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Research paper

Shallower structure and geomorphology of the southern Puerto Rico offshore margin

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ABSTRACT

Oblique convergence between the North American and Caribbean plates along the eastern Greater Antilles island arc has yielded the asymmetric Muertos thrust belt in the backarc region. Offshore south of Puerto Rico, this thrust belt disappears and is replaced by a succession of NE–SW- and E–W-trending deep basins and steep ridges that characterize the western Anegada passage, resulting in a complex deformation pattern. Using new high-resolution multibeam bathymetry and seismic reflection profiles, we studied the geomorphology and shallower structure of the southern Puerto Rico offshore margin. We have identified four morphotectonic provinces: the Puerto Rican sub-basin and Muertos trough, the Muertos margin, the insular shelf and the western Anegada passage. The Muertos margin province shows two distinct slope sub-provinces: the active Muertos thrust belt – which includes lower and upper thrust belts with distinct deformational styles and lateral continuity – and the shelf slope highly-incised by a dense canyon network. This network is disrupted by the Investigator fault zone consisting of a 130 km-long E–W-trending band of active extensional deformation. The Investigator fault zone shows differential surface expression caused by along-strike changes in the magnitude and distribution of the deformation, though this deformation is driven by a N–S-oriented extension. In the western Anegada passage province, the Whiting basin and Whiting and Grappler ridges are formed by large dip-slip normal faults driven by a NW–SE-oriented extensional regime. The western St. Croix rise shows a complex structure where the NE–SW-trending NW-dipping normal faults observed at the summit of the rise predate the E–W-bounding faults that could accommodate the extensional deformation at the Present. This study provides detailed observations on the active tectonic and sedimentary processes to help future studies assessing the natural resources and the seismic and tsunamigenic hazard in the Puerto Rico region.

1. Introduction

Thrust belts are commonly built by a sequence of imbricate thrust slices forming a deformed sediment wedge along the subduction zone (e.g., Scholl et al., 1980; Davis et al., 1983). The forearc region of island arcs is often characterized by accretionary systems or thrust belts lying along the lower slope and perched basins occupying the upper slope region close to the arc (e.g., Aleutian arc, Holbrook et al., 1999; Nankai, Moore et al., 1990). However, at several places around the world, thrust belts have developed on both sides of island arcs (e.g., Java-Timor, Panama, Vanuatu and the northeastern Caribbean). In these localities, the overall vergence of the backarc or retroarc thrust belt is opposite to that of the forearc thrust belt. For example, in the northeastern Caribbean, a north-verging accretionary prism lies to the north of the eastern Greater Antilles arc (Hispaniola and Puerto Rico), whereas a S-verging thrust belt lies to the south (Fig. 1). GPS-derived velocities and the occurrence of large earthquakes suggest that significant convergence across the plate boundary can take place in the backarc thrust belt (Java-Timor; Genrich et al., 1996; Vanuatu; Lagabrielle et al., 2003). Therefore, the seismic hazard of backarc thrust belts should be considered (ten Brink et al., 2009).

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The surface expression of the submarine active thrust systems is a sequence of long, narrow, sub-parallel anticline ridges (e.g., Cascadia, Flueh et al., 1998; Makran, Smith et al., 2012; Kukowski et al., 2001; Nankai, Gulick et al., 2004). The lateral and vertical growth and evolution of such accretionary systems are associated with a deformation pattern that controls the seafloor morphology and the dynamics of the sedimentary process along and across the slope margin (Underwood, 1991). The study of the morphology and subsurface structure of the submarine thrust belts and associated slope processes is a key to understand the active sedimentary and tectonic processes associated with compressive margins (e.g., Underwood and Moore, 2011; Smith et al., 2012). An understanding of such active processes allows characterization of the deformation pattern and provides a basis for predicting the distribution of faulting and the nucleation of earthquakes.

In the offshore northeastern Caribbean, studies of the shallower tectonic structure were mainly focused on the main boundary plate at the Puerto Rico trench where the North American plate obliquely subducts beneath the Caribbean plate (e.g., Grindlay et al., 2005a; ten Brink, 2005, Fig. 1). Until the beginning of the 21st century, there were only sparse seismic reflection profiles and GLORIA side-scan sonar data along the southern slope of eastern Hispaniola and Puerto Rico (i.e., Muertos margin; Fig. 1). These data helped to document the active underthrusting of the Caribbean plate's interior beneath the island arc along the Muertos margin as well as the active extensional tectonics in the western Anegada passage (e.g., Matthews and Holcombe, 1976; Ladd et al., 1977, 1981; Jany, 1989; Jany et al., 1990; Masson and Scanlon, 1991; Dillon et al., 1996). From 2004 the cooperative work undertaken by the U. S. Geological Survey and the Universidad Complutense of Madrid using high-resolution multibeam bathymetry and 2D seismic reflection yielded a good coverage of the Puerto Rico–Virgin Islands region (Carbó-Gorosabel et al., 2005, 2010; Andrews et al., 2014). These data allowed several studies to focus on the active tectonics, recent sedimentation and seismic hazard in the Puerto Rico trench and the Mona and Anegada passages (e.g., ten Brink et al., 2004; López-Venegas et al., 2008; Chaytor and ten Brink, 2010, 2014). Old reprocessed multichannel seismic reflection data and new multibeam bathymetry data were used to investigate the shallower structure of the western and central Muertos margin (Granja Bruña et al., 2009, 2014). However, the eastern region of the Muertos margin (i.e., southern Puerto Rico insular slope) has not been investigated using new high-resolution multibeam bathymetry and seismic reflection data.

