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Tide-dominated deltas in active margin basins: Insights from the Guayas estuary, Gulf of Guayaquil, Ecuador

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ABSTRACT

The Gulf of Guayaquil, Southern Ecuador, is the largest tidal system of the Pacific margin of South America. The incipient oceanic tide has a tidal range of over 1 m and is amplified on the continental shelf, which is widened in this area by the tectonic activity related to the northward escape of the North Andean Block. The head of this embayment connects to the Guayas River, roughly running along the dextral strike-slip fault bounding the North Andean Block. The Guayas River connects to the Gulf of Guayaquil through a tide-dominated delta, the supratidal part of which is composed of mangroves drained by a network of tidal channels. The river channels merge into the Jambelí Channel, a subtidal valley forming the main distributary channel of the delta. Very high resolution seismic profiles collected at the junction between the Jambelí Channel and the Gulf of Guayaquil show the architecture of several depositional sequences preserved in the first 0.1 s twt beneath the sea bed. These sequences mainly consist of a lowstand to transgressive systems tract comprised of fluvial to estuarine channels topped by a highstand systems tract of prodeltaic muds. The progradational muds volumetrically dominate the stratigraphic record and characterize the Guayas delta facies. By contrast, the near bed features close to the mouth of Jambelí Channel show the present dominance of tidal scour, forming hollows up to 50 m deeper than the surrounding area, reworking the underlying deposits and forming levees or, inside the subtidal valley, tidal ridges. The prodeltaic muds may reach and cover the tidal scour hollows during the late highstand only, in favor of a damping of tides due to the reduction of the tidal prism caused by the advance of the Guayas delta. The sequences preserved in the outer part of Jambelí Channel pinch out toward a hinge line located along the Puná - Santa Clara fault system. This fault system is responsible of the uplift and emergence of a topographic barrier at the entrance of the Jambelí Channel. As a result, the Estero Salado was progressively disconnected from the Gulf and the tidal flows were concentrated in the Jambelí Channel, bringing about tidal scour hollows. In the meantime, the tidal prism was maintained and subsidence took place in a sub-basin located landward of the uplifting barrier. This caused the Jambelí Channel to remain subtidal during most of the past sea-level highstands, in spite of the large amount of sediment supplied by the Guayas River.

1. Introduction

Tide-dominated depositional systems are rare in active margin basins, as compared to their counterparts along passive margins or in foreland basins (see review in Reynaud and Dalrymple, 2012). This is mostly because the continental shelf along active margins is too narrow to permit tidal resonance to develop and therefore embayments within which the oceanic tide can be amplified (Pugh, 1987; Dalrymple and Padman, 2018). Conversely, the coasts of active margins are generally wave-dominated because there is a lesser dissipation of wave energy on the shelf than on wider, passive margins. As a consequence, fluvial- or wave-dominated systems are expected to occur in coastal areas of active margins. A few exceptions are noted along subduction margins dissected into coastal ranges and fore-arc basins (e.g. New Zealand: Kamp et al., 1988; Anastas et al., 1997) or along transform margins (e.g. Alaska: Galloway, 1976; California: Hoppie, 1996). In those cases, the basins commonly comprise narrow seaways or embayments with linear subtidal ridges and tidal flats in coastal areas (e.g. the California Gulf: Meckel, 1975; Thompson, 1968).

Structural embayments that formed across tectonically active margins are propitious to the funneling of the tide and, in the meantime, they may be privileged pathways for the routing of sediments from the margin hinterland to the deep sea. Therefore, large deltas are expected to occur at the head of those embayments. Because active margins are

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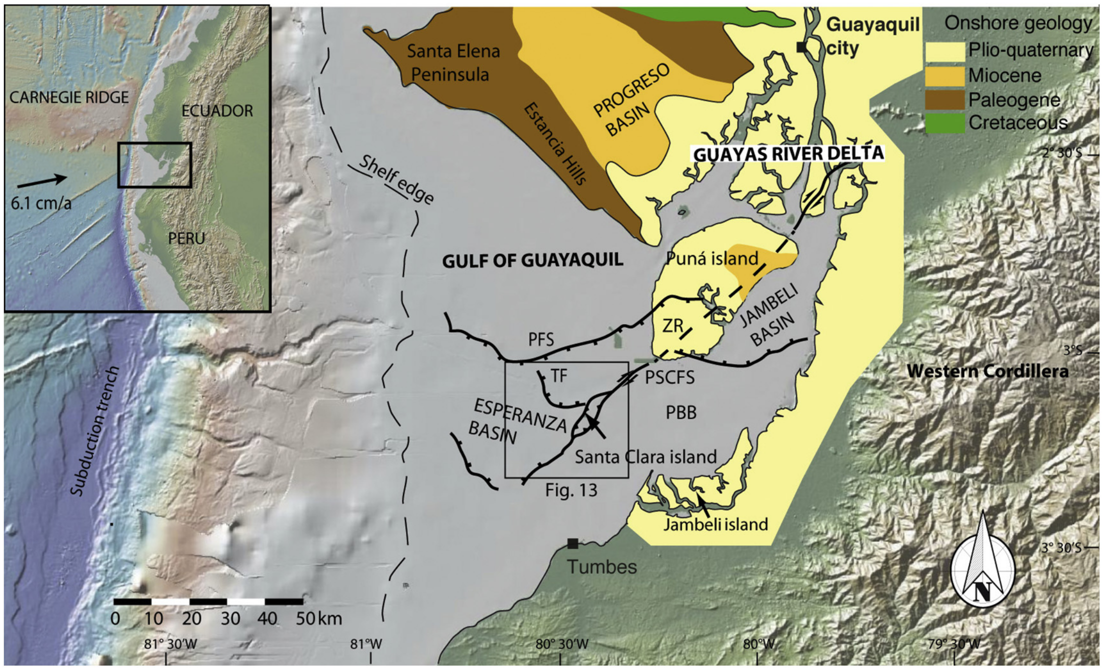

