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Reply to the comment of Mitchell et al. on "Geomorpho-tectonic evolution of the Jamaican restraining bend" by L. Domínguez-González, L. Andreani, K.P. Stanek and R. Gloaguen [Geomorphology, 228 (2015) 320–334]

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ABSTRACT

We reply to the comments of Mitchell et al. on our paper entitled "Geomorpho-tectonic evolution of the Jamaican restraining bend". The comments contain statements about the methods that need to be balanced. We agree that the interpretation of the modeled drainage network in some karstified parts of the Jamaican island is difficult, but this does not affect the validity of our analysis elsewhere. We consider that our geomorphic analyses (which also include topographic profiles and morphometric maps) are still valid. The view expressed by Mitchell et al. that we used serially developed landscapes to 'date' progressive uplift is an oversimplification of our discussion. We highlighted the differences between the geomorpho-tectonic provinces of Jamaica, and we proposed to explain these differences by a model which involves (1) a westward propagation of the restraining bend and (2) a difference in tectonic styles between the different provinces of Jamaica. Our interpretation does not contradict existing models based on seismotectonic data, provenance analysis or on the origin of Jamaican bauxite. There is a disagreement between James-Williamson et al. (2014), which suggested that central Jamaica was already being uplifted by the end of the Late Miocene, and Domínguez-González et al. (2015), which proposed a Pliocene to present onset of the NE-trending compression toward the SW. However, the timing of the deformation in central and western Jamaica is still poorly constrained and, at this time, any interpretation of the uplift history of central Jamaica should be considered as hypothetical.

1. Introduction

We reply to the comments of Mitchell et al. on our paper which addresses the interactions between tectonics and geomorphology in Jamaica (Domínguez-González et al., 2015). Mitchell et al. raised several issues and criticism regarding (1) the review of previous works, (2) the quality and relevance of our data, and (3) our interpretations and conclusions regarding the evolution of the Jamaican restraining bend.

2. Bibliographical issues

According to Mitchell et al., the review of the literature cited by Domínguez-González et al. (2015) is incomplete, and does not include recent papers on the geology or geomorphology of Jamaica. First, our study focused on the recent (Late Miocene to present) interactions between tectonics and landscapes in Jamaica. Most of the papers 'identified' by Mitchell et al. regarding the geology of Jamaica did not appear relevant to us. Most of the references deal with detailed stratigraphic descriptions and revisions of the Cretaceous inliers and Tertiary limestones. We simply did not consider the Cretaceous tectonics as of primary importance for the topic of our paper, nor details about sequence stratigraphy in the Eocene–middle Miocene limestones.

However, we agree on the fact that our paper would have benefited from a discussion on the development of the landscapes, and their relations with karsts and bauxite deposits. We discuss this point in the last section of this reply. Regarding papers related to tectonics, we were not aware of the work from Draper (2008). Unfortunately, the paper from James-Williamson et al. (2014) was published a few weeks before we submitted our own manuscript and we were not aware of it at this time, nor during the review process.

Mitchell et al. criticize the fact that we used tectonic maps from Draper (1986) and DeMets and Wiggins-Grandison (2007) to introduce regional scale tectonic features. The aim of these maps is to show which tectonic features really matter from a tectonic or seismogenic point of view. We do not think that showing a dense array of small scale

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structures (most of which were probably interpreted from aerial photography) would significantly improve our understanding of the interactions between tectonics and landscapes. In addition, the map from Draper (1986) was actually based on the 1:250,000 scale geological map of Jamaica (McFarlane, 1977). We used maps that have commonly been used in international peer-reviewed literature.

3. Methodological issues

In their comment, Mitchell et al. question the source and vertical accuracy of the digital elevation models (DEMs) we used. Our work is based on freely available ASTER GDEM data. ASTER digital elevation data are available at http://gdem.ersdac.jspacesystems.or.jp/. The accuracy (defined by the standard deviation of the differences between predicted values and observed values) is 6 m for open flat areas and 15 m for mountainous areas covered by forests (ASTER GDEM Validation Team, 2011). Datasets were downloaded in 'geotiff' format.

The drainage network was extracted using TecDEM (Shahzad and Gloaguen, 2011a,b), a MATLAB based toolbox. There is no need to convert raster data in ASCII format as suggested by Mitchell et al., since MATLAB is able to process a broad variety of geo-referenced images such as 'geotiffs'. Mitchell et al. also argue that a 'better' drainage network could have been produced using the ARC HYDRO tool of the commercial product ARC GIS. However, we disagree with that since TecDEM uses the similar pre-processing steps as ARC HYDRO. TecDEM is an open source toolbox that has been tested and validated in numerous regions of the world (e.g., Anoop et al., 2012; Mumipour et al., 2012; Andreani et al., 2014; Barcelona et al., 2014; Fuchs et al., 2014; Yildirim, 2014). First pits and holes are filled and then flow directions and contributing area are computed for each pixel using the D8 algorithm (e.g., Fairfield and Leymarie, 1991; Jones, 2002). This has been clearly indicated in our paper. A detailed description of the algorithms used by TecDEM is provided by Shahzad and Gloaguen (2011a).

