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Research paper

Niger Delta gravity-driven deformation above the relict Chain and Charcot oceanic fracture zones, Gulf of Guinea: Insights from analogue models

Jonny E. Wu*, Ken McClay, Edyta Frankowicz [1]

Fault Dynamics Research Group, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, UK

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ABSTRACT

The Niger Delta is a classic example of a passive margin delta that has gravitationally deformed above an overpressured shale decollement. The outboard Niger Delta clastic wedge, including the Akata Formation overpressured shale decollement, is differentially thickened across relict oceanic basement steps formed at the Chain and Charcot fracture zones. In this study, five analogue models were applied to investigate the effects of a differentially thickened overpressured shale decollement across relict stepped basement on Niger Delta gravity-driven deformation. Gravity-driven delta deformation was simulated by allowing a lobate, layered sandpack to deform by gravity above a ductile polymer. A first series of experiments had a featureless, horizontal basement whereas a second series had differentially thickened polymer above Niger Delta-like basement steps. Two syn-kinematic sedimentation patterns were also tested. Surface strains were analysed using digital image correlation and key models were reconstructed in 3D. All five model deltas spread radially outward and formed plan view arcuate delta top grabens and arcuate delta toe folds. The arcuate structures were segmented by dip-oriented radial grabens and delta toe oblique extensional tear faults, which were formed by along-strike extensional strains during spreading. Basement steps partitioned delta toe gravity spreading into dual, divergent directions. Similarities between the analogue model structures and the Niger Delta strongly suggest a history of outward radial gravity spreading at the Niger Delta. The Niger Delta western lobe has potentially spread downdip more rapidly due to a thicker or more highly overpressured underlying Akata Fm. shale detachment. Faster western lobe spreading may have produced the Niger Delta toe 'dual lobe' geometry, perturbed up dip Niger Delta top growth fault patterns, and implies that western lobe toe thrusts have been very active.

1. Introduction

The Niger Delta has prolific hydrocarbon reserves and is a well-documented example of gravity-driven deformation at a passive margin delta above an overpressured shale detachment (Fig. 1) (Doust and Omatsola, 1990; Haack et al., 2000; Corredor et al., 2005; Cobbold et al., 2009). The Niger Delta clastic wedge is up to 12 km thick and has a concave-seaward, lobate profile in plan view (Fig. 1b) (Cobbold et al., 2009). The main deltaic sedimentation pulse began in the Eocene and the delta front has prograded outward approximately 300 km to its present-day position (Evamy et al., 1978). Gravity-driven deformation is characterized by delta top extensional faults and delta toe imbricate fold-thrusts that detach within the Akata Formation, a prodelta marine shale that is typically overpressured (Fig. 1c & d). Deformation began in the Eocene and continues to the present-day (Doust and Omatsola, 1990; Cobbold et al., 2009).

The outboard Niger Delta has gravitationally deformed above stepped oceanic basement formed by the Chain and Charcot fracture zones (Fig. 1a & b). The fracture zones were transforms during mid-Atlantic opening in the Aptian and have been inactive since the Santonian (Lehner and de Ruiter, 1977; Briggs et al., 2009). Geodynamic models show that fossil transforms juxtapose oceanic lithosphere of different ages that thermally subside at different rates, producing differential sediment thickening across the transform (Sibuet and Mascle, 1978). This appears to be true at the Niger Delta, where regional isopach maps show differential

* Corresponding author. Now at: Department of Geosciences, National Taiwan University, Taipei City, 10617, Taiwan.
E-mail address: jonnywu@ntu.edu.tw (J.E. Wu).
[1] Now at: Shell International Exploration & Production, The Hague, Netherlands.