The aim of the present study is to interpret the along- and across-strike variations of the geomorphology and shallower structure of the offshore Puerto Rico southern insular slope. To address our objective, we carried out a combined interpretation of new high-resolution multibeam bathymetry and a dense data set of mostly new seismic reflection profiles. This study provides detailed observations of the shallower structure in the eastern Muertos margin, completing the studies carried out in the western and central sectors of the margin (Granja Bruña et al., 2009, 2014) and in the western Anegada passage (Raussen et al., 2013; Chaytor and

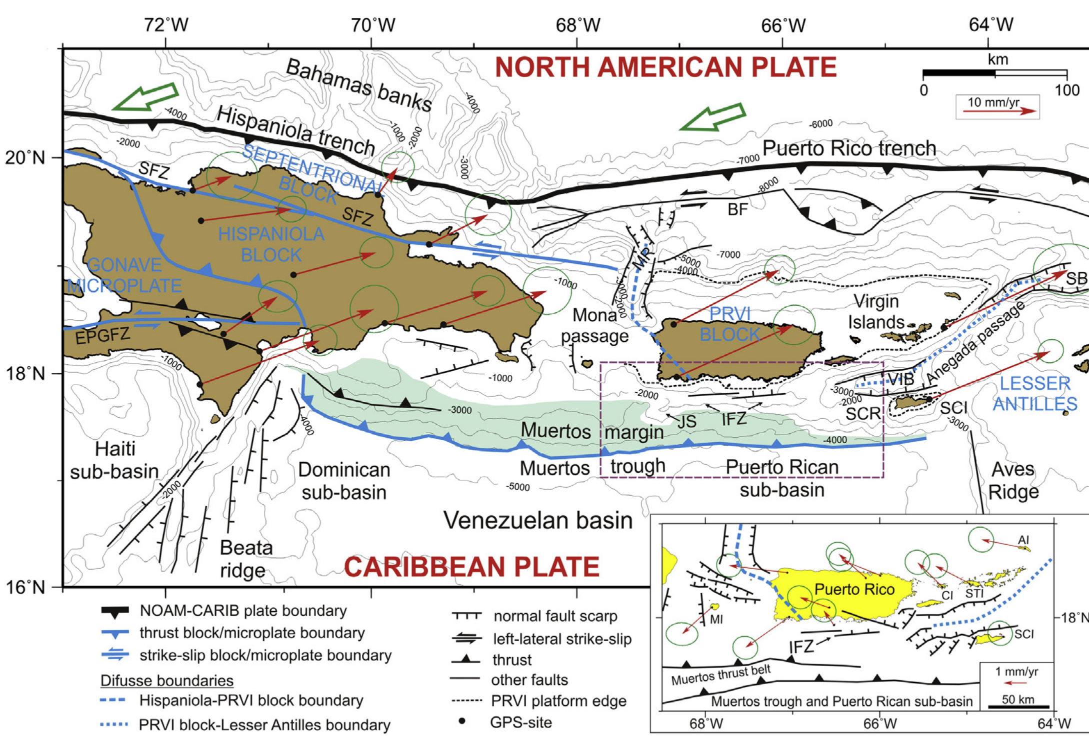

Figure 1. Contoured bathymetry map of the northeastern Caribbean showing a summarized tectonic setting. Isobaths based on satellite-derived bathymetry gridded at 1 arc-minute intervals (Smith and Sandwell, 1997) using the free software Generic Mapping Tools (GMT; Wessel and Smith, 1998). The purple dashed rectangle marks the study area. Thick green arrows show the relative convergence motion between the North American and the Caribbean plates. GPS-derived velocities with respect to the North American plate are shown with thin red arrows, the arrow length being proportional to the displacement rate (Manaker et al., 2008). Error ellipse for each vector represents two-dimensional error, 95% confidence limit. The thick blue dashed line marks the Hispaniola-PRVI block boundary as suggested by ten Brink and López-Venegas (2012). The green area shows the extension of the Muertos thrust belt (Granja Bruña et al., 2009, 2014, this study). NOAM = North American. CARIB = Caribbean. EPGFZ = Enriquillo-Plantain Garden fault zone. SFZ = Septentrional fault zone. BF = Bunce fault. SB = Sombrero basin. PRVI BLOCK = Puerto Rico–Virgin Islands block. VIB = Virgin Islands basin. MR = Mona rift. IFZ = Investigator fault zone. JS = Jaguey spur. SCR = St. Croix rise. SCI = St. Croix Island. The inset map shows GPS-derived velocities with respect to St. Croix Island (SCI), the arrow length being proportional to the displacement rate (ten Brink and López-Venegas, 2012). Error ellipse for each vector represents two-dimensional error, 95% confidence limit. MI = Mona Island. CI = Culebra Island. STI = St. Thomas Island. AI = Anegada Island. SCI = St. Croix Island. IFZ = Investigator fault zone. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)