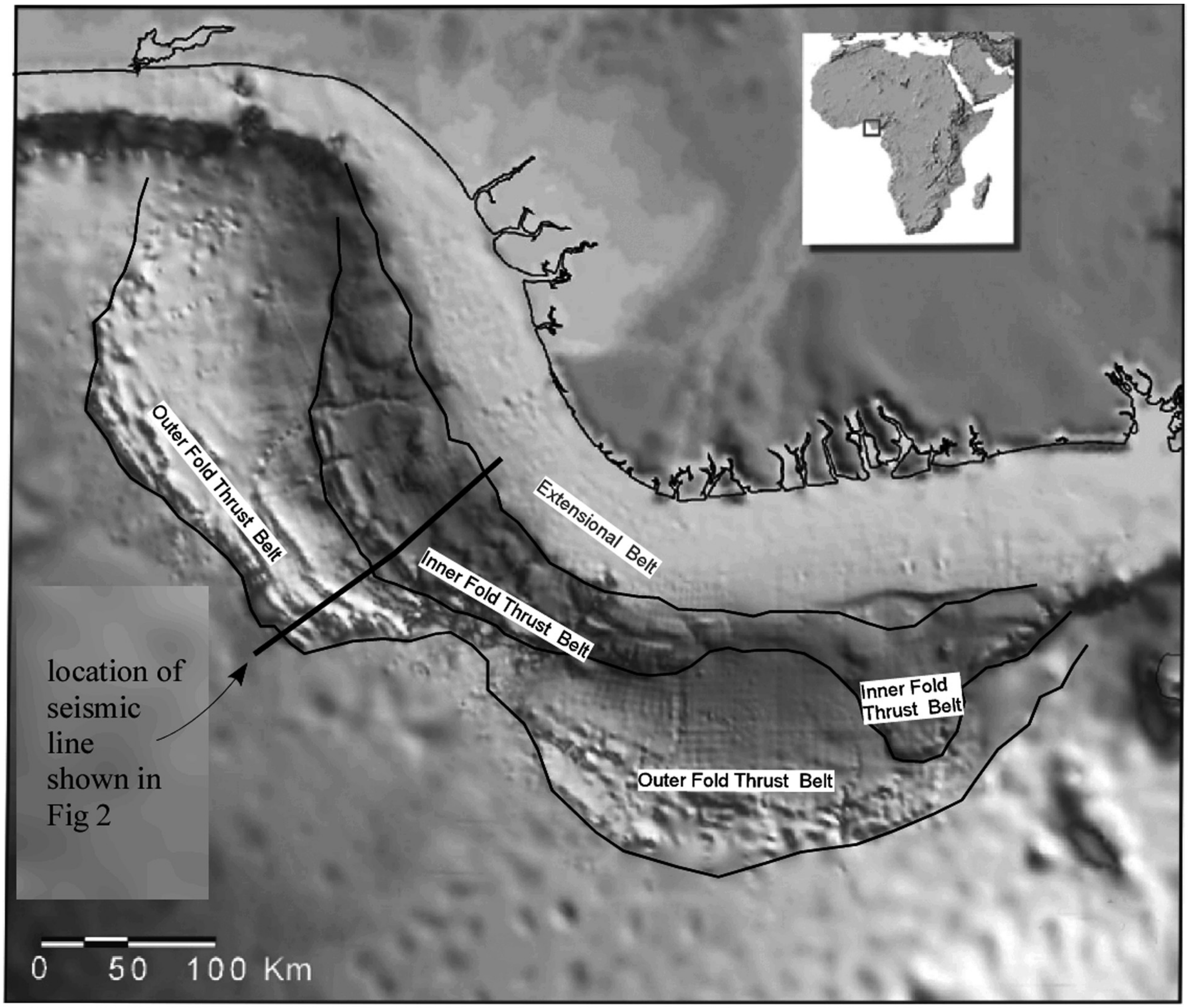

Figure 1. Structural provinces of the offshore Niger Delta from the interpretation of NigeriaSpan seismic data, overlain on bathymetry. An Extensional Belt and two distinction contractional belts are recognized and labelled, including a more ductile Inner Fold and Thrust Belt and a more brittle Outer Fold and Thrust Belt (Bathymetry from Corredor *et al.*, 2005).

boundaries in Neogene and Quaternary strata. We used standard sequence stratigraphic concepts to interpret sequence boundaries away from well control and for Paleogene and older strata. The top of ocean crust was recognized by high amplitude, low frequency reflection above chaotic, hummocky seismic facies. The Moho was interpreted as a discontinuous high amplitude reflector several km below ocean crust.

