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Amazon fluid mud impact on tide- and wave-dominated Pliocene lobes of the Orinoco Delta

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ABSTRACT

The modern Orinoco Delta is a major sink for the world's largest alongshore (littoral) mud dispersal system; it receives some 10^8 tons/yr from the Amazon river delta. The influence of these huge volumes of Amazon mud on the paleo-Orinoco Delta succession is now investigated for the first time. Abundant fluid-mud deposits are preserved in outcrops from the Pliocene Orinoco Delta deposits (Lower Morne L'Enfer, Manzanilla and Mayaro formations on Trinidad) with different styles in tide-dominated, in tide-dominated and wave-influenced, and in storm wave-dominated delta lobes. Fluid-mud deposits in sandy parasequences (10–20 m thick) of the Lower Morne L'Enfer Formation change from thin layers amalgamating to form mud bedsets (up to 4 cm) or draping across ripple laminae in the lower part, to thick layers (up to 10 cm) occasionally with deformed and load structures at their top, in the upper part. The Manzanilla Formation parasequences (30–40 m thick) exhibit coarsening-to-fining-upward (CUFU) facies successions with fluid-mud deposits located mainly in the middle to upper parts of the parasequences, near the transition between the CU and FU parts of the units. Most of the fluid-mud layers are interbedded with bi-directional, current rippled-sandstones, whereas minor mud layers are associated with erosion-based sandstones with small-scale swaley strata and bi-directional symmetrical ripples. The Mayaro Formation parasequences (5–15 m thick) are characterized by alternating fluid-mud intervals and sets of hummocky cross-stratified sandstones (HCS) passing upward into amalgamated swaley cross-stratified (SCS) sandstones. The fluid-mud intervals have flat or irregular tops occasionally overlain by amalgamated SCS sandstones with fluid-mud clasts.

Very thick (1–1.5 m) fluid-mud intervals occur in places in both tide- and wave-dominated strata and these are probably large muddy bedforms similar to mud banks that migrate currently along the modern Amazon-Orinoco coast. The outcrop analysis strongly suggests that the fluid-mud banks, as they approached the Orinoco delta-front area, were handled differently depending on whether the delta-front lobes were wave- or tide-dominated. Tide-dominated delta lobes tended to trap the muds near the shoreline and on the subaqueous delta-front platform in water depth < 10 m with only minor volumes escaping offshore. In contrast, storm wave-dominated delta lobes had a more dynamic impact on the approaching mudbanks. Mud accumulated in the shallow water tend to be eroded and re-deposited into deeper water near the storm wave base (15–50 m water depth).

The volumes of Pliocene Amazon mud transported along the innermost shelf and arriving on the Orinoco Delta were likely influenced by high-amplitude, Pliocene glacio-eustatic sea level fluctuations. During sea-level fall and lowstand periods, increased volumes of Amazon mud would have bypassed to the deep water and thus decreased mud volumes drifted and became incorporated in the Orinoco delta front. In contrast, sea-level rise and highstand periods would have promoted increased volumes of Amazon mud both on the shelf and onto the Orinoco, similar to the Holocene and modern muddy system.

1. Introduction

The modern Orinoco Delta is one of the major sinks for Amazon-derived mud (Fig. 1A) (Eisma et al., 1978; Eisma et al., 1991; Warne et al., 2002; Aslan et al., 2003; Anthony et al., 2014). Research suggests that 36–68% ($4.3–8.3 \times 10^8$ tons) of the yearly Amazon mud supply

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(Kuehl et al., 1986) are deposited on the Amazon shelf off the river mouth, 20% are being transported along the coast either in suspension (1.5×10^8 tons) or in the form of migrating mud banks (1×10^8 tons), and 20% are deposited in the Orinoco Delta and Gulf of Paria (2.5×10^8 tons), with the remainder small amount deposited on the Guianas coast (French Guiana, Suriname, and Guyana) or transported off the shelf (Eisma et al., 1978; Wells and Coleman, 1978; Eisma et al., 1991). This huge supply of Amazon mud is a significant additional sediment source to the Orinoco Delta; it accounts for at least half of the muddy sediment deposited on the Orinoco Delta (Eisma and Van der Marel, 1971; Eisma et al., 1978). Although there have been several studies on Amazon-derived mud on the Guianas coast (e.g., Rine and Ginsburg, 1985; Aslan et al., 2003; Anthony and Dolique, 2004; Wong et al., 2009), as well as on generic fluid mud in the Orinoco stratigraphy (Chen et al., 2014), there has been little research on Amazon-derived mud in the Orinoco Delta stratigraphy other than that of Peng et al. (2018).

Mud dispersal is mainly controlled by interplay of muddy sediment supply and basinal processes (tides, waves, and currents) (Walsh and Nittrouer, 2009) that result in mud distribution to variable locations on shelves as muddy coasts, nearshore/inner-shelf mud belts, mid- and outer-shelf mud belts (McCave, 1972; Hanebuth et al., 2015; Li and Schieber, 2018). Eustatic sea-level falls and rises can drive regressive and transgressive transits of shorelines, between the innermost and the outermost reaches of the pre-existing shelf, and therefore decrease and increase shelf width and accommodation for muddy sediment on the shelf. In the meantime, coastal and shallow marine processes may correspondingly shift as sea level changes. The marine processes and eustatic sea-level changes play important roles on the muddy systems and remain understudied.

The objectives of this work are (1) to provide well exposed outcrop examples of how Amazon-derived fluid-mud layers are recognized and characterized in both tide- and wave-dominated settings, (2) to show how littoral fluid mud tended to accumulate on the subaqueous platform of strongly tide-influenced delta lobes, whereas on wave-dominated lobes the mud was commonly eroded and reworked farther out into deeper settings, and (3) to suggest that the glacial-interglacial, Pliocene sea-level changes (10 s of ky duration) are likely to have affected the overall increased or decreased volumes of mud incorporated into the Orinoco during falling-stage, lowstand, transgressive, and highstand sea-level intervals.

