Marine and Petroleum Geology 64 (2015) 76–103

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Review article

Tectonics and sedimentation interactions in the east Caribbean subduction zone: An overview from the Orinoco delta and the Barbados accretionary prism

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ARTICLE INFO

Article history:
Received 29 April 2013
Received in revised form
24 December 2014
Accepted 29 December 2014
Available online 23 February 2015

Keywords:
Turbidite system
Active margin
Orinoco
Barbados

ABSTRACT

The interactions between the sand-rich Orinoco turbidite system and the compressional structures of the Barbados prism have been active since Eocene time as illustrated by the study of outcrops onshore Barbados Island. Because of strong morphologic and tectonic control, the present-day Orinoco turbiditic pattern system does not exhibit a classic fan geometry. The sea-floor geometry between the slope of the front of the Barbados prism and the slope of the South-American margin induces the convergence of the turbidite channels toward the abyssal plain, at the front of the accretionary prism. Whereas in most passive margins the turbidite systems are organized upstream to downstream as canyon, channel-levee and lobes, here, due to the tectonic control, it is organized as channel-levee, canyons and channelized lobes. At the edge of the Orinoco platform, the system has multiple sources with several distributaries and downstream the channel courses are complex with frequent convergences or divergences. While erosion processes are almost absent on the highly subsiding Orinoco platform and in the upper part of the turbidite system, they develop mostly between 2000 and 4000 m of water depth, above the Barbados prism. In the abyssal plain, the main turbiditic channel develops toward the east and connects with the Vidal mid-Atlantic channel. The sediments transported in this channel are filling elongated basins linked with fracture zones (notably the Barracuda Basin), and finally end their course in the Puerto-Rico trench. The turbidite sediments above the accretionary prism and in the abyssal plain are mostly coarse sandy deposits covered by recent pelagic planktonic-rich sediments. Stratigraphic modelling suggests that during the last glacial event, the main depocentres were located in the abyssal plain and that, during the Holocene eustatic rise, a large accommodation space formed on the shelf confining sedimentation mostly on the Orinoco platform.

1. Introduction

Main offshore deltas and deep-sea fans on passive margins (Mississippi, MacKenzie, Amazon, Rio de la Plata, Niger, Nile, Congo, Zambeze, Mahakam, Ob, Yangtse, …) are characterized by upstream sources of siliciclastic sediments resulting from onshore erosional processes, the location of which is globally more or less constant over long periods of time (several tens of Ma). They are also commonly characterized by deep marine erosion processes at the border of the platform incising the shelf-edge (canyons), by a divergent channel-levees turbidite system along the continental slope (deep-sea fans), and by the deposition of sediments as lobes in the abyssal plain. This classical scheme is not anymore valid in active margin context (Orinoco, Magdalena, Indus, Gange, …). In

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http://dx.doi.org/10.1016/j.marpetgeo.2014.12.015

this case, the deposition system is controlled by several additional parameters including extensive migration of the main source of siliciclastic input during time, high subsidence rates on the platform, tectonic mobility of the topography of active margins and progressive deformation of sediments within the accretionary prism and sometimes within the abyssal plain ahead of the accretionary prism. Thereby, a major difference between deep sea fan systems of tectonically active margins and their analogues of passive margins is the high versatility of their architecture due to the progressive deformation processes that drastically influences the location of the depocentres, and the nature and geometry of the deposition system. Notably, several points remain poorly understood in turbidite systems deposited on mobile substratum of tectonically active margins, like the global evolution of the sedimentary systems during the migration of the deformations, the sedimentary implications of the dynamic physiography resulting in a system much more complex than a classical fan, and the processes of sedimentation/erosion in the deep sea area incising the tectonic structures. Only few published works describe the deposition systems, the spatial distribution and the geometry of the turbidite reservoirs in tectonically active context. Also, only few explanations have been published about the fact that these tectonically active systems are less prone to develop canyons at the shelf-edge (Orinoco, Magdalena, MacKenzie; Callec et al., 2010; Ercilla et al., 2002). Deep water erosional processes of the tectonic structures are also poorly understood (Mascle et al., 1990; Deville et al., 2003a,b; Huyghe et al., 2004). No specific work have been published concerning the sedimentary and tectonic processes responsible for the progressive incorporation of turbidite sediments inside the accretionary prisms and where should we expect to find good turbiditic reservoir inside the accretionary wedge.

In sand-rich tectonically active systems, previous works have shown punctually that sand rich-deposits can be scattered in piggyback basins on top of the accretionary prism or in the abyssal plain (Faugères et al., 1991; Callec et al., 2010) but no available work provides a large scale understanding of the general distribution of sand-rich deposits.

