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Syn-Sedimentary Structural Growth and Transient Fan Development in the Isongo Formation (Late Miocene), Equatorial West Africa

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Introduction

Deepwater coarse-grained clastic deposits of the Late Miocene Isongo Formation provide a unique opportunity to investigate the role of syn-sedimentary structural growth on transient fan development. Located on the continental slope of the southeastern Niger Delta, the transient Isongo Fan is characterized by: (1) A 30 km-long fan-shaped feature that thickens and widens (>20 km) to the southwest and thins and pinches out to the east; and (2) A subsequent through-going channel system that bypasses sediment downslope to the basin-floor Calabar Fan system. These patterns, summarized by Adeogba et al. (2005), have been recognized elsewhere in the Niger Delta and transient fan development has been attributed to local gradient changes due to salt diapirism and fold-and-thrust tectonics (e.g., Heiniö and Davies, 2007). This study investigates the role of a growing anticline on changes in gradient, characterized by (1) grain size and lithology, (2) sedimentary body type and distribution, and (3) temporal and spatial changes in stratigraphic architecture. Construction of a robust five-fold stratigraphic hierarchy (i.e., 2^{nd}-6^{th} order stratigraphic cycles) permits use of autogenic (*Build-Cut-Fill-Spill*, BCFS) and allogenic (*Adjustment-Initiation-Growth-Retreat*, AIGR) stratigraphic models, which reflect internal and external controls on sedimentation, respectively.

Location and tectonic controls on deposition in the Gulf of Guinea

Corredor et al. (2005) identified five structural domains in the modern Niger Delta. Extensional provinces on the shelf are kinematically linked via transitional zones to contractional inner- and outer- fold and thrust belts. In the southeastern Niger Delta, these provinces converge west of Bioko Island, resulting in compressed zones of deformation. During the Late Miocene, the Niger Delta deformation front migrated eastward across the study area; regional thrust fault propagation during the Mio-Pliocene resulted in deposition of debris-flow dominated deposits of the Intra-Qua Iboe member of the Agbada Formation (Shanmugam et al., 1997; Faminkawa et al., 1996).

Deepwater channels that cross-cut contractional features of the southeastern Niger Delta were likely sourced from the Cross River drainage system, which lies adjacent to the delta and west of the Cameroon Volcanic Line (CVL) uplift. North of the study area, the Cross River drainage may be associated with incision and development of Mio-Pliocene submarine canyons (e.g., Principe Canyon, Qua Iboe Canyon); to the south, sediment sourced from the Cross River feeds the downslope Calabar Fan system. Confinement of this drainage basin is partly due to uplift of the CVL, an onshore-offshore linear trend of volcanic edifices that extends from Lake Chad to Annobón Island in the Gulf of Guinea. Episodic volcanism and growth of Mount Cameroon, located approximately 50 km northeast of the study area along the eastern flank of the Cross River, strongly influenced the sediment-routing system in this region as well as provided a source for coarse-grained volcaniclastics. The CVL, as a whole, acted as a backstop for deformation in the southeastern Niger Delta.

Dataset and Methods

This study utilizes a variety of subsurface data to investigate controls on syn-sedimentary structural growth in the Late Miocene Isongo Formation. Detailed description of > 400m of conventional core recovered from five wells allow investigation of depositional processes and establishment of 14 hydrodynamic lithofacies, ranging from high energy coarse-grained pebbly conglomerates to pelagic organic-rich mudstones. Incorporation of wireline log responses with sedimentological observations provides a framework for petrophysical facies analysis (*sensu* Sullivan et al., 2003) and robust prediction of lithology in uncored intervals. Biostratigraphic data from 11 wells constrain the timing of deposition of the Isongo Formation and aid in correlation of intermediate-frequency stratigraphic cycles. Utilization of low-resolution 3D seismic data of the study area provides information regarding regional depositional trends and timing of syn-sedimentary structural growth relative to Mio-Pliocene deposition.

