Marine and Petroleum Geology 68 (2015) 307–324

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Morphology of submarine canyons along the continental margin of the Potiguar Basin, NE Brazil

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ARTICLE INFO

Article history:
Received 19 February 2015
Received in revised form
28 August 2015
Accepted 29 August 2015
Available online 2 September 2015

Keywords:
Submarine canyon
Continental slope
Morphology
NE Brazilian margin

ABSTRACT

New insights into equatorial slope morphology were acquired through analysis of the continental margin of the Potiguar Basin (NE Brazil). In this paper, we present the first full data coverage of the seafloor between the upper and middle continental slopes (100–1300 m) adjacent to the Brazilian equatorial margin, developed using multibeam bathymetric data. Some of the submarine canyons mapped in this study have wall gradients greater than 35°. Wide (~1700 km) and deep (~250 m) incisions are present on the continental slope and can be linked to incised valleys that are underfilled or incised only on the outer shelf at depths up to 60 m. Two different types of canyons were identified. Canyons of one type are characterized by heads that indent the shelf edge, association with incised valleys and large fluvial systems, high sinuosity, 'V' shapes, and terraces along margins, in addition to erosive features such as landslides and gullies. These characteristics suggest that canyons of this type are associated with the deposition of submarine fan systems, which are considered permeable hydrocarbon reservoirs, on the base of the continental slope. The presence of gullies and sediment waves illustrates the role of bottom currents in the shaping of the slope. The enlargement of the canyons in the study area and the changes in their courses where they cross an important fault suggest that tectonic activity has probably also influenced the morphology of the deep-water environments of the Potiguar Basin. The results of this study constitute initial steps in describing and understanding submarine canyons as part of the equatorial continental Brazilian margin.

1. Introduction

Submarine canyons, which are significant morphological features on the continental slope (Pratson et al., 2007), incise most of the edges of the world's continental margins (Shepard, 1972; Shepard and Dill, 1966) and commonly reflect the structural control on the active margins (Carlson and Karl, 1988; Mountjoy et al., 2009). Furthermore, investigations of submarine canyon geomorphology may support the installation of cables and pipelines, as well as naval submarine operations (Piper, 2005; Piper et al., 1999).

Submarine canyons are important conduits able to transport large amounts of sediment from the continental shelf to the abyssal plain via gravity flows (Gardner, 1989; Shepard and Dill, 1966). Submarine fans, which are fan-shaped or lobate deposits located in front of submarine canyons or channels, have been studied in detail as analogues for ancient deposits of economic significance (Clark et al., 1992; Walker, 1992; Weimer and Slatt, 2004). According to Normark (1970) and Shepard (1972), submarine fans are considered to be formed primarily by turbidity currents that originate from a point source, forming turbidites that are the main reservoirs of the giant oil fields of the world (Bouma et al., 1985; Weimer and Link, 1991; Weimer and Slatt, 2004). The general characteristics of the depositional lobes of submarine fans include the following: (1) they are considered to develop at or near the mouths of submarine-fan channels analogous to distributary mouth bars in deltaic systems; (2) they do not exhibit basal channelling; (3) they usually display upward-thickening depositional cycles composed of classic turbidites; and (4) they exhibit sheetlike geometries (Mutti and Ricci Lucchi, 1978).

Some submarine canyons in the Brazilian Continental Margin have been studied previously. Prominent examples are the Amazon Canyon, the São Francisco Canyon, the Salvador Canyon, and the

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http://dx.doi.org/10.1016/j.marpetgeo.2015.08.035
0264-8172/

canyons of the Campos Basin (e.g., Dominguez et al., 2013; Martins and Coutinho, 1981; Viana and Rebesco, 2007). The Amazon Canyon formed as a result of mass failures that were modified by subsequent erosion due to turbidity currents (Damuth and Kumar, 1975). The associated fan provides examples of the large, sinuous, leveed valleys that are common on delta-fed submarine fans (Normark and Carlson, 2003). The submarine canyons in the Campos Basin have an average depth of 300 m and an average width of 8000 m (Kowsmann et al., 2002; Viana et al., 1998; Viana and Rebesco, 2007).

Despite the extensive shallow-water oil exploration that has been conducted in this area since the 1970s and the recent discovery of oil deposits in the deep waters of the Potiguar Basin (PETROBRAS, 2013), almost no data on the seabed morphology of deeper regions of this margin have been published. This type of data is essential to the characterisation of geohazards (e.g., Chiocci and Cattaneo, 2011). For example, submarine landslides, one of the most destructive types of geohazards, pose significant risks to pipelines and seabed installations. Deep-water pipelines are often laid on the seabed without pre-trenching or cover, which exposes them directly to debris flows (Yuan et al., 2012).

Therefore, it is important to have a good understanding of the seabed, including the geomorphology of submarine canyons, to avoid the installation of submarine structures at unstable locations, to optimise environmental management, and to determine the existence of deposits of economic importance, such as turbidites and contourites.