Structural interpretation was guided by the concept that the tectonics of the Niger Delta is gravity driven and thus detached. Detachment surfaces were recognized where normal faults and thrust faults sole into a surface conformable with foot wall strata or hanging wall strata. Standard fault-related folding concepts (Shaw *et al.*, 2005) were applied where appropriate, and ductile structures were interpreted in areas where seismic facies did not show laterally continuous reflectors and discrete faults were difficult to discern.

Results

Figure 1 shows the grouping of discrete deformational belts based on mapping of the NigerSpan data set. The most proximal is the Extensional Belt, a regional of substantial extensional growth faults due to progradation of the delta. The region is limited to the shelf, and is equivalent to extensional provinces documented by Doust and Omatsola (1990). Translation from the soling out of these listric normal faults results in contrac-

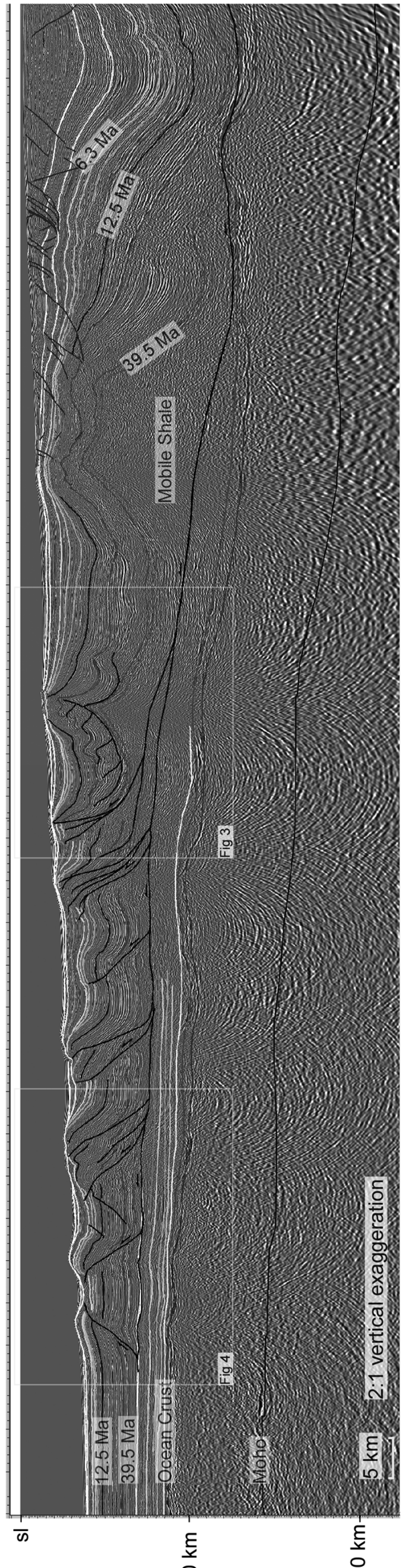

Figure 2. Regional, prestack depth migrated and interpreted seismic line across the offshore Niger Delta. See figure 1 for location.

