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Influence of increasing convergence obliquity and shallow slab geometry onto tectonic deformation and seismogenic behavior along the Northern Lesser Antilles zone

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A B S T R A C T

In subduction zones, the 3D geometry of the plate interface is one of the key parameters that controls margin tectonic deformation, interplate coupling and seismogenic behavior. The North American plate subducts beneath the convex Northern Lesser Antilles margin. This convergent plate boundary, with a northward increasing convergence obliquity, turns into a sinistral strike-slip limit at the northwestern end of the system. This geodynamic context suggests a complex slab geometry, which has never been imaged before. Moreover, the seismic activity and particularly the number of events with thrust focal mechanism compatible with subduction earthquakes, increases northward from the Barbuda–Anguilla segment to the Anguilla–Virgin Islands segment. One of the major questions in this area is thus to analyze the influence of the increasing convergence obliquity and the slab geometry onto tectonic deformation and seismogenic behavior of the subduction zone. Based on wide-angle and multichannel reflection seismic data acquired during the Antithesis cruises (2013–2016), we decipher the deep structure of this subduction zone. Velocity models derived from wide-angle data acquired across the Anegada Passage are consistent with the presence of a crust of oceanic affinity thickened by hotspot magmatism and probably affected by the Upper Cretaceous–Eocene arc magmatism forming the '*Great Arc of the Caribbean*'. The slab is shallower beneath the Anguilla–Virgin Islands margin segment than beneath the Anguilla–Barbuda segment which is likely to be directly related to the convex geometry of the upper plate. This shallower slab is located under the forearc where earthquakes and partitioning deformations increase locally. Thus, the shallowing slab might result in local greater interplate coupling and basal friction favoring seismic activity and tectonic partitioning beneath the Virgin Islands platform.

1. Introduction

In subduction zones, the downgoing plate dynamics directly influence the upper plate deformation and geological processes such as uplift and subsidence within forearc and backarc, strain partitioning in oblique subduction (e.g. McCaffrey, 1992), location of the volcanic arc (e.g. Syracuse and Abers, 2006), and seismogenic potential (e.g. McCann et al., 1979). At shallow depths (0–40-km), chemical reactions, fluid release within the subducting plate and upper plate nature can play a key role in behavior and geometry of the subduction interface (e.g. Barker et al., 2009 and references therein), such as in the Hikurangi interplate subduction (e.g. Barker et al., 2009). Many plates subduct under a curved margin (as Scotia, Marianas, Northern Chilean, Aleutian subductions ...). At large scale (0–600-km-depth), curved deformation front are often related with slab complex 3D geometry proposed by modeling (e.g. Schellart et al., 2007; Bonnardot et al., 2008) and observed in different real cases (e.g. Hayes et al., 2012). Subsequently, observed variations of nature and geometry of the subducting plate at shallower depths (<40-km-depth) for curved margins can play a major role on subduction zone processes and upper plate deformation.

The northeast Caribbean margin is sharply curved with a NS-trending subduction line offshore of the Central Lesser Antilles progressively rotating northward to an E–W direction to the north of the Greater Antilles (Figs. 1 and 2). On the one hand, the N254°E convergence direction does not change along-strike resulting in an arcuate slab with a westward dip beneath the Central Lesser Antilles and a southward dip beneath Puerto Rico and Hispaniola islands. On the other hand, the Lesser Antilles margin

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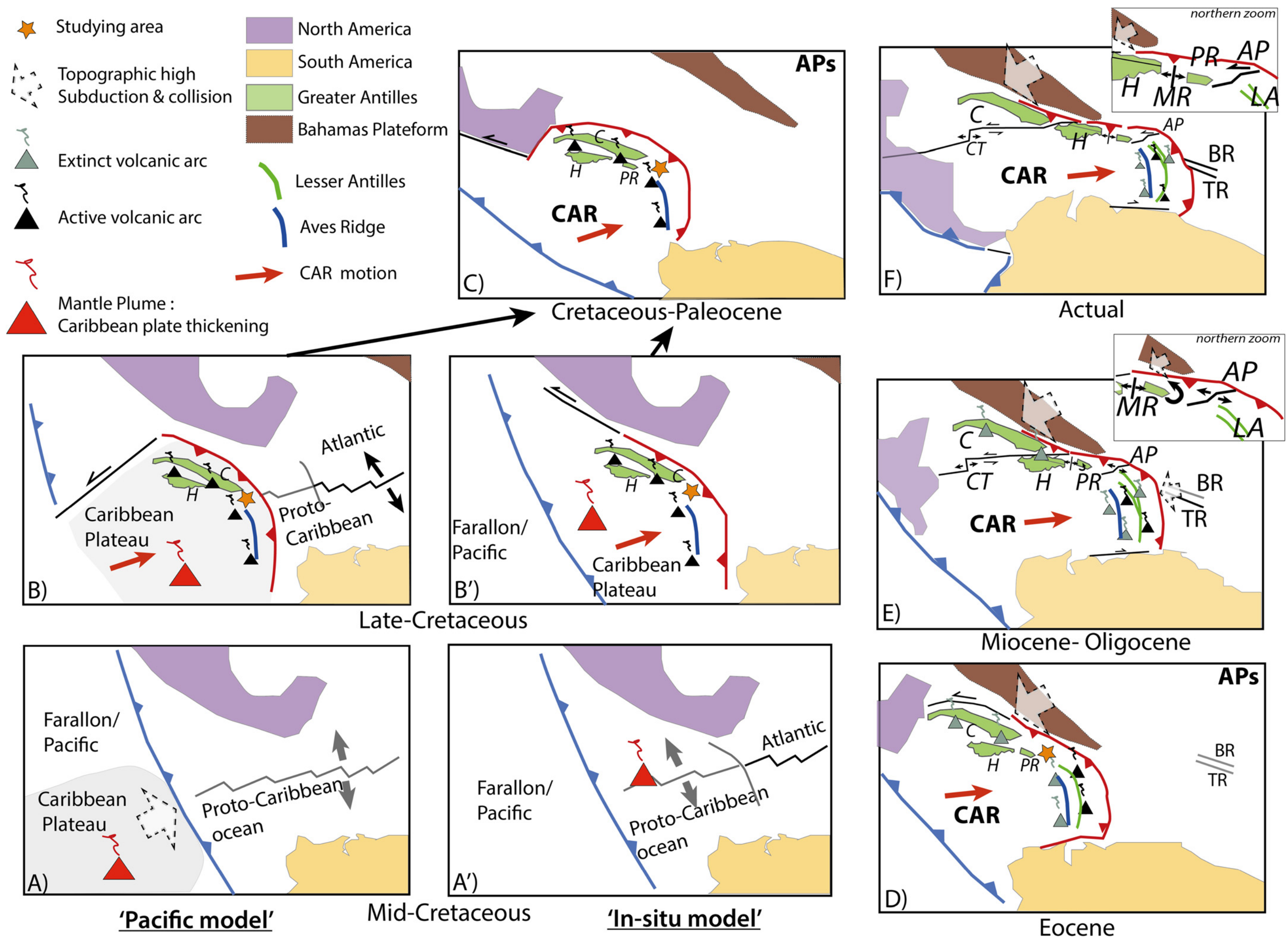

