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Geomorpho-tectonic evolution of the Jamaican restraining bend

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ABSTRACT

This work applies recent advances in tectonic geomorphology in order to understand the geomorphic evolution of the Jamaican restraining bend located along the Caribbean–Gonâve–North American plate boundary. We propose a classification of landscapes according to their erosional stages. The approach is mainly based on the combination of two DEM-based geomorphic indices: the hypsometric integral which highlights elevated surfaces, and the surface roughness which increases when the relief is incised by the drainage network. River longitudinal profiles were also analyzed as the drainage network responds quickly to base-level change triggered by external forcing such as tectonics. Anomalies in river profiles (knickpoints and convex segments) were mapped using stream length-gradient (SL) and normalized steepness (k_{sn}) indices. The results provide new insights for understanding the complex evolution of the Jamaican restraining bend. Three main morphotectonic regions were identified in Jamaica: (1) the Blue Mountain–Wagwater unit located at the eastern tip of the island, (2) the Jamaican highlands plateau which covers most of the northern and central areas and (3) the tilted block province located along the southern part of Jamaica. Each region has a specific morphological signature which marks a different stage in the Late Miocene to present evolution of the Jamaican restraining bend. The evolution of the bend is mainly associated with the western propagation of major E-trending strike-slip faults and NW-trending thrusts. In the western and central parts of Jamaica the present-day motion between the Caribbean plate and the Gonâve microplate is broadly distributed along several structures, while in the easternmost part of the island this motion seems to be almost completely accommodated along the Blue Mountain range and the Plantain-Garden Fault.

1. Introduction

Jamaica is located along the complex North America–Gonâve–Caribbean plate boundary (Fig. 1). Both the Gonâve microplate and Caribbean plate are moving to the east in a fixed North American reference frame. The boundary between the Gonâve microplate and the Caribbean plate consists of two major left-lateral faults: the Walton Fault (WF) and the Enriquillo–Plantain Garden Fault Zone (EPGFZ) (DeMets and Wiggins-Grandison, 2007; Mann et al., 2007). The motion between the two faults is transferred along the Jamaican restraining bend (Mann et al., 1985; Cunningham and Mann, 2007). As a result, Jamaica is affected by E-trending strike-slip faults and NNW-trending fold belts and thrust faults (DeMets and Wiggins-Grandison, 2007). Kinematic and seismological data suggest that the restraining bend accommodates a deformation rate from 8 to 14 mm/yr (DeMets and Wiggins-Grandison, 2007; Mann et al., 2007, and references therein). Previous works also suggest that faulting and folding associated with the present tectonic regime in Jamaica started about 10 Ma ago (Wadge and Dixon, 1984; Mann et al., 1985; Draper, 1986; DeMets and Wiggins-Grandison, 2007).

Former studies focused on the Wagwater belt and the EPGFZ located in the eastern part of Jamaica but only few studies have been undertaken in the central and western parts of the island. Therefore most of tectonic features in Jamaica and their interactions with landscapes remain poorly known. Recent investigations (Mann et al., 1985, 2007; Calais et al., 1998; DeMets and Wiggins-Grandison, 2007) have also provided suitable interpretations and models about the neotectonic evolution of the northern Caribbean realm. However, some important questions remain regarding the long-term evolution of the Jamaican restraining bend and its connections to major active structures (WF and EPGFZ).

The relief of seismically active ranges is the result of the interactions between tectonics and erosional processes (Ollier, 1981; Keller and Pinter, 1996). Quantitative measurements of geomorphic indices have been applied broadly to detect the responses of landscapes to active tectonics in other regions of the world (e.g. Anderson, 1994; Cowgill et al., 2004; Gomez et al., 2007; Martín-González, 2009; Delcaillau et al., 2011; Elter et al., 2012). Our aim is to examine geomorphic features along deformed areas in Jamaica in order to better understand the Late Miocene to present evolution of the Jamaican restraining bend. Our approach combines different geomorphic indices. Topographic surfaces were analyzed using hypsometric integral and surface roughness in order to

