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Erosive effects of the storm Helena (1963) on Basse Terre Island (Guadeloupe — Lesser Antilles Arc)

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ABSTRACT

Erosive effects of the tropical storm Helena that hit the volcanic island of Basse Terre (Guadeloupe — Lesser Antilles Arc) on 24 October 1963 has been measured using 80 aerial images acquired by the French geographic institute (IGN — Institut Géographique National) at the approximate scale of 1/8000 less than three months after the storm Helena. On these images, 253 landslides triggered during the storm were identified and mapped. These landslides were located in the central region of the island where catchments exhibit the highest relief. Even though the average thickness of the landslides was only 1 m, i.e., less than the thickness of the weathered layer, the total volume of displaced sediments corresponded to an average denudation of 2800 t km^{-2}, i.e., 1.4 mm, on the watersheds affected by landsliding. To assess the erosional significance of this single climatic event, we compare the volume of sediment mobilized by the storm Helena to the long-term denudation rate. The latter, estimated from a calculation of the total volume of material eroded since the emplacement of lavas using a digital elevation model, is found to be 0.14 mm/y. Assuming that Helena is representative of the storms that hit Basse-Terre Island during the Quaternary, we find that a return period of about 10 to 15 years is enough to account for the long term denudation rate recorded for this Island. Such a period is comparable with the actual return period of the tropical cyclones of the order of 4 to 5 years, suggesting that the erosion of Basse-Terre Island is entirely controlled by tropical hurricanes.

1. Introduction

Extreme meteorological events are responsible for intense sediment transport in mountainous regions of the tropical belt (Page et al., 1994, 1999; Reid and Page, 2002; Korup, 2010). Storms and hurricanes induce landslides and scars in the weathered layers. The sediments fall in overflowing rivers and are transported to the ocean (Lin et al., 2008). Relationships between landslide characteristics, watershed properties, seismic conditions, and intensity of the meteorological events have been evaluated in various geological contexts (e.g., Lin et al., 2008). These studies demonstrate that (i) landslides are controlled by precipitation amount, lithology, hydrology, and relief possibly affected by seismic history, (ii) single extreme meteorological events may result in a global catchment denudation up to several millimeters (Page et al., 1994; Hovius et al., 1997). However most parameters (lithology, relief, hydrology, etc.) vary from one study to the other making it difficult to draw a general conclusion.

The return period of extreme meteorological events is generally well known for the current conditions except for the very catastrophic events that occur with a period greater than 1000 years (Korup, 2012). The past calendar of these events is deduced from the study of recent sediments deposited or reworked by oceanic storms (Reid et al., 1996; Bertran et al., 2004; Donnelly and Woodruff, 2007; McCloskey and Keller, 2009). This technique is efficient for the Holocene period but lacks precision for older periods.

Atlantic volcanic islands located in the tropical belt are ideal places for testing and measuring the geomorphic effect of extreme meteorological events that occurred during the Quaternary period. Indeed, the tectonics is very low (Feuillet et al., 2002), and the relief is constructed during punctuated volcanic episodes that produce homogeneous lithology at the scale of the islands and that can be well dated by absolute geochronology (Samper et al., 2007). Moreover, these islands are subject to storms and hurricanes producing heavy rainfall associated with strong winds. This favors landslide development by the destabilization of the canopy and the decrease of the soil stability because of the increase of pore pressure. In this paper we describe the effects of the storm Helena (26–28 October 1963) on the Basse Terre Island in the archipelago of Guadeloupe. In the center of the island, this storm initiated numerous landslides visible on aerial images acquired <4 months after the event (December 1963 and January 1964). We estimate the amount of sediment displaced in the main watersheds during the storm and we

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compare these values to the total amount of erosion since the emplacement of volcanic rocks.

2. Context of the study

The volcanic island of Basse-Terre belongs to the archipelago of Guadeloupe located in the Lesser Antilles Arc (Fig. 1A), which results from the subduction of the Atlantic plate under the Caribbean plate at a velocity of 2 cm/y (DeMets et al., 2000). Basse-Terre is the westernmost island of the archipelago. It is around 45 km long in the north–south direction with a width of 20 km. The island is composed of five main volcanic andesitic massifs (Samper et al., 2007) whose timing of effusive events has been recently investigated by K–Ar methods (Samper et al., 2007). The results of absolute geochronology show a north to south gradient of age, with the older products (2.79 Ma) being at the north. The active volcano called *Soufriere de Guadeloupe* belongs to the *Grande Découverte* massif, which is dated from 0.2 Ma to present. The *Monts Caraïbes* massif located at the extreme south of the island is composed mainly of hydromagmatic products emitted between 0.555 and 0.472 Ma (Samper et al., 2007). This massif will not be discussed in this paper as its lithology and morphology are different from the rest of the island.