Fig. 1. The Gulf of Guayaquil and Guayas River in the Southern Ecuadorian margin. Simplified onshore geological map modified from Baldock (1985) and main offshore tectonic structures, simplified from Witt and Bourgois (2010). PBB- Puerto Bolivar Block; TF- Tenguel Fault; PSCFS- Punta Santa Clara Fault System; ZR- Zampabala Range; PFS- Posorja Fault System.

characterized by fast vertical tectonics, the subsiding areas of those embayments may provide ideal conditions to study the geomorphic and stratigraphic expression of the fluvial-tidal transition (Dalrymple and Choi, 2007). This part of the depositional system is of economic importance, especially in petroleum geology, due to the reconsideration of heterolithic facies and permeability barriers in reservoirs (e.g. Musial et al., 2012).

Thus, the location of the Gulf of Guayaquil at the junction between a major tidal system and a large river in the active margin of Southwestern Ecuador (Fig. 1) points it as a prime study area for tidal sedimentologists. Surprisingly, while the Gulf of Guayaquil is a petroleum province (Higley, 2004), this manuscript might be the first attempt to explore its sedimentary dynamics as a whole, in the perspective of its evolution in the late Neogene and Quaternary. Landward from the Gulf, the Guayas River basin extends over an area of about 10,000 km^2 of marshes, tidal flats and channel networks (Fig. 2). This domain is mesotidal over its total length up to the city of Guayaquil, ~100 km inland. Although the management of this sensitive area is vital for the development of the city, the most populated in Ecuador, little is known about the present-day sedimentary dynamics and recent evolution of the tidal coastal plain (Twilley et al., 2001), or offshore area of the gulf (Benites Acosta, 1975).

After an overview of the characteristics of the Guayas tidal system, this article focuses on the dynamics and evolution of its outer part, based on a set of very high resolution seismic profiles collected by INOCAR (the Ecuadorian Oceanographic National Institute). A selection of these profiles is presented and analyzed, in order to: 1) define and interpret the sediment facies and stratigraphic architecture present at the seabed or in the near subsurface and 2) set up a stratigraphic model of the last Quaternary depositional sequences. The results are discussed in the light of the fast tectonic evolution of the area, showing the interplay between tidal erosion and deltaic progradation.

2. Regional setting

2.1. The Gulf of Guayaquil

The Gulf of Guayaquil, at the boundary between Ecuador and Peru, is a triangular embayment of the continental shelf (Fig. 1). It developed during the Plio-Quaternary in a forearc context (Deniaud et al., 1999; Witt et al., 2006), in a highly subsiding area located above a complex fault system that accommodates the dextral strike-slip motion related to the escape of the North Andean Block (most probably accelerated in the Quaternary by the subduction of the Carnegie Ridge, Fig. 1, inset; Witt et al., 2006; Michaud et al., 2009; Egbue and Kellogg, 2010; Alvarado et al., 2016; Yepes et al., 2016). The Gulf of Guayaquil, 13,000 km^2 in size, is bounded to the west by the shelf break, in 180 m water depth, to the north by the Santa Elena Peninsula, and to the south by the Tumbes onshore basin Fig. 1). The submarine topography of the shelf in the Gulf of Guayaquil is almost flat, with a regularly decreasing depth toward the coast (Michaud et al., 2006). The Peninsula coast is wave dominated, half of it composed by active cliffs fronted by dominantly steep beaches (Dumont et al., 2014). The Tumbes coast also has active cliffs, intersected by small river-dominated deltas such as that of the Tumbes River. The apex of the Gulf, to the East, connects to the Guayas River area, the largest tidal coastal system of the Pacific coast of South America (Twilley et al., 2001).

2.2. The Guayas coastal area

The Guayas River, the most important of Ecuador with an annual runoff of 1350 m^3/s in average (Twilley et al., 2001), forms at the confluence of two meandering rivers, Daule and Babahoyo (Fig. 2). To the south of Guayaquil city, the Guayas River has a main, straight trunk channel which bifurcates into an anastomosed network of river channels running through 30 km of mangroves and tidal flats also drained by numerous tidal channels. The tidal flats and salt marshes cover a total area of about 4000 km^2 over the entire Guayas area (Fig. 2). The largest tidal channel in this area, the Estero Salado (Fig. 2), 40 km long, 15 km wide and 12 m deep on average, is a remnant of a former distributary