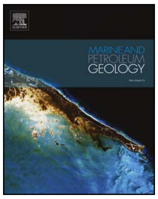
ARTICLE IN PRESS

Marine and Petroleum Geology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo



Research paper

Structural evolution of thrust-related folds and associated fault systems in the eastern portion of the deep-water Niger Delta

Yonghe Sun[a,b,c,*], Lu Liu[a,b,c]

[a] Innovation Team of Science and Technology for Fault Deformation, Sealing and Fluid Migration, Northeast Petroleum University, Daqing 163318, Heilongjiang, China
[b] Laboratory of CNPC for Fault Controlling Reservoir, Northeast Petroleum University, Daqing 163318, Heilongjiang, China
[c] Earth Science College, Northeast Petroleum University, Daqing 163318, Heilongjiang, China

ARTICLE INFO

Keywords:
Structural evolution
Thrust-related folds
Oblique inversion anticline
Fault systems
Gravity-driven
Deep-water Niger Delta

ABSTRACT

The geometry and kinematic evolution of a gravity-driven system consisting of thrust-related folds and associated fault systems located in the detachment fold province of the eastern portion of the deep-water Niger Delta were analyzed using a high-resolution 3D seismic dataset. This paper suggests that the structural evolution of delta progradational units can be divided into six episodes, which together represent a typical evolutionary cycle under gravity-driven processes that have resulted in the formation of distinct thrust-related folds and associated fault systems. An oblique anticline (Anticline E) trending NE-SW is subparallel to the regional transport direction (NNE-SSW) of the delta progradational units and sub-perpendicular to the main trend of the main structures (WNW-ESE). Before the shortening of the H4-H6 period, the region of this anticline was a half-graben associated with a normal fault (F0). Subsequently, during the shortening of the H2-H4 period, this normal fault acted as an oblique lateral ramp along which the half-graben sediments were shortened, forming an oblique anticline. Ultimately, growth of this anticline ceased during the H0-H1 period. The majority of faults associated with Anticline E can be divided into two types. (1) One type includes the domino normal faults generated during the H1-H4 period, these faults located in the west limb, were primarily caused by a secondary gravity-driven mechanism related to the dip of the anticline limb and gradually migrated as the crest or hinge line moved westward in subsequent intervals. The fault spacing and density are negatively and positively correlated, respectively, to the dip of the anticline limb. (2) The other fault type includes the conjugate normal faults generated during the H0-H1 period. These faults are located in the east limb and are related to the reactivated fault F0. These conjugate faults were primarily caused by a combination of local gravitational collapse resulting from the withdrawal of a mobile delta unit and the regional maximum horizontal stress caused by oblique sliding along the trend of F0. The reactivation of F0 was kinematically coupled with Anticline E and the conjugate normal faults through the delta units, and was a key factor in the origin of the anticline and faults.

1. Introduction

The deep-water Niger Delta is located in the Gulf of Guinea in central West Africa (Fig. 1a) at the southern culmination of the Benue trough (Corredor et al., 2005). This delta is one of the most prolific petroleum basins in the world (Hooper et al., 2002; Briggs et al., 2006). Much of the earlier literature on the structural evolution of the Niger Delta focused on several conclusions. (1) The regional tectonic evolution was characterized by pre-rift phase (i.e., interior sag basins) during the Proterozoic era to the Jurassic period, a syn-rift phase (i.e., interior fracture basins) during the Late Jurassic to the Early Cretaceous periods, a transitional phase (i.e., interior sag basins) during the late Early Cretaceous period, and a post-rift phase (i.e., thermal subsidence basins or marginal sag basins) during the late Early Cretaceous period to the present (Anderson et al., 2000; Lawrence et al., 2002; Séranne and Anka, 2005; Vera et al., 2010; Beglinger et al., 2012). Moreover, during the post-rift phase (i.e., during the gravity-driven construction of the Niger Delta), two stages were recognized: an open marine post-rift stage occurring during the pre-Oligocene period and a deltaic post-rift stage occurring from the Oligocene period to the present. (2) The structural styles included thrust- and fault-related folds throughout the contractional zone, and these folds were dependent on growth triggered by gravity-driven mechanisms and controlled by multiple factors, such as the static differential loading of deltaic sedimentation (Wright and

---

* Corresponding author. Earth Science College, Northeast Petroleum University, Xuefu Street 99, High and new tech development zone, Daqing City 163318, Heilongjiang Province, China.

E-mail address: syh79218@163.com (Y. Sun).

https://doi.org/10.1016/j.marpetgeo.2017.12.012
Received 12 July 2017; Received in revised form 27 November 2017; Accepted 6 December 2017

Please cite this article as: Sun, Y., Marine and Petroleum Geology (2017), https://doi.org/10.1016/j.marpetgeo.2017.12.012