To address the lack of information on submarine canyons along the continental margin of the Potiguar Basin off the coast of northeastern Brazil, we performed a multibeam bathymetry sonar survey to map these seafloor features (Fig. 1). The selection of the area was related to the presence of two incised valley systems (Apodi-Mossoró and Açu) of the Potiguar Basin. They are called 'incised valleys' because the ancient Apodi-Mossoró River (Lima and Vital, 2006; Vital et al., 2010a) and Açu River (Gomes et al., 2015b; Schwarzer et al., 2006) cut the shelf deposits, forming valleys that are now represented by cut and fill features. These processes are indicative of an erosional surface during lowstand conditions. Gomes et al. (2014) suggest that these incised valley morphologies are directly associated with the geomorphic response to tectonic activity that occurred when faults reshaped the pre-Holocene coast and shelf domains.

In this paper, we provide the first detailed picture of the continental slope adjacent to the Potiguar Basin of northeastern Brazil by presenting the most complete and highest-resolution bathymetric dataset available for the region. The objectives of this study were the following: (1) to provide the first characterisation and analysis of the continental slope morphology of the Potiguar Basin (Fig. 1), focusing on the submarine canyons; and (2) to reconstruct the main shaping processes along the mapped canyons.

We analysed the morphometric characteristics of the submarine canyons and sedimentary features, and in this paper, we discuss the processes involved in their evolution, the controlling factors, and recent sedimentary activity. The results of this study contribute to the understanding of the transport pathways of sediments from the shelf to the deep basin and provide a morphological framework for detailed future research.

2. Geological setting

The South Atlantic opening occurred during the Early Cretaceous (Neocomian– Barremian), whereas the opening in the Equatorial Atlantic occurred later (Aptian–Albian) (Asmus and Porto, 1972; Szatmari et al., 1987). The separation of the Pangaea Supercontinent resulted in the formation of the Brazilian Cretaceous Rift System, forming passive continental margins and the Brazilian marginal basins (Matos, 1999, 2000).

The study area is located in the pull-apart Mesozoic–Cenozoic Potiguar Basin of the Brazilian Equatorial passive margin. The Potiguar Basin has three stages of evolution: rift (Neocamian–Eo–Aptian), post-rift (Neoaptian–Eo–Albian), and continental drift (Albian–Holocene) stages (Bertani et al., 1990). The rift, post-rift, and continental drift stages are characterised by continental, transitional, and marine megasequence deposits, respectively (Matos, 1992).

According to Matos (1992), the basin is controlled by basement faults. East–west-oriented strike–slip faults were reactivated as normal faults in a compressive regime, according to breakout and focal mechanism data that indicate the magnitude of the maximum horizontal E–W stress (Assumpção, 1992; Bezerra et al., 2007, 2011; Castro et al., 2012; Ferreira et al., 1998; Gomes et al., 2014; Reis et al., 2013). Bezerra et al. (1998) identified neotectonic events that affected the quaternary rocks.

With respect to the oceanographic setting, trade winds arise in the E–NE, attaining a maximum velocity of 18 m/s (Vital et al., 2010b). The semi-diurnal mesotidal regime dominates, with a maximum spring tide range of 3.3 m and a minimum range of 1.2 m during neap tides (Vital et al., 2010b). The North Brazilian Current flows in a direction relatively parallel to the coast (W–NW). The bottom currents, which reach velocities of 30–40 cm/s on the shelf, are overlain by tidal and wave components (Knoppers et al., 1999; Vital, 2009).

The submerged portion of the Potiguar Basin is composed of mixed carbonate–siliciclastic deposits (Gomes et al., 2015a; Vital et al., 2008), and the shelf physiography is partitioned as an inner, a middle, and an outer shelf (Gomes and Vital, 2010). Several morphological seafloor features have been identified, such as sediment waves, isolated shallow marine sandy bodies, patches of coral reefs, beachrocks, and incised valleys (Lima and Vital, 2006; Schwarzer et al., 2006; Testa and Bosence, 1998, 1999; Vital et al., 2008, 2010a).

The earliest evidence of the shelf submarine incisions associated with the Açu and Apodi-Mossoró Rivers were reported by Pessoa Neto (2003). These rivers were exposed on the continental shelf, acting as a source of the siliciclastic influx and its distribution in the shelf and slope. According to (Pessoa Neto, 2003), incisions were active on the shelf during the Miocene, as demonstrated by the occurrence of coastal clastic wedges on the seismic sections and the well samples.

Lima and Vital (2006) studied the evolution of the Apodi-Mossoró Valley during the Pleistocene–Holocene. During the Pleistocene, the continental shelf was exposed, and the valley was formed. This channel was partially buried during the sea level rise that occurred during the Holocene. These authors identified tectonic activities in the Apodi-Mossoró Valley, suggesting the uplift of this shelf portion.

The main river systems of study area are the Açu River and Apodi-Mossoró River. The Açu River is an intermittent river in natural conditions. However, the continuity of its flow is ensured by two built reservoirs. It is 405 km long and reaches a drainage area of almost 44,000 km^2 (AESA, 2011; CBHPA, 2011). Its flow discharge and velocity reach 434 m^3/s and 0.6 m/s, respectively (Soares, 2012). The Apodi-Mossoró River is the second most important river in the study area. It is 220 km long, ~80 km wide, and reaches a drainage area of 14,270 km^2 (Maia and Bezerra, 2013). The climate of the area varies from tropical dry to semi-arid (Vital et al., 2010b).

3. Dataset and methods

High-resolution bathymetry data were collected along the study