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Chemical weathering and erosion rates in the Lesser Antilles: An overview in Guadeloupe, Martinique and Dominica

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ABSTRACT

Guadeloupe, Martinique and Dominica islands, like numerous tropical environments, have extreme weathering regimes. Physical denudation is mainly controlled by landslides, which reflect the torrential dynamics of the rivers. In Guadeloupe, the mechanical weathering rates vary between 800 and 4000 t/km^2/yr. The lithology is very porous with high infiltration rates, which suggests that most of the element fluxes are produced in the subsurface, with chemical erosion rates 2–5 times higher than the rates from surface water. We show how the kinetics of chemical weathering rates depend on the age of the lava and subsurface circulation. In addition, erosion timescales were calculated from U-series analyses of river sediments. Our results show a broad range: 0–150 ka in Martinique and 0–60 ka in Guadeloupe. We evaluated residence times in river water on the basis of the dissolved load analyses. It appears that water circulation is globally 3-fold longer for subsurface water than for surficial water (Rad et al. 2011a,b). Moreover, these islands are highly impacted by agriculture. However, contrary to what one might think, our results show that human activity does not disturb critical zone processes. Indeed, we show that among the combined impacts of all parameters (climate, runoff, slope, vegetation, etc.), the basin's age seems to be the control parameter for chemical weathering and land use—the younger the basin, the higher the weathering rates. We could observe a combined effect between the higher erodibility and a higher climate erosivity of the younger reliefs.

1. Introduction

As erosion is at the interface between the lithosphere, atmosphere and biosphere, it is a particularly complex phenomenon. Erosion processes and fluxes of continental material have been the focus of increased attention from the geosciences community over the last decades. The factors controlling erosion rates, such as lithology, climate, relief, tectonics, vegetation cover and human activity, are well known. However, the mechanisms that control weathering fluxes on large scales are only partly understood.

Quite early it was observed that subduction zones are propitious to alteration. One of the first studies on weathering in this type of geological setting was carried out by Lacroix (1904) after the eruption of Montagne Pelée, Martinique, in 1902. High standing oceanic islands of the East Indies alone contribute 20–25% of the global sediment exported from land to sea (Milliman et al., 1999), and this figure can even reach as high as 33% (Lyons et al., 2002). Meybeck (1986, 1987) pointed out the variable weatherability of different lithologies and showed that volcanic rocks such as basalt weather 10 times faster than other silicate rocks. Other studies, based on laboratory experiments, have demonstrated differences in weathering kinetics according to the type of rocks and minerals (Drever, 2003; White and Brantley, 2003; Buss et al., 2008).

However, laboratory-derived weathering rates are consistently from 2 to 3 orders of magnitude greater than field-derived rates (White and Brantley, 2003). In recent decades, small and medium size "basaltic" rivers have thus been the focus of numerous studies. Meybeck (1987) first estimated that volcanic rock erosion contributes to 2.8% of the transport of the global dissolved load into the oceans. Bluth and Kump (1994), in their study of Hawaiian rivers, showed that after schists, basalts are among the most weathered silicate rocks. After a comparison of rivers from Hawaii, Iceland and other regions, they concluded that tropical regions with high temperatures and precipitation are paradoxically not necessarily the most weathered. Indeed, tropical climatic conditions combined with dense vegetation favors basalt dissolution but also the

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development of thick soils that reduce chemical weathering. The present study will discuss these parameters and their effects on chemical and physical erosion rates in the Lesser Antilles. The aim of this article is to present an overview of chemical and physical erosion rates and processes in the Lesser Antilles. Lithology, climate, hydrology, land use, timescale, age of volcanic massif are parameters that can control these rates.

2. Geological setting

The Caribbean islands form a large archipelago of thousands of islands that separate the Caribbean Sea from the Atlantic Ocean in an area of over 900 km. They are located in the north tropical zone between 10° and 27° latitude north, 59° and 85° longitude west (Fig. 1). The volcanism is generated by the subduction of the Atlantic seafloor beneath the Caribbean plate at a relatively low subduction rate of 2 cm/yr (Jordan, 1975; Deng and Sykes, 1995; DeMets et al., 2000).

Guadeloupe and Martinique are part of both the outer and the inner northern arcs. Although the evolution of the main active volcanoes from the Lesser Antilles Island arc is relatively well documented, only a few reliable rock dating data are available. Germa et al. (2011a,b) underlined that recent geochronological studies in Guadeloupe (Carlut et al., 2000; Samper et al., 2007, 2009) and in other Plio-Pleistocene Lesser Antilles Islands