Stratigraphic Hierarchy of the Late Miocene Isongo Formation

Five temporal and spatial scales of stratigraphic cycles have been identified in Mio-Pliocene strata of equatorial West Africa. Lower, Middle, and Upper Members of the Late Miocene Isongo Formation comprise one > 4.3 million year episode of deepwater siliciclastic deposition (>650m). Third- and fourth-order stratigraphic cycles are internally defined using (1) grain size and lithology, (2) correlative organic-rich pelagic mudstone drapes, (3) biostratigraphic zonation, (4) chemostratigraphic trends, and (5) dynamic production data. High-frequency fifth- and sixth-order cycles are defined using temporal and spatial distribution of sedimentary bodies and are correlated to core-calibrated petrofacies where possible.

Allogenic and autogenic stratigraphic modeling of the Isongo Formation

Stratigraphic modeling of the Late Miocene Isongo Formation utilizes a set of nested models to describe autogenic and allogenic process-response patterns and trends. The autogenic *Build-Cut-Fill-Spill* (BCFS) model describes phases of sedimentation, denudation and migration of the channel-lobe transition zone (Gardner et al., 2008). BCFS patterns in the Isongo Fan are based on sedimentological observations and petrophysical calibration, which permit identification of sedimentary body type and distribution.

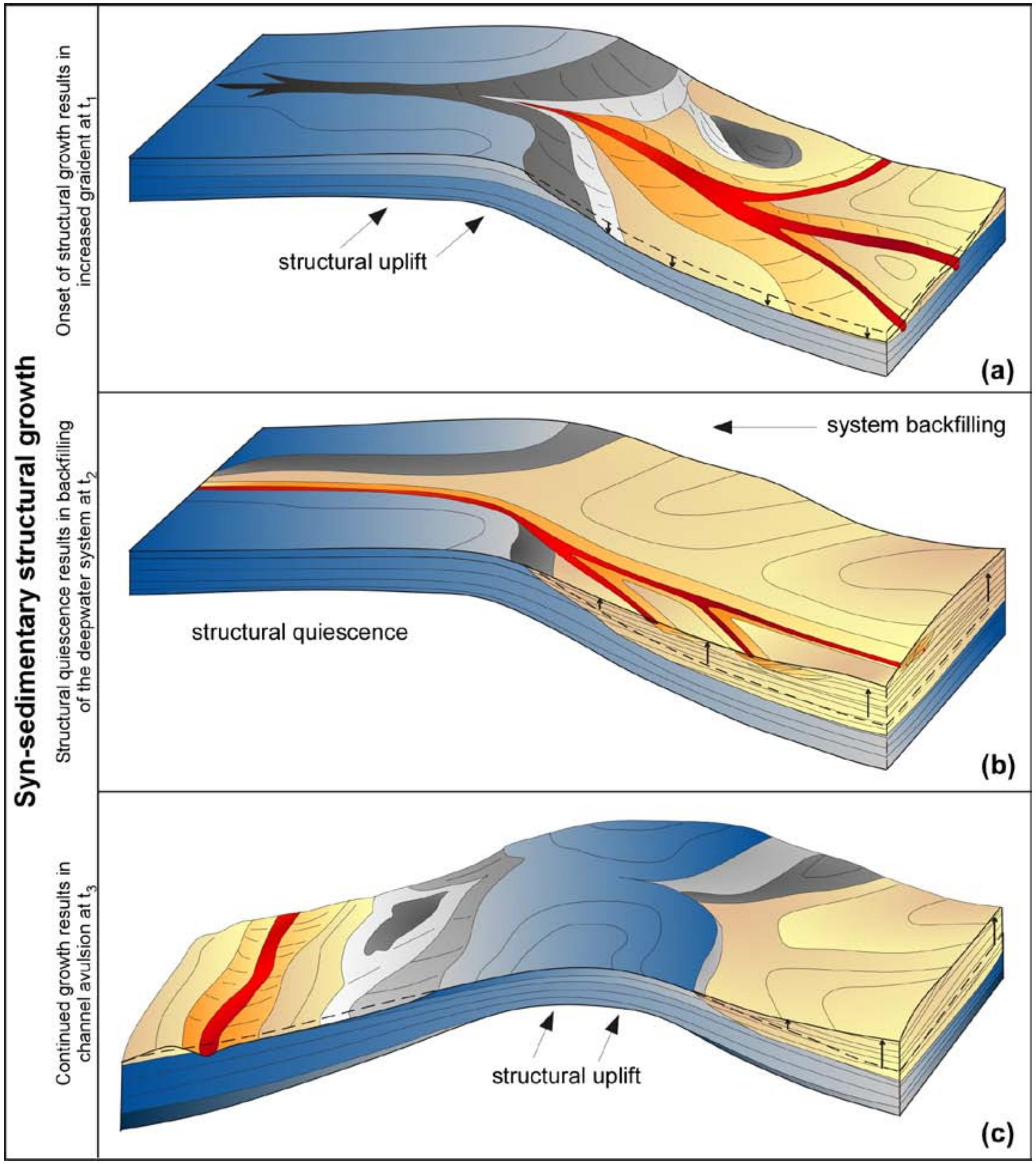
Syn-sedimentary structural growth
Onset of structural growth results in increased graident at t_1
structural uplift
(a)
Structural quiescence results in backfilling of the deepwater system at t_2
system backfilling
structural quiescence
(b)
Continued growth results in channel avulsion at t_3
structural uplift
(c)