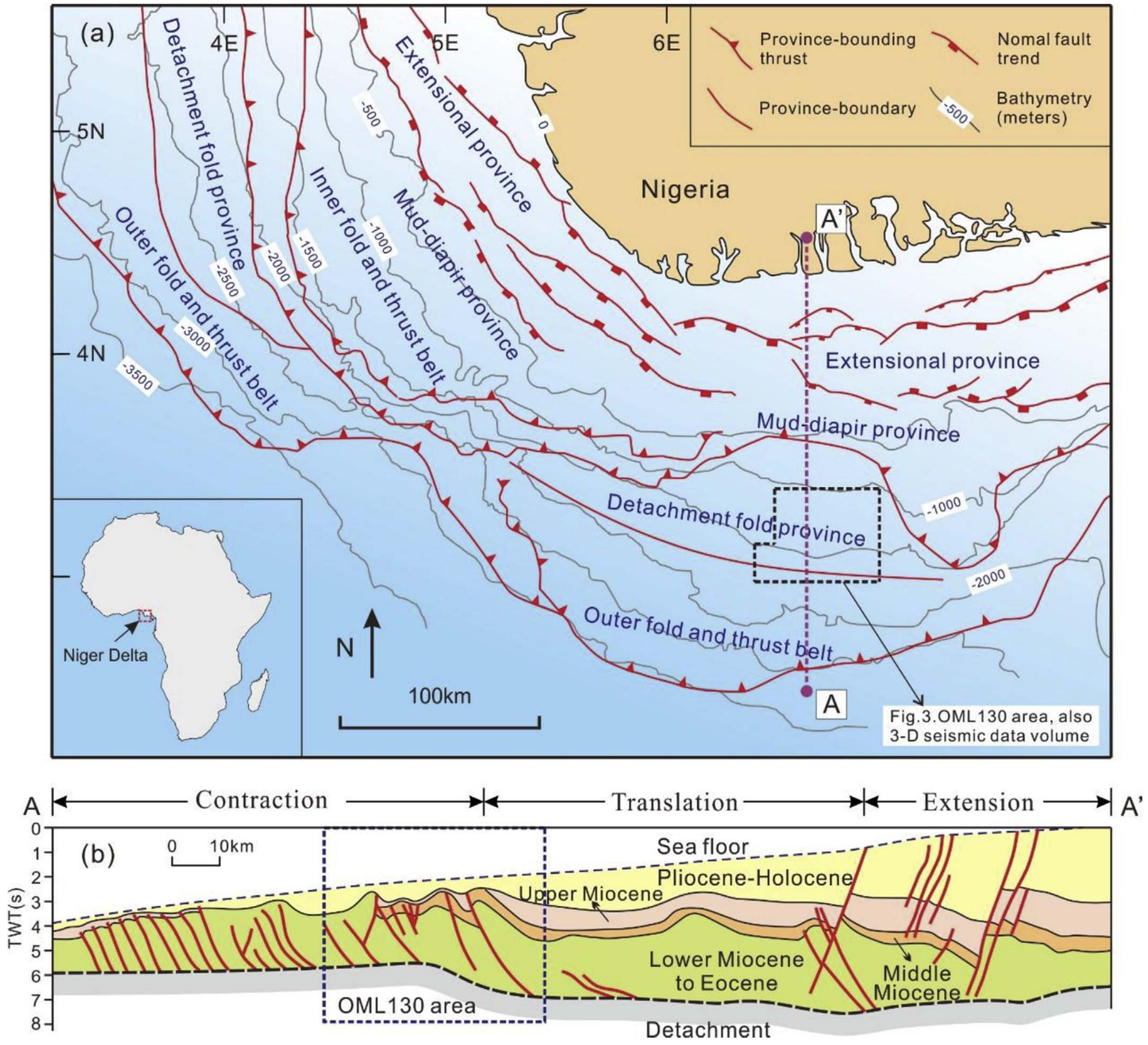


Fig. 1. A generalized map of the main structural provinces and the principal faults of the Niger Delta. A cross-section shows the stratigraphy and the deformed structures. Also shown are the locations of the OML130 area and the three-dimensional (3-D) seismic data volume used in this study (Modified from Corredor et al., 2005; Frank and John., 2005; Nathan et al., 2014; Rouby et al., 2011).

Friedrichs, 2006; Yang and Davies, 2013; Wu et al., 2015), the formation of detachments along shaley units at the bottom delta progradational sequence (Morley, 2003a; Totterdell and Krassay, 2003; Rensbergen and Morley, 2003), and an overpressurization of the shale caused by disequilibrium, tectonic stresses and hydrocarbon maturation (Morley et al., 2008a; Cobbold et al., 2004; Mourgues et al., 2009). These conclusions are supported by the results of analog modeling of gravity-driven deformation (Koyi and Vendeville, 2003; Morley and Guerin, 1996; McClay et al., 1998, 2003; Gaullier and Vendeville, 2005; Mourgues and Cobbold, 2006; Mourgues et al., 2009; Loncke et al., 2010; Cartwright et al., 2012). (3) The differential shortening in the contractional zone of the Niger Delta, particularly the outer fold-and-thrust belt, resulted in the occurrence of tear faults or oblique-thrust folds that share a common detachment level with the thrust faults (Morley, 2009a; Benesh et al., 2014). These thrust-transfer structures accommodated differential movement between the footwall and hanging wall blocks of the thrust sheets. (4) Many crestal normal faults are associated with deep-water thrust-related fold growth along the continental passive margin (Morley, 2007, 2009b; Hesse et al., 2010; Ze and Alves, 2016). The crestal normal faults dip toward the limbs of the folds and were generated by gravity-driven failure mechanisms in response to gravitational instability within the syn-kinematic sediment induced by anticline growth (Rouby and Cobbold., 1996; Morley and Leong, 2008b; Ings and Beaumont, 2010). Obviously, at present, the detailed structural evolution of the delta, which developed via gravity-driven processes, is not well understood, largely because of uncertainties related to the scarcity of data and poor seismic imaging. To represent the detailed gravity-driven structural evolution of delta stratigraphy based on structural interpretations obtained from high-quality seismic reflection data, this paper describes the geometries and kinematics of thrust-related folds and associated fault systems of the OML130 area (Fig. 1a), which is located in the detachment province of the eastern portion of the deep-water Niger Delta. We also document the progressive evolution of the thrust-related folds and demonstrate