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Crustal structure of western Hispaniola (Haiti) from a teleseismic receiver function study

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ABSTRACT

Haiti, located at the northern Caribbean plate boundary, records a geological history of terrane accretion from Cretaceous island arc formations to the Eocene to Recent oblique collision with the Bahamas platform. Little is presently known about the underlying crustal structure of the island. We analyze P-waveforms arriving at 27 temporary broadband seismic stations deployed over a distance of 200 km across the major terrane boundaries in Haiti to determine the crustal structure of western Hispaniola. We compute teleseismic receiver functions using the Extended-Time Multi-Taper method and determine crustal thickness and bulk composition (V_p/V_s) using the H-κ stacking method. Three distinctive and fault-bounded crustal domains, defined by their characteristic Moho depth distributions and bulk crustal V_p/V_s, are imaged across Haiti. We relate these domains to three crustal terranes that have been accreted along the plate boundary during the northeastwards displacement of the Caribbean plate and are presently being deformed in a localized fold and thrust belt. In the northern domain, made up of volcanic arc facies, the crust has a thickness of ~23 km and Vp/Vs of 1.75 ± 0.1 typical of average continental crust. The crust in the southern domain is part of the Caribbean Large Igneous Province (Caribbean LIP), and is ~22 km thick with Vp/Vs of 1.80 ± 0.03 consistent with plume-related rocks of late Cretaceous age. Significantly thicker, the crust in central Haiti has values of Moho depths averaging ~41 km and with Vp/Vs of 1.80 ± 0.05. We propose that the central domain is likely constructed of an island arc upper crust with fragments of dense material originating from mafic lavas or LIP material. We produce a crustal profile along a N-S transect across Haiti accounting for the surface geology, shallow structural history, and new seismological constraints provided by variations of crustal thickness and bulk composition.

1. Introduction

1.1. Overview

One of the keys to understanding the transpressive northern Caribbean plate boundary and its geodynamic evolution is constraining crustal thickness and composition. Several geological field studies have led to a description of the shallow structure and stratigraphy of the island of Hispaniola (e.g., Mann et al., 1995; Pubellier et al., 2000). The Mw 7.0 2010 Haiti earthquake prompted several geological and geophysical studies to constrain the fault geometry and the crustal structure in the area of the mainshock (e.g., Douilly et al., 2013). However, our knowledge of the mid- and lower-crustal tectonics remains very limited in the absence of whole crustal geophysical studies in Haiti. In Dominican Republic, the eastern part of Hispaniola Island, interpretation of crustal thickness from gravity data shows thick crust below the southern flank of the Dominican Central Cordillera (Bowin, 1976). From April 2013 for nearly 14 months, a temporary seismic network consisting of 27 stations was deployed in Haiti (Trans-Haiti project) to determine its crustal thickness and bulk composition using teleseismic

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P-wave data. In addition, we analyze seismograms from 3 permanent stations of the Canadian National network (2010–2015) operated by the Bureau des Mines et de l'Energie and UTS. This paper is the first one about works on temporary deployment of seismometers cross-cutting the whole of the island.

The purpose of the present study is to determine crustal structure across Haiti from receiver function (RF) analysis below Haiti so as to better constrain plate scale tectonic evolution of the region responsible for the development of the current fold-thrust belt (Mann et al., 1995; Pubellier et al., 2000; Hernaiz Huerta et al., 2007). The receiver function analysis technique is an appropriate approach to image major discontinuities within the crust and upper mantle from incoming teleseismic P-waveforms (e.g. Ammon, 1991).

1.2. Geological and tectonic setting of Haiti

Haiti, the western part of the Hispaniola island, is located on the Northern Caribbean plate boundary, which separates the Caribbean plate from the North American plate (Fig. 1). Currently, the Caribbean plate moves in a east-northeast direction at about 20 mm/yr relative to the North American plate (Symithe et al., 2015). As the plate boundary is oriented E-W and the displacement vector of the Caribbean plate is about N70°, the area undergoes oblique collision and transpression at a large restraining bend in the strike-slip plate boundary. The deformation of the Northern Caribbean plate boundary in Haiti is partitioned and two major E-W left-lateral strike-slip faults, the Septentrional-Oriente Fault Zone (SOFZ) in the North and the Enriquillo-Plantain-Garden Fault Zone (EPGFZ) in the south with both faults accommodating the strike-slip component of the displacement (Fig. 1). GPS geodesy shows that compression is mainly accommodated by Miocene to recent folding and thrusting in the North-Haitian thrust fault and the Massif de la Selle in southern Haiti (Symithe and Calais, 2016). The Trans-Haitian fold-and-thrust belt in central Haiti (Fig. 1) was active until the late Neogene (Mann et al., 1995) but does not appear to accommodate significant shortening today.