Figure 1. Syn-sedimentary structural growth schematic. *The onset of structural growth* ***(a)*** *increases local gradient, which results in channel incision, erosion and bypass of sediment on the crest of a seafloor high and development of a transient fan system downslope. During periods of structural quiescence* ***(b)****, the system backfills through autogenic (internal) modulation of topography. Continued structural growth* ***(c)*** *may result in development of a topographic high and result in channel avulsion adjacent to the structure.*

The allogenic *Adjustment-Initiation-Growth-Retreat* (AIGR) stratigraphic model captures abrupt changes in lithology, stacking patterns and overall stratigraphic architecture representative of genetically-related deepwater packages (Gardner et al., 2008). AIGR patterns in the Isongo Formation describe phases of deep-water syn-sedimentary growth including: (1) *Adjustment* of the slope following pulses of structural growth that create seafloor topography; (2) *Initiation* of sedimentation following adjustment and beginning to heal topography; (3) *Growth* of deepwater channel complexes during structural quiescence; and (4) *Retreat* and backfilling of the deepwater system.

Impact of syn-sedimentary growth on development of the Isongo Fan

Penecontemporaneous anticlinal fold growth and deposition of the Isongo Formation is indicated by the following: (1) Development of a fan-shaped feature that thickens and widens to the southwest, subparallel to the plunging anticline axis; (2) Deposition of coarse-grained siliciclastic material in erosional slope channelforms incised into the anticline crest; and (3) Northward onlap of distributive channel and lobe deposits along the southern flank of the structure. Changes in gradient associated with pulses of structural growth govern the distribution of sedimentary bodies and an overall shift from confinement in the northwest to unconfinement in the southeast characterizes the Isongo Fan system (Figure 1).

Application of the BCFS and AIGR stratigraphic models within the context of syn-sedimentary structural growth allow development of a temporal and spatial energy matrix for Mio-Pliocene deposits of equatorial West Africa. This study demonstrates that gradient changes which produce longitudinal shelf-to-basin patterns of sedimentation in other deepwater settings (e.g., Brushy Canyon Formation in West Texas, El Rosario Formation in Baja California, Mexico, etc.) may also be characteristic of transient fan development on the southeastern Niger Delta continental slope.

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