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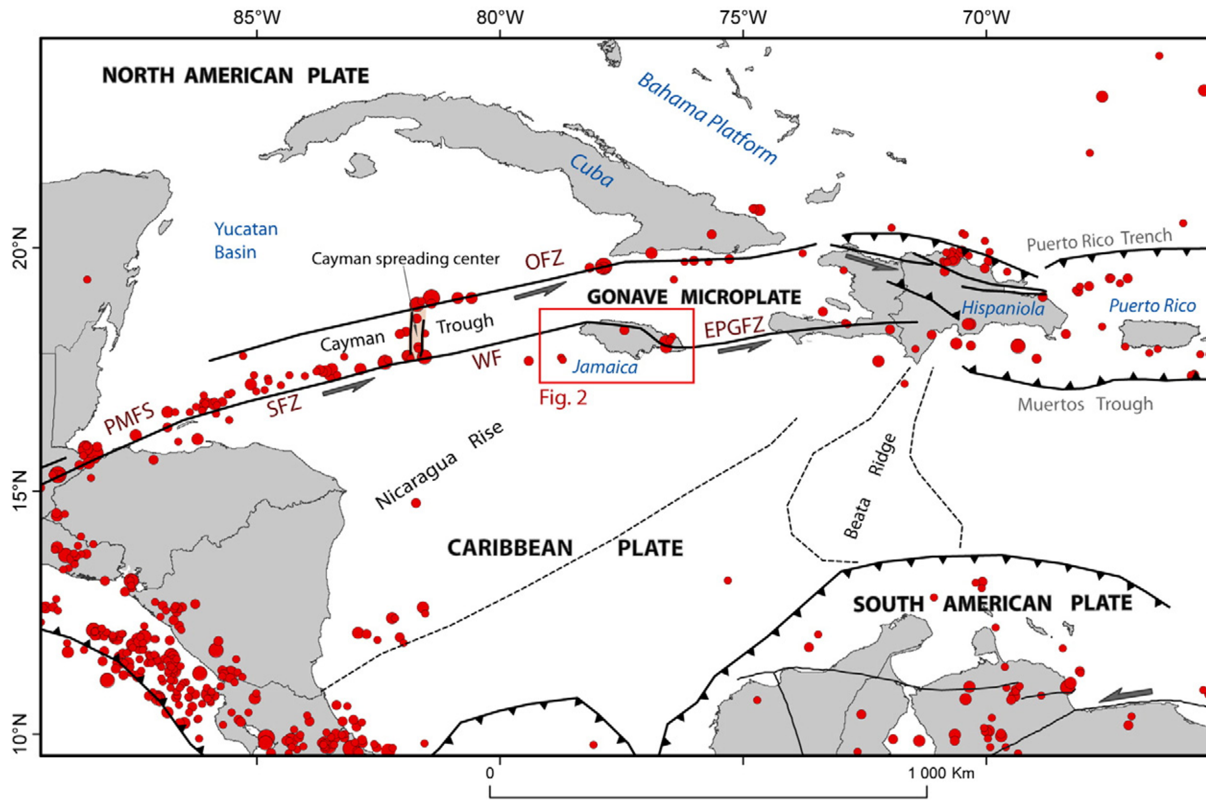

Fig. 1. Tectonic setting and seismicity (circles, M4.5, source: USGS) of the North America–Gonâve–Caribbean plate boundary. Heavy lines indicate major faults, adapted from Mann et al. (1995). Box indicates study area. Abbreviations: EPGFZ — Enriquillo Plantain Garden Fault Zone; OFZ — Oriente Fault Zone; PMFS — Polochic–Motagua Fault System; SFZ — Swan Fault Zone; and WF — Walton Fault.

classify landscapes with different erosional (and thus evolutionary) stages, as well as river longitudinal profiles to detect active structures and delineate spatial patterns in rock uplift rates. The results from our geomorphic analyses were then combined with available geophysical data (GPS and seismicity) in order to propose a dynamic model for the Late Miocene to present evolution of the Jamaican restraining bend.