The geological and geodynamical history of Haiti is complex, however, two distinct domains have been identified. Haiti is part of the Cretaceous volcanic island arc constituted at the boundary of the Pacific realm (Pindell et al., 2006) called the Greater Antilles arc. The Greater Antilles volcanic arc was initiated by an eastward dipping subduction in Central America (Pindell et al., 2012; Van der Lelij, 2013; Hastie et al., 2013). The Greater Antilles arc now consists of a part of Cuba, Hispaniola and Puerto Rico islands (Mann et al., 1995). This island arc constitutes two thirds of Hispaniola Island, and is mainly made up of arc magmatic facies (Boisson, 1987; Escuder Viruete et al., 2006). The southern part of Haiti has been interpreted to be part of the Caribbean Large Igneous Province (LIP), formed during the Cretaceous on the Pacific Farallon plate, over the Galapagos hotspot (Duncan and Hargraves, 1984). The LIP outcrops as a tholeitic substratum associated with Upper Cretaceous sediments in the Southern Peninsula of Haiti (Calmus, 1983), and has been imaged south and west of Haiti with refraction and reflection data (Leroy et al., 2000; Mauffret et al., 2001; Corbeau et al., 2016a). The volcanic island arc and the LIP subsequently moved north- and eastwards from their Pacific position between the North and South American plates, thus partitioning the current Caribbean plate (Pindell et al., 2012). The Greater Antilles arc became an inactive intra-oceanic arc at the end of the Upper Cretaceous when it collided with the Bahamas carbonate platform (Leroy et al., 2000; Cruz-Orosa et al., 2012; Iturralde-Vinent, 2006). Between the island arc and the LIP lies the Quaternary Cul-de-Sac sedimentary basin (Fig. 1), which is bounded to the North by the thrusts of the Trans-Haitian belt, also called Haiti fold-and-thrust belt. This belt is formed of NW-SE thrusts having propagated towards the SW since the Lower Miocene (Pubellier et al., 2000).

1.3. Previous geophysical work

Previous geophysical studies have placed crude constraints on crustal structure in the south and in the vicinity of Haiti that help place our results in context and aid interpretation.

A compilation of seismic refraction data acquired in the Caribbean plate shows that the thickness of the crust is not uniform (Diebold et al., 1981; Mauffret and Leroy, 1997; Mauffret et al., 2001). The Caribbean oceanic crust is 5-km thick in Haitian sub-basin, Colombia and Venezuela basins (Fig. 1). In the middle of the Caribbean plate, the original oceanic crust is underplated by ultra-mafic material (Leroy et al., 2000), forming a LIP of ~10 to 15 km in thickness. The Beata Ridge (Fig. 1), 20–30 km thick, is composed of oceanic crust underplated by

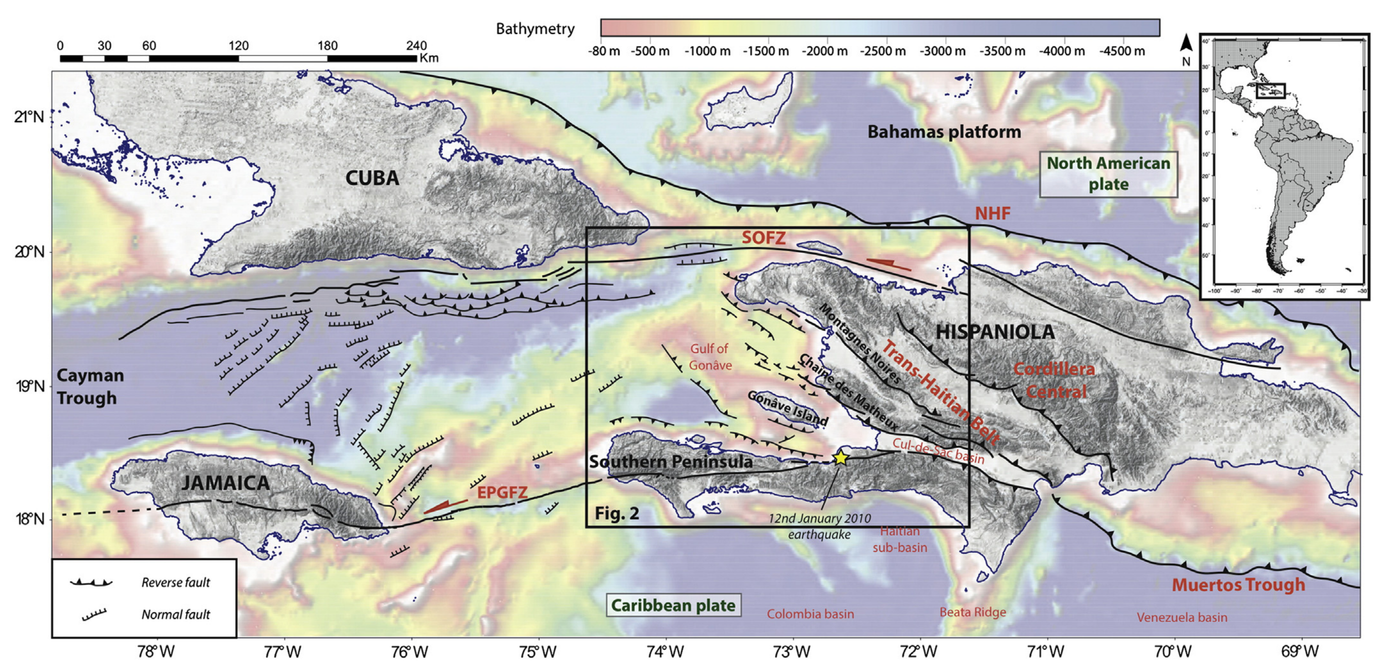

Fig. 1. Tectonic map of the Northern Caribbean plate boundary. Faults are from previous studies (Calais and Mercier de Lepinay, 1991; Mann et al., 1995; Leroy et al., 1996, 2015; Granja-Bruña et al., 2014). NHF: North-Hispaniola Fault; SOFZ: Septentrional-Oriente Fault Zone; EPGFZ: Enriquillo-Plantain-Garden Fault Zone.