Marine and Petroleum Geology 57 (2014) 294–311

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Seismic geomorphological analysis of deepwater gravity-driven deposits on a slope system of the southern Colombian Caribbean margin

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ARTICLE INFO

Article history:
Received 2 September 2013
Received in revised form
28 May 2014
Accepted 4 June 2014
Available online 16 June 2014

Keywords:
Caribbean margin
Seismic attributes
Seismic geomorphology
Mass-transport deposits
Deepwater deposits
Diapirs

ABSTRACT

Gravity-driven processes are important agents for transporting sediments downslope into deep-marine environments. The Pliocene to Holocene offshore succession of the Colombian Caribbean margin and its stratigraphic distribution, have been affected by faulting and mud diapirism, and have been characterized using 3D seismic data. Nine stratigraphic intervals were characterized within the study, and are interpreted to consist of a range of seismic geomorphologies, including slumps and debrites. Nine gravity-driven deposits were defined within the study area, interpreted to have been transported to the north and northwest. Slumps display high-amplitude, high continuity, elongated, stratified, lobate and confined morphologies, while debrites have a reflection-free pattern or show discontinuous, low-amplitude and chaotic reflections. Mixed slumps-turbidites-debrites deposits are composed by a succession of laterally and vertically interfingered slumps, debrites and turbidites. These deposits are morphologically lobate and broadly scattered. In addition, erosional features such as basal small scours, megascours, linear scours and rafted blocks were used as kinematic indicators within the gravity-driven deposits. There are several candidates triggering mechanism, including over-steepening of slope (related to high sediment supply or slope tectonism). In the study area, confined slumps and debrites with a main transport direction from south to north have been observed, while transport direction of the mixed slumps-turbidites-debrites was toward northwest. Additionally, the fact that slumps and debrites are found in depocenters between periclines suggests a confined environment of deposition. Finally, mixed slumps-turbidites-debrites are unconfined without evident structural control. We suggest that local intraslope sub-basin margin become over-steepened as a result of mud diapirism in the subsurface. In this situation, the paleobathymetry was sufficient to trap the resultant gravity-driven deposits within the sub-basins, suggesting a local origin. Seismic evidence of BSR (Bottom Simulating Reflector) suggests the presence of gas hydrate in the study area, and is taken as an additional potential mechanism to provide instability of slope and generate gravity-driven deposits.

1. Introduction

Submarine slope failures are an important mechanism in shaping and moving vast quantities of sediment down continental slope on both active and passive margins (Goldfinger et al., 2000; McAdoo et al., 2000; Urgeles et al., 1997; Richardson et al., 2011; Norem et al., 1990; Masson et al., 1998; Gee et al., 2005, 2006, 2008) and at all latitudes, from glacial to equatorial regions (Alves, 2010a,b; Hünerbach and Masson, 2004; Laberg et al., 2000; McAdoo et al., 2000). These processes have been classified according to: nature of material, nature of movement, sediment concentration, fluid rheology, flow state, geometry and scale (Dott, 1963; Nardin et al., 1979; Moscardelli et al., 2006; Shanmugam, 2006; Moscardelli and Wood, 2007). Normally, submarine slopes are frequently composed of gravity-driven deposits (Mienert et al., 2003; Maslin et al., 2004; Newton et al., 2004; Fowler et al., 2004; Hünerbach et al., 2004; Talling et al., 2007; Hjelstuen et al., 2007; Madof et al., 2009). The causes of such intense gravity-driven sedimentation on the continental slopes include relative base level changes and syn-sedimentary tectonics causing mud

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http://dx.doi.org/10.1016/j.marpetgeo.2014.06.002
0264-8172/

diapirism which results in the creation of inter- and intra-basinal bathymetry (McGilvery and Cook, 2003).

The morphology of the Colombian Caribbean margin and its sedimentation patterns have been studied since the fifties by Heezen (1956); Duque-Caro (1978, 1979, 1980, 1984, 1990, 1997); Hoover and Bebout (1985); Vernette (1989); Pujos and Javelaud (1991); Villamil (1999); Ercilla et al. (2002); Flinch (2003); Flinch et al. (2003); Estrada et al. (2005a, b); Romero-Otero et al. (2010) and Vinnels et al. (2010). Vernette (1989), using 2D seismic profiles and cores, observed that gravity-driven sedimentary transport occur with high frequency in the high-angle flanks of mud-diapir domes in the Colombian Caribbean margin near to Gulf of Morrosquillo and Cartagena (Fig. 1), hence, both tectonic events and sedimentation induce the development of intense mud diapirism causing over-steepening in slope and gravity-driven sedimentation. Vinnels et al. (2010), using 2D seismic reflection profiles and multi-beam bathymetry data from Sinú basin, offshore Colombia, observed that features associated to gravity currents dominated the sedimentary successions, which are characterized primarily by channel- and sheet-like architectures dominated by hemipelagic fills. Romero-Otero et al. (2010) using multi-beam bathymetry, side-scan sonar images and 2D seismic profiles, identified a series of Miocene to recent detached and shelf attached mass transport complexes in the Magdalena Fan. Causal mechanisms that could have triggered shelf attached mass transport complexes in the Magdalena Fan, are instability after abandonment of the delta front, sea level changes, seismic activity in the area and active deformation of the upper slope (Romero-Otero et al., 2010). Vernette (1989), Romero-Otero et al. (2010) and Vinnels et al. (2010) identified gravity-driven deposits as important component elements of the stratigraphic sequences in the Colombian Caribbean coast, and have provided descriptions and formulated observations on various aspects of these strata. A lack of 3D seismic data increase the uncertainty of the controls and causes associated with these gravity-driven deposits. In the present study, we used 3D seismic and biostratigraphic data from wells. The 3D seismic data allow us to get a more detailed understanding of architecture associated to these deposits from which process based interpretations were developed. The seismic volume and the high stratigraphic and structural definition provided by seismic attribute analysis allowed us to interpret nine gravity-driven sedimentary events, revealing its geomorphological elements from palaeo-shelf break to intraslope. The scope of the paper is: (1) a detailed characterization of the geomorphological architecture of gravity-driven deposits on the tectonically active Caribbean margin in Colombia and (2) an interpretation of the triggering mechanism of gravity-driven sedimentary processes in this area.