Mitchell et al. claim that the cell size of the DEM (30 m by 30 m) should not lead to a dense stream network. They also compare a network generated with ARC HYDRO with the results of our study. In fact, the density of an extracted drainage network is not related to the DEM resolution, but to the definition of a minimum contributing area (i.e., the threshold in the flow accumulation needed to 'create' a stream). This threshold is introduced in order to take into account the transition from debris-flow (colluvial) to stream-flow (fluvial channel) dominated channel and it is usually comprised between 0.5 and 1 km^2 in temperate humid regions (e.g., Montgomery and Foufoula-Georgiou, 1993; Wobus et al., 2006). For our study we selected a threshold of 1 km^2 which appears more than adequate for the Blue Mountains region where the drainage network is well developed. Mitchell et al. do not indicate which threshold they used, but we suspect that the differences in density between the two modeled drainage (from TecDEM and ARC HYDRO) result from the use of different thresholds rather than a methodological problem. Indeed, some published papers using ARC HYDRO show how the density of the modeled drainage changes with the applied threshold (e.g., Li, 2014).

Based on a comparison between the modeled drainage and a map from the Water Resources Authority of Jamaica, Mitchell et al. argue that our data are of too low resolution to adequately determine the drainage network of Jamaica and, in consequence, any interpretations or conclusions based on such a model are likely to be highly spurious. We think that these generalized conclusions are misleading and need to be balanced. Both the spatial and vertical resolutions of the DEM (30 m and 6–15 m respectively) are adapted to the modeling of the drainage network. We recognize that in some areas (Manchester and St. Ann plateaus, cockpit karst country) our modeled drainage appears inaccurate, mainly as the result of advanced karstification (Sweeting, 1958). Mitchell et al. focus their argument on the fact that no surface streams are to be observed. However, the occurrence of dry gullies over partially-buried karst in the Manchester plateau shows that surface runoff locally occurs. Day (1978, 2002) pointed out the evidence for relict drainage systems in karstic regions of Jamaica, as many cockpits are elongated or connected by corridors which possibly reflect abandoned surface courses or tectonic lineaments. Other authors (Smith, 1975; White, 1988) proposed the incorporation of a fluvial phase in models of karst development. According to them, abandonment of the initial drainage system occurs subsequently as the surface drainage is 'pirated' underground as the result of an increasing permeability of limestones. Moreover, the modeled drainage is based on the flow accumulation grid which is itself derived from the topography. In other words, topographic trends related to tectonic features (e.g., scarps, linear valleys) affect the flow direction and will be then reflected by the modeled drainage network. Thus, even if the modeled drainage in Manchester and St. Ann plateaus does not reflect the present day subsurface drainage, it may still give indications on structural anomalies or reflect possibly abandoned surface courses. In fact, the topographic scarps which create the anomalies observed in the modeled drainage network are also observed in swath topographic profiles and morphometric maps. We combined all of this complementary information (topographic profiles, morphometric maps and modeled drainage) for our final interpretations of the plateaus and tilted blocks in central and western Jamaica. In other areas, such as the Blue Mountains, where V-shaped valleys are well defined and drained by rivers, we consider that the modeled drainage network is more accurate and that our conclusions are valid.

Mitchell et al. claim that river profiles from Domínguez-González et al. (2015) were extracted using 150 m contour intervals and would lead to a misinterpretation of knickpoints. This is a flawed conclusion possibly based on a misunderstanding of the method. River profiles were extracted from the modeled drainage network. In other words, elevations from the 30 m resolution DEM were collected along the modeled flow paths. Knickpoints were primarily identified using visual interpretation of river longitudinal profiles. On top of that, we also identified knickpoints from changing trends in logarithmic plots of slope vs. area, which are related to different concave or convex segments in river longitudinal profiles (Kirby and Whipple, 2001; Wobus et al., 2006). Finally, we proposed to use the stream length-gradient index (Hack, 1973) to map gradient anomalies related to these knickpoints. To compute this index, we actually used segments delimited by a vertical threshold of 150 m; it is perhaps this that led Mitchell et al. to the erroneous understanding that river profiles were extracted using a 150 m contour interval.

Mitchell et al. argue that the knickpoints in the lower reaches of the Hope River, and the Yallahs and Mundicott rivers, can be attributed to stream diversion by alluvial fan avulsion and river capture. If we except the Hope River, for which an avulsion has been documented by Wood (1976), all other knickpoints occur in tributaries of the Yallahs and Mundicott rivers which are located within deep valleys. There is no clear evidence of such river captures for these tributaries and avulsion is expected to be less common within incised V-shaped valleys.

Finally, Mitchell et al. criticize us for having thrown '*a suite of names for faults* (*many of which do not exist*)', taking as an example the Christiana-Bakefield fault (which should have been spelled 'Christiana-Wakefield'). Mitchell et al. argue that a quick look at Google Maps show uniform karst developed in the White Limestone formation between Christiana and Wakefield. Yet, we relied on other arguments than a quick look at Google Maps to define this fault. First of all, such NW-trending structure appears in the 1:250,000 scale geological map of Jamaica (McFarlane, 1977) as well as in structural maps of former works (e.g., Draper, 1986; Lewis and Draper, 1990; Robinson, 1994). Then, this structure clearly separates a topographic high to the east from a depression formed by the flank of a tilted block to the west. This can be clearly observed in shaded relief maps overlaid with elevations (Fig. 9 from Domínguez-González et al., 2015) and in swath topographic profiles (profile 1 in Fig. 11 from Domínguez-González et al., 2015), but admittedly not in Google Maps.

4. Interpretation of landscapes and tectonic evolution

As pointed in our paper (Domínguez-González et al., 2015) and in the comments of Mitchell et al., the landscapes of Jamaica consist of