Tectonics and sedimentation processes in a tectonically active area are well illustrated in the zone of interaction between the Orinoco siliciclastic deposition system and the deformation structures associated with the east Caribbean active margin. The Orinoco detrital system develops over a distance of several thousand kilometres, from 3 major South American topographic highs (Guyana Shield in Venezuela, Western Cordillera of Colombia and Merida Andes culminating at Pico Bolivar 4978 m) to the deepest point of the Atlantic Ocean, the Milwaukee deep (−8385 m), in the Puerto Rico Trench (Fig. 1). Onshore, this siliciclastic system develops mostly in the Andean belt and the Caribbean costal belt and their foreland, whereas, offshore, the turbidite system issued from the Orinoco delta is closely tectonically controlled by the deformation processes of both the Barbados accretionary prism and the diffuse plate boundary between North and South America in the Atlantic abyssal plains. Former papers gave local illustrations of some of these processes at the connection between the turbidite system of the Orinoco delta and the Barbados accretionary prism (Biju-Duval et al., 1982; Brown and Westbrook, 1987; Mascle et al., 1990; Faugères et al., 1991; Huyghe et al., 1996, 1999, 2004; Deville et al., 2003a,b; Callec et al., 2010; Patriat et al., 2011; Pichot et al., 2012). The objectives of this paper is to provide a comparison between a fossil system preserved inside the tectonic prism and the active modern system and to provide information of how tectonics controls sedimentation in an active margin and how it controls the incorporation of the sand-rich sediments inside the accretionary wedge. This approach was made in order to provide a better understanding of spatial and temporal variations in geometry and lithofacies organization of reservoir quality sediments in the accretionary complex. For this, we made an integration of partly published data but also unpublished data acquired both offshore and onshore. Finally, stratigraphic modelling is proposed to try to understand better the large scale sedimentary processes.

2. Geological setting

From a geodynamic point of view, the region corresponds to the triple junction area between (1) the North American plate, (2) the South American plate and (3) the Caribbean plate (Fig. 1). It is characterized by complex and multidirectional recent deformations distributed throughout the area. The two American plates are involved into the westward subduction beneath the east Caribbean active margin (Fig. 1). This active subduction is associated with significant seismicity under the volcanic arc of the Lesser Antilles. The seismicity associated with the East Caribbean margin is notably highlighting the geometry of the subduction of the Atlantic oceanic lithosphere beneath the Caribbean plate (Fig. 2). Earthquakes located near the plate boundary are deepening westward to more than 150 km under the volcanic arc of the Lesser Antilles (Fig. 2). North of the active margin, the subduction slab is continuous and extends far to the west below Puerto Rico (Fig. 1). South of the active margin, the seismicity shows that the subduction slab sinks below the island of Trinidad and the Paria Peninsula in north-eastern Venezuela and stops south of the Orinoco Delta Fault Zone (Deville and Mascle, 2012). Earthquakes are expressed in both, the upper plate in the volcanic arc, and also in the subducted slab (Fig. 2). The Barbados accretionary prism, meanwhile, is almost aseismic. The latest GPS studies (Demets, 2000; Weber et al., 2000; Jansma et al., 2000; Calais et al., 2002; Mann et al., 2002) showed that the Caribbean plate is moving east–northeast in the direction N70° at a speed of 20 ± 3 mm/a with respect to the North American plate (Fig. 1). Convergence associated with the subduction below the Lesser Antilles volcanic arc caused the deformation of the sedimentary pile and the formation of the Barbados accretionary prism which is one of the largest accretionary wedges in the world (Westbrook, 1975, 1982; Stride et al., 1982; Westbrook et al., 1982, 1984, 1988; Biju-Duval et al., 1982, 1984; Westbrook and Smith, 1983; Mascle et al., 1988; Mascle and Moore, 1990; Henry et al., 1990; Deville and Mascle, 2012).

In the Atlantic domain, the deformations associated with the relative motion between the North America and South America plates are distributed over a large domain (several hundreds of kilometres from north to south). The rare and diffuse seismicity associated with uncharacteristic bathymetric features is still a source of misunderstanding concerning the exact location of the plate boundary between South America and North America. However, the kinematic models have demonstrated quite early the existence of this border (Minster and Jordan, 1978; Roest and Collette, 1986; Klitgord and Schouten, 1986; Campan, 1995; Gordon, 1998). These deformations are well expressed in the area between the Fifteen–Twenty transform fracture zone to the north and the Marathon fracture zone to the South (Roest and Collette, 1986; Roest, 1987; Sumner and Westbrook, 2001; Pichot et al., 2012; Fig. 1). In this wide deformation zone, the oceanic lithosphere is characterized by a system of transform fracture zones partly recently re-activated and locally associated with recent folds trending WNW–ESE. We observe in particular, in this area, different sea floor highs associated with the relative movements between North and South America, the most noticeable being the Barracuda ridge, the Tiburon rise and the Researcher ridge (Birch, 1970; Brown and Westbrook, 1987; Patriat et al., 2011; Pichot et al., 2012; Fig. 1).