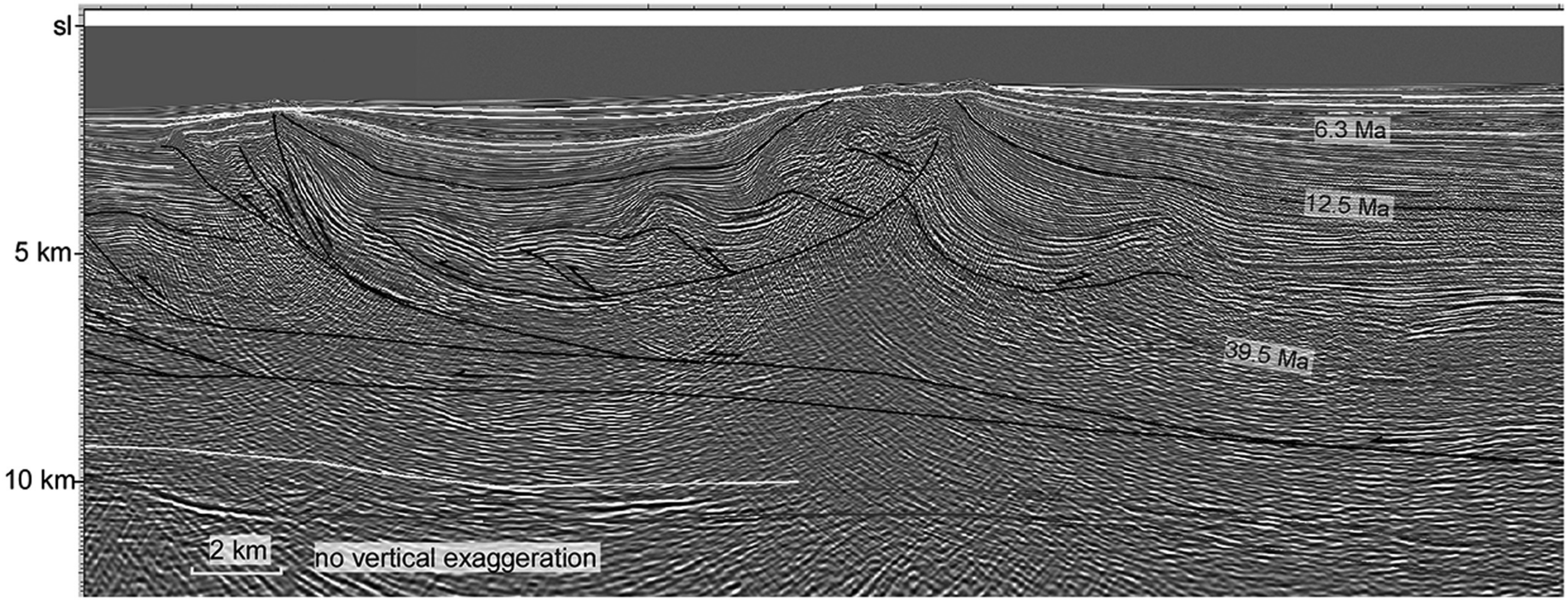

Figure 3. Complex brittle and ductile structures of the Inner Fold and Thrust Belt. Shown is a long-lived structural high with early thrusting, later refolding as part of a larger detachment fold, with substantial cut-and-fill geometries and several unconformities on the crest. Enlargement of part of figure 2.

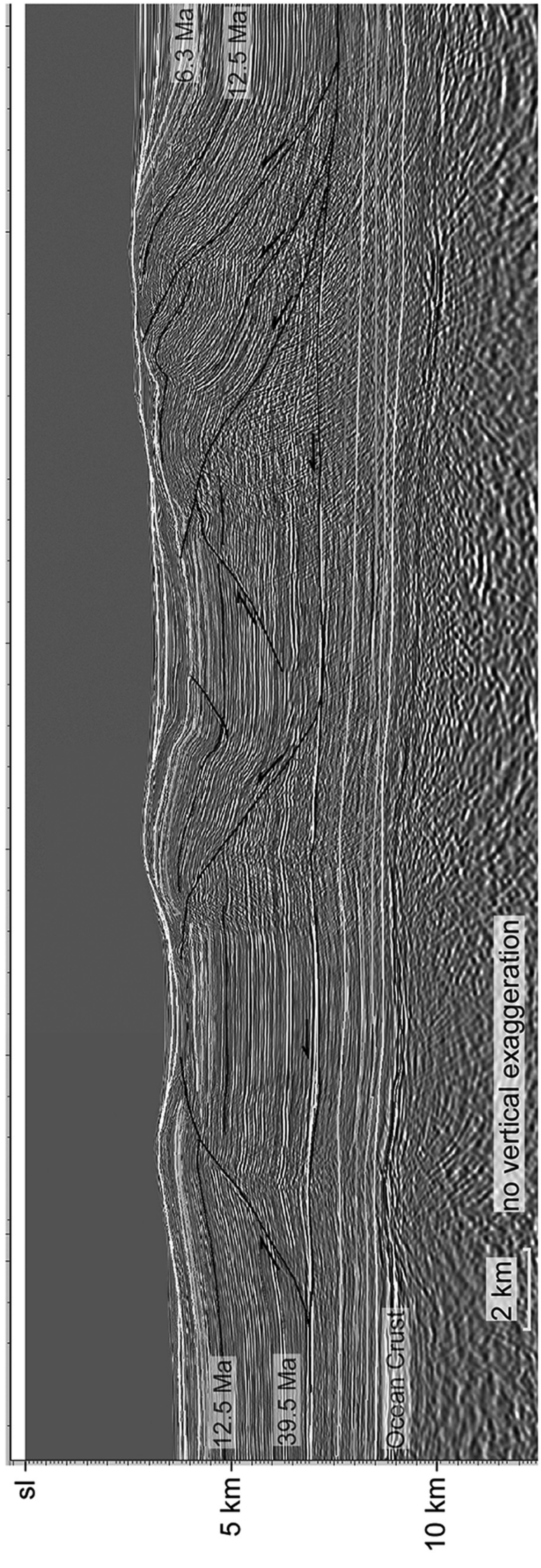

Figure 4. Brittle fold-and-thrust belt of imbricate fault-related folds stepping up from a clear detachment in the Oligocene-Eocene strata. Enlargement of part of figure 2.

tional accommodation on the slope in the Inner Fold and Thrust Belt, as well as distal contraction in the Outer Fold and Thrust Belt.