Fig. 1. Two alternate geodynamic reconstructions for the Caribbean Plate since Mid-Cretaceous: the 'Pacific model' (A–B) from Pindell and Kennan (2009) and Boschman et al. (2014), the 'in-situ' model (A′B′) from Meschede and Frisch (1998) and James (2009). These reconstructions include (C–D) the collision of the Bahamas Bank, (E) the westward migration of the Lesser Antilles volcanic arc (Bouysse and Westercamp, 1990); the rotation of Puerto Rico–Virgin Islands bloc (Reid et al., 1991); the Mona rift and Anegada Passage opening (Mann et al., 2005; Laurencin et al., 2017) and (F) the current tectonic partitioning (Laurencin et al., 2017). AP: Anegada Passage; APs: American plates; BR: Barracuda Ridge; C: Cuba; CAR: Caribbean plate; CT: Cayman Trough; H: Hispaniola; MR: Mona rift; PR: Puerto Rico; TR: Tiburon Ridge. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

presents heterogeneities in seismicity (McCann and Sykes, 1984) and partitioning (Laurencin et al., 2017) locations. The Antithesis 1 (11/2013–01/2014) and Antithesis 3 (05/2016) cruises were aimed at studying the deep structure and the tectonic deformation of the poorly investigated Northern Lesser Antilles margin (Barbuda-Virgin Islands). Subsequently, using combined wide-angle and deep multichannel seismic data, we investigated the geometry of the downgoing slab and the nature of the overriding crust in order to discuss its influence onto partitioning deformation and seismic coupling.

2. Geodynamical setting

2.1. Nature and origin of the eastern Caribbean region

The eastern Caribbean plate, bounded by convergent margin from the southeast of Cuba to the south of the Lesser Antilles, includes an active island arc (Lesser Antilles arc) and a remnant arc, named the '*Great Arc of the Caribbean*' (currently the Greater Antilles and the Aves Ridge), setting up on the '*Caribbean Plateau*' (Figs. 1 and 2). Two competing models depict the '*Caribbean Plateau*' formation. The '*Pacific*' model proposes an initiation of the '*Caribbean Plateau*' within the Pacific plate during Jurassic, thickened during the Cretaceous by magmatism above a mantle plume (Galapagos), (Fig. 1-A–B), and later drifted to its present position between the two American plates (e.g. Pindell and Kennan, 2009). On the contrary, the '*in situ*' model suggests that the thickening by decompression melting during Mid-Cretaceous of the '*Proto-Caribbean*' oceanic crust, forms the '*Caribbean Plateau*' (Meschede and Frisch, 1998; James, 2009), (Fig. 1-A′–B′).

The subduction of Atlantic lithosphere beneath the Caribbean plate since at least Cretaceous to Eocene times forms the '*Great Arc of the Caribbean*'. Fragments of this volcanic arc can be found in the residual Greater Antilles islands for Aptian times and in Puerto Rico for mid-Eocene times (Jolly et al., 2008; Boschman et al., 2014), (Fig. 1-AB–A′B′–C).

During the Eocene (Fig. 1-D), the arc volcanism likely migrated eastward from the Aves Ridge to the Lesser Antilles arc caused by the collision of the Bahamas on the northern Caribbean margin (Bouysse et al., 1985; Neill et al., 2011), (Fig. 1-D). This Lesser Antilles arc was active from Eocene to Oligocene (Bouysse and Westercamp, 1990). During the Oligocene (Fig. 1-E), the Lesser Antilles arc moved westward to its current position possibly due to slab flattening or in response to the subduction of the Barracuda and Tiburon ridges in the Central Antilles (Bouysse and Westercamp, 1990).