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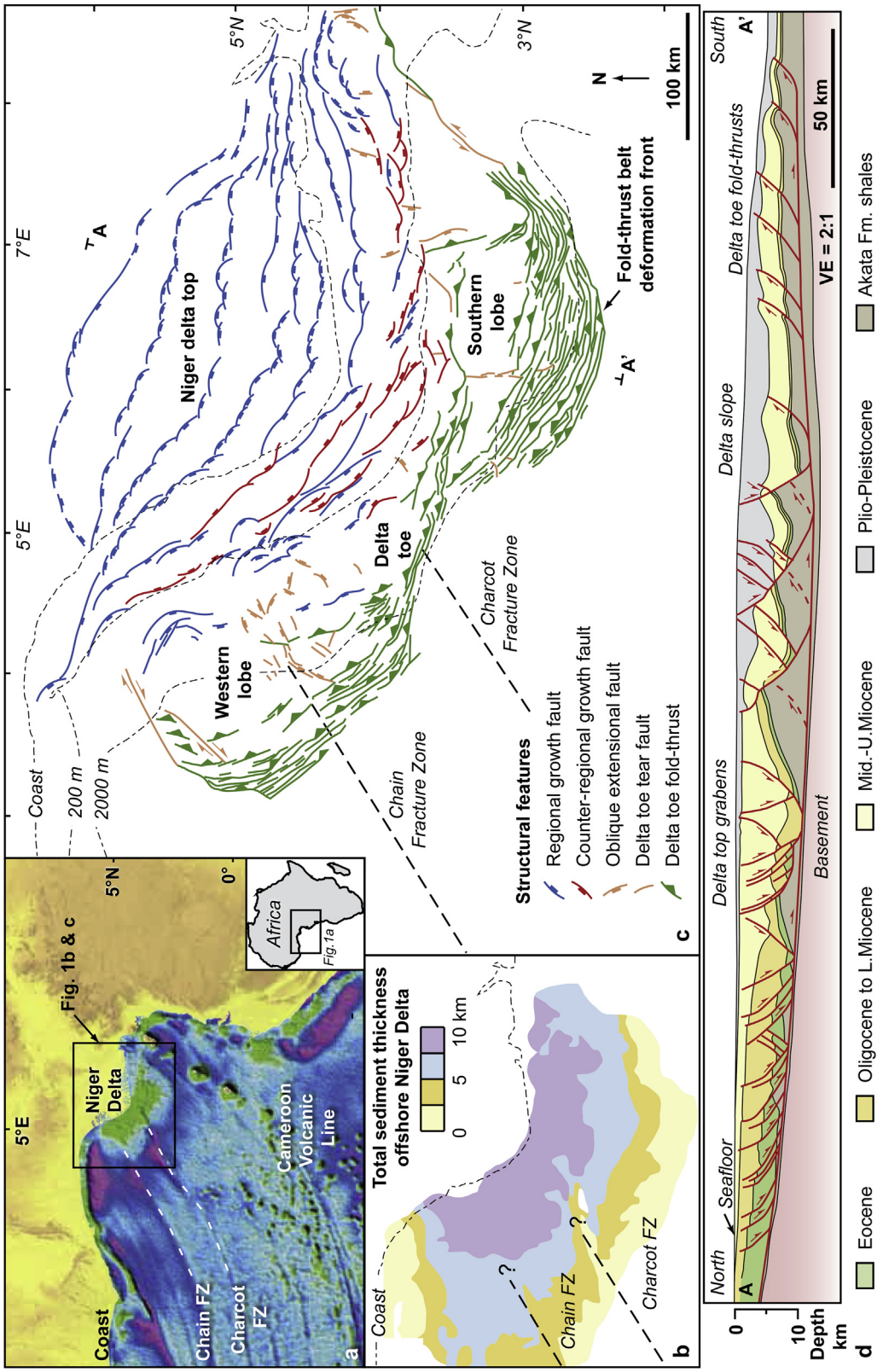

Fig. 1. a) Location map of the Niger Delta and the offshore Chain and Charcot oceanic fracture zones shown by onshore SRTM3 digital elevation model and offshore free-air gravity data (Sandwell and Smith, 2009). Note the delta sediments deposited across the basement fracture zones. FZ = Fracture Zone. b) Lobate shape of the Niger Delta clastic wedge revealed by a total sediment thickness isopach map (redrawn from Cobbold et al., 2009). The landward termination of the fracture zones is not well constrained. c) Niger Delta structural map (modified from Saugy and Eyer, 2003; Krueger and Grant, 2011). d) Schematic 2:1 vertical exaggeration cross-section across the Niger Delta (modified from Haack et al., 2000; Rouby et al., 2011). Cross-section location is shown in c).