2. Regional setting

The study area is part of South Caribbean Deformed Belt which comprises a large tectonic province in the northwestern margin of South America in the Colombian Caribbean Sea (Fig. 1). The area is controlled by the interaction between Andean Orogeny, the Caribbean, South American, Nazca and Cocos plates and the Panama Arc (Kolla et al., 1984; Mattson, 1984; Mascle et al., 1985; Vitali et al., 1985; Bowland, 1993; Giunta et al., 2002; Pindell and Kennan, 2001; Pince et al., 2003; Cediel et al., 2003; Flinch, 2003; Corredor et al., 2005; Pindell et al., 2005; James, 2009) (Fig. 2). The Meso-Cenozoic stratigraphy exceeds 4 km in thickness, and is locally controlled by growing of Sinú Fold Belt. Sediments have undergone a lot of compression deformation, with the formation of associated structures (Duque-Caro, 1980, 1984, 1990; Kolla et al., 1984; Corredor et al., 2003). Transpression is evident, forming fold belts and relay structures which still active (Rossello, 2007; Bermudez et al., 2009). The Colombian Caribbean area has been relatively unexplored. Oil seeps are seen across the southern Caribbean Basin, suggesting a working hydrocarbon system, as yet sparsely tested by exploration drilling activities. Channel-levee complexes, confined and unconfined channel–lobe complexes have been interpreted as the more important reservoirs.

The Pliocene to Holocene siliciclastic succession in the southern Colombian Caribbean Fold Belt has been fed by major fluvial systems from the northwestern Andean region such as Magdalena,

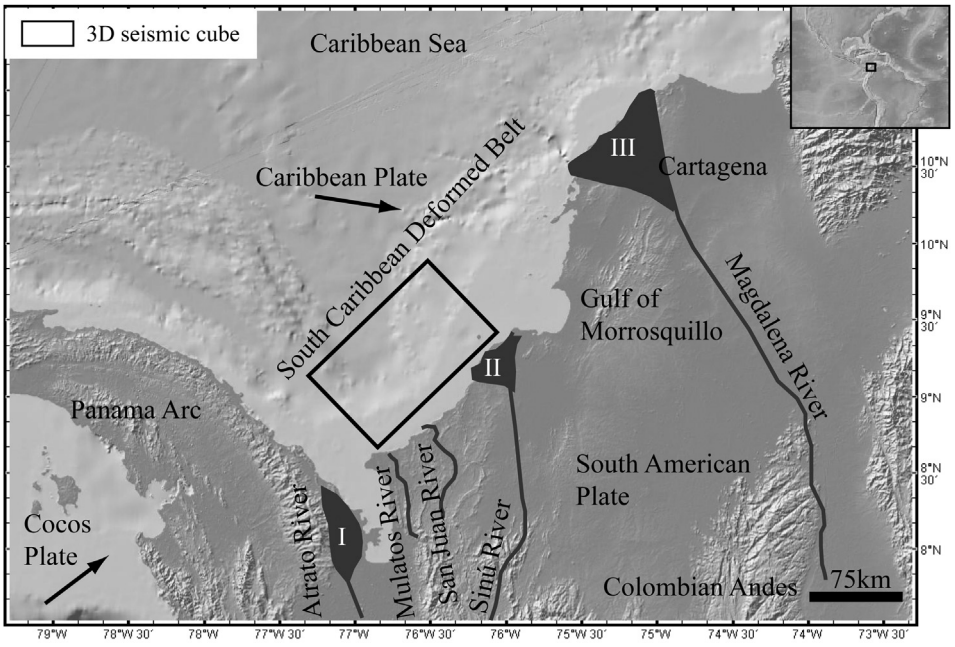

Figure 1. Map of the northwestern Colombian Caribbean margin showing the location of the study area (in black square) and its relation with main delta systems. I, II and III indicate the location of Atrato, Sinú and Magdalena deltas, respectively (basemap from Ryan et al., 2009).