2. Geodynamic and structural settings

The Caribbean plate represents a lithospheric unit between the North American and South American plates (Fig. 1). Since the Miocene, the Gonâve microplate has been detached from the Caribbean plate in response to the ongoing collision between the leading edge of the Caribbean plate (in Hispaniola) and the Bahamas carbonate platform (Mann et al., 1984, 1995, 2007). Therefore, the motion between the Caribbean and North America plates is not only accommodated along the Oriente Fault Zone (OFZ, Fig. 1) as a significant part of the motion is transferred along the WF and EPGFZ (DeMets et al., 1990; Mann et al., 1995; Calais et al., 1998; DeMets and Wiggins-Grandison, 2007).

The island of Jamaica lies at the boundary between the Caribbean plate and the Gonâve microplate (Fig. 1). Jamaica is commonly interpreted as a restraining bend between the Walton Fault (WF) and the Plantain-Garden Fault (PGF, Fig. 2A) (Mann et al., 2007, and references therein). Restraining-bend formation and widespread uplift in Jamaica began in the Late Miocene (Mann et al., 2007). The tectonic evolution of Jamaica is divided into four main phases: (1) a Cretaceous island arc, (2) a Paleocene to middle Eocene transitional phase, (3) a middle Tertiary period of relative quiescence with the formation of a carbonate platform, and (4) a late Neogene to recent phase of renewed tectonic activity (Lewis and Draper, 1990; Robinson, 1994). The mid-Tertiary rocks (mainly limestones, Fig. 2A) cover most of the island, forming a cockpit karst landscape. The Cretaceous rocks locally crop out below the Tertiary cover. The Late Cenozoic uplift was particularly intensive in the eastern part of the island where Late Miocene strata have been uplifted up to 2000 m and early Pleistocene units up to 200 m above present day sea level (Robinson, 1994). Late Pleistocene terraces along the northern coast also show evidence of differential uplift and folding (Horsfield, 1972; Lewis and Draper, 1990; Robinson, 1994; Miller et al., 1994).

The observed GPS velocity field suggests that the left-lateral shear between the Gonâve microplate and the Caribbean plate is transmitted at a rate from 8 to 14 mm/yr across the Jamaican restraining bend (Fig. 2B) (DeMets and Wiggins-Grandison, 2007; Mann et al., 2007, and references therein). Kinematic and seismological data indicate left-lateral shearing along the main E-trending strike-slip faults, but some earthquakes have pure NE–SW reverse faulting component along NW-trending faults (Fig. 2B) (DeMets and Wiggins-Grandison, 2007).

East- and NNW-trending faults delimit neotectonic blocks and form a series of bended structures, including the Blue Mountain in eastern Jamaica (Fig. 2) (Mann et al., 2007). The E-trending strike-slip faults are from east to west: the Plantain Garden Fault (PGF), the Blue Mountain Fault (BMF), the Rio Minho–Crawle River Fault Zone (RMCR), the South Coastal Fault, and the Duanvale Fault along the northern coastline (Fig. 2) (Mann et al., 1985; Robinson, 1994; DeMets and Wiggins-Grandison, 2007). The PGF continues offshore and connects with the Enriquillo Fault in southern part of Hispaniola (Fig. 1). The Duanvale Fault zone is connected to the offshore Walton Fault which forms the southern tip of the Cayman spreading center (Rosencrantz and Mann, 1991). All these faults define the southern boundary of the elongated Gonâve microplate (Mann et al., 1995).

East-trending strike-slip faults of mainland Jamaica are connected to a series of prominent NNW-trending faults: the Spur Tree, Santa Cruz and Wagwater faults in central, western Jamaica, and in eastern Jamaica (Blue Mountains), respectively (DeMets and Wiggins-Grandison, 2007). Up to now, the relative slip rates for the NNW-