Figure 2 is a 275 km, prestack depth migrated and interpreted seismic line across the offshore Niger Delta that extends from the shelf to the basin floor outboard of the deformation front associated with gravity spreading. The line sits outboard of most of the Extensional Belt, but displays the result of this proximal gravity-driven extension as translation that occurs on an unambiguous detachment surface at over 11 km subsea, near the base of the Tertiary. In the contractional toe of the delta this fundamental detachment shallows to about 7 km subsea, rather uniformly in the Upper Eocene to Lower Oligocene section.

The inner slope is both translating and accommodating shortening from updip extension, and exhibits a ductile and complex shale response. One very large fold is shown in figure 2. Based on the high quality of the NigeriaSpan imaging we interpret structures such as these as primarily contractional, asymmetric, sometimes thrusted, detachment folds with mobile, Eocene-Early Oligocene prodelta and marine shale chaotically deformed in the cores of these structures. An adjacent updip basin shows evacuation of the prodelta and marine shale out of the syncline forming a weld on the underlying Lower Tertiary strata. While this relationship implies mobility to the Lower Tertiary strata we would not characterize this as diapiric. Growth commenced in the late Oligocene, and continues to the present day on many of these structures. This can be seen in figure 3 where just outboard of the large detachment fold, older contractional structures are refolded during more recent contraction. These long-lived structural highs often show later thrusting, with substantial cut-and-fill geometries and several unconformities on their crests (Fig. 3).

This structural and stratigraphic style is in stark contrast to the deepwater contractional toe of the delta which is primarily a brittle fold-and-thrust belt of imbricate fault-bend, fault-propagation folds, and shear fault-bend folds (Fig. 4). Growth strata on these fault-related folds, constrains timing from late Miocene to the present day, but individual structures do not generally show long-lived activity. Instead, thrusting in the more brittle toe tends to be a relatively systematic break-forward sequence (Fig. 4).

Discussion and conclusions

New long offset, long recording time, prestack depth migrated from the NigeriaSpan regional seismic reflection data set shows clear differences in structural style from the more ductile Inner Fold and Thrust Belt to the more brittle Outer Fold and Thrust Belt. Detachment horizons are well constrained below the shelf at around 11 km subsea, near the base of the Tertiary. In the contractional toe of the delta this fundamental detachment lies at about 7 km subsea, in the Upper Eocene to Lower Oligocene section. Growth is more long-lived in the Inner Fold and Thrust Belt, commencing in late Oligocene and many structures are still active. In the Outer Fold and Thrust Belt growth commenced in the late Miocene, with some structures still active. The differences in the structural styles and timing are probably the result of several factors related to the underlying prodelta and marine shales including differences in overpressure, original thickness and composition of the shales.

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References

CORREDOR, F., SHAW, J. H. and BILOTTI, F. (2005): Structural styles in deepwater fold and thrust belts of the Niger Delta. *AAPG Bull.*, 89: 753-780.

DAMUTH, J. E. (1993): Neogene gravity tectonics and depositional processes on the deep Niger Delta continental margin. *Mar. Petrol. Geol.*, 11: 320-346.

DOUST, H. and OMATSOLA, E. (1990): Niger Delta. In: J. D. EDWARDS and P. A. SANTAGROSSI (eds): *Divergent/Passive Margins Basins*. *AAPG Mem.*, 48: 201-238.

EVAMY, B. D., HAREMBOURE, J., KAMERLING, P., KNAAP, W. A., MOLLOY, F. A. and ROWLANDS, P. H. (1978): Hydrocarbon Habitat of the Tertiary Niger Delta. *AAPG Bull.*, 62: 1-39.

LEHRNER, P. and DE RUITER, P. A. C. (1977): Structural History of the Atlantic Margin of Africa. *AAPG Bull.*, 61: 961-981.

ROWAN, M. G., PEEL, F. J. and VENDEVILLE, B. C. (2004): Gravity-driven fold belts on passive margins. In: K. R. MCCLAY, (ed): *Thrust tectonics and hydrocarbon systems*. *AAPG Mem.*, 82: 157-182.

SHAW, J. H., CONNORS, C. D. and SUPPE, J. (2005): Part 1: structural interpretation methods. In: J. H. SHAW, C. D. CONNORS and J. SUPPE, (eds): *Seismic Interpretation of Contractional Fault-Related Folds. AAPG Studies in Geology*, 53: 1-58.