Basse-Terre Island is characterized by high relief. The maximum elevation is reached at the Soufrière de Guadeloupe (1467 m asl). The slope distribution is asymmetric with average slopes larger on the western side of the island than on the eastern side. A positive north–south gradient of elevation related to the gradient of age is also observed. The morphology of the island has been shaped by volcanic constructions eroded by rivers, runoff, and landslides and by two episodes of huge flank collapses (Deplus et al., 2001; Samper et al., 2007; Lahitte et al., 2011). The first one occurred at 640 ka (Samper et al., 2007) on the western side of the island. It was limited to the north by the Vieux Habitant River north escarpment that has a typical horseshoe shape. The second one, which occurred at 550 ka, affected the southeastern

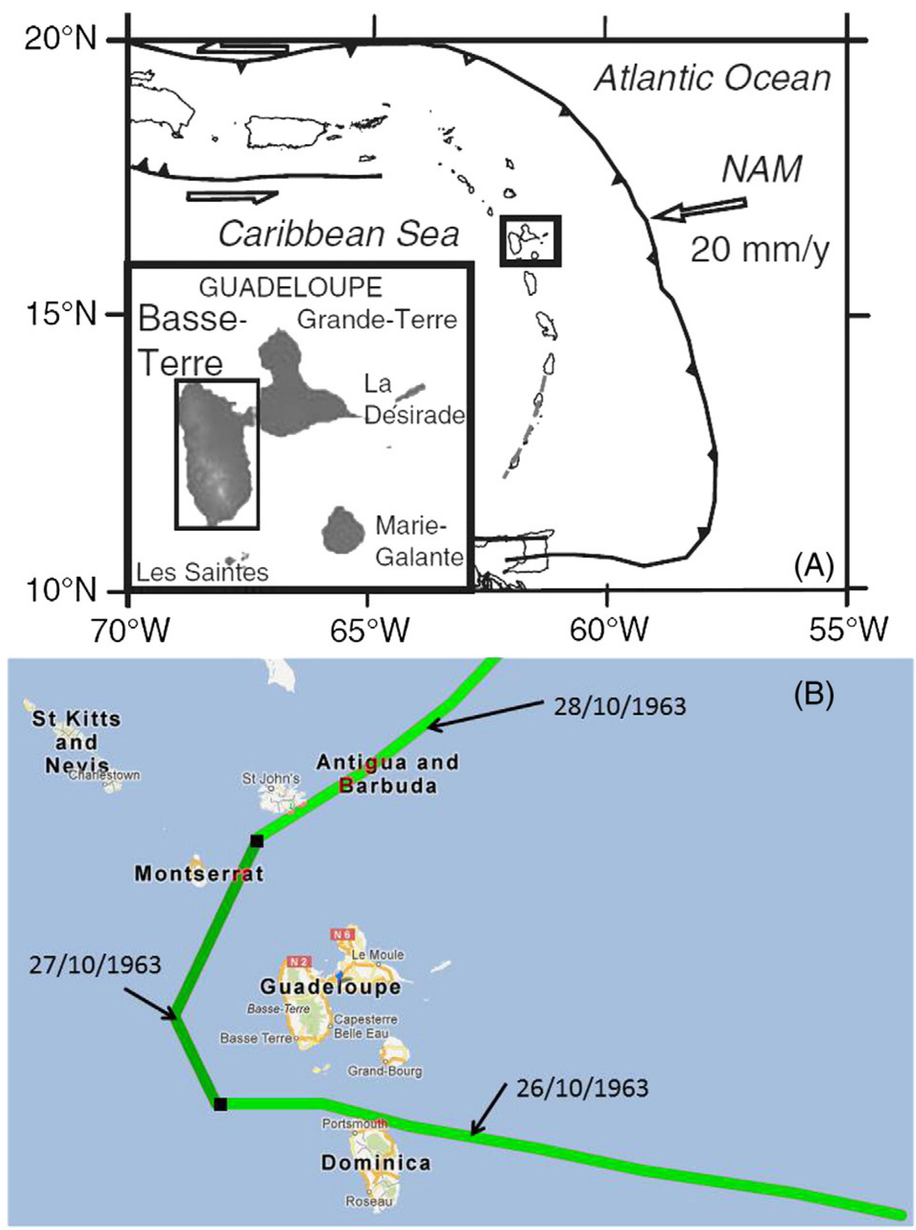

Fig. 1. (A) Geodynamic setting of Guadeloupe archipelago in the Caribbean arc. (B) Path of storm Helena (Dunn et al., 1964). Panel A: modified from Lahitte et al. (2011).