2. Background

2.1. Fluid mud formation

The Amazon-Orinoco coastline in south America is the world's largest (1600 km) migrating muddy systems (Fig. 1A), and it shows a morphodynamic interaction with the shoreline along which it drifts. Tremendous volumes of fluid mud (10–400 g/L) (Allison et al., 1995b) that consist of mostly silt and clay are formed as the Amazon fresh water and saline Atlantic Ocean water meet (estuarine circulation) in a turbidity-maximum area due to mud coagulation and flocculation (Gibbs and Konwar, 1986) in an area 100–200 km seaward of the Amazon River mouth (Nittrouer and DeMaster, 1986; Trowbridge and Kineke, 1994; Kineke et al., 1996). The nearbed suspended fluid mud (up to 7 m thick) covers an area about 5700 km^2 during falling and low river discharge and about 10,000 km^2 during rising and high discharge on the inner and middle shelf northwest of the Amazon river mouth (Kineke and Sternberg, 1995). The cross-shelf extent of fluid mud is greater during rising and high discharge, and reaches the outer topset and upper foreset of the subaqueous clinoform at a water depth of > 35 m compared to the period of falling and low discharge (i.e., 15 m water depth on the mid-outer topset) (Kineke and Sternberg, 1995). Thick mud layers (up to 1.5 m; containing about 1.5×10^8 tons sediment) were deposited rapidly from the fluid-mud suspension before remobilization to the northwest (Allison et al., 1995b).

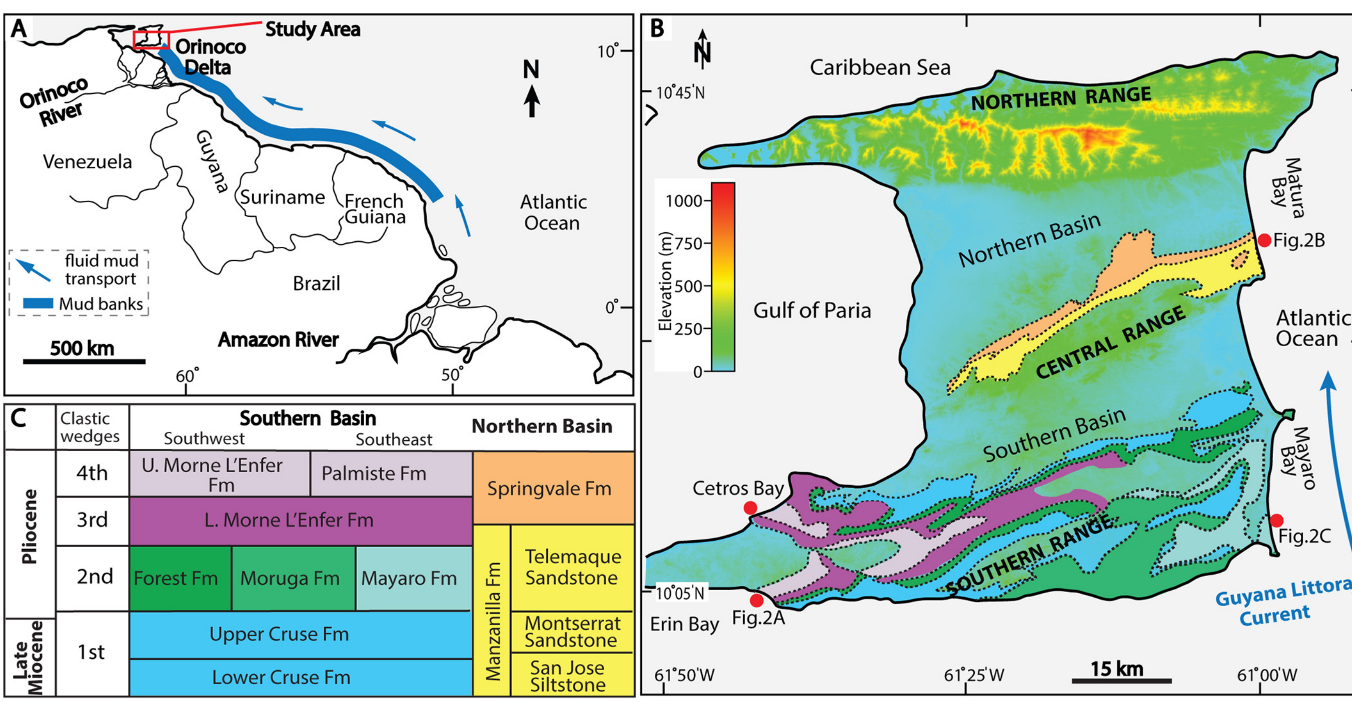

Fig. 1. (A) Sketch map of the 1600-km muddy Amazon-Orinoco coast in South America. The blue bold line indicates the zone of mud banks and the blue arrows indicate fluid mud transport direction. (B) Geologic map of Trinidad showing the late Miocene-Pliocene Orinoco deltaic to deep-water deposits in the Northern and Southern Basins of Trinidad. The island of Trinidad was plotted with the DEM elevation to emphasize the main mountain ranges using the NASA's Shuttle Radar Topography Mission (SRTM) Version 3.0 data. Red dots indicate the locations of all studied outcrops which includes locations of the three selected successions in Fig. 2A–C. (C) Stratigraphic column for the four clastic wedges and tentative correlation between the formations of the Northern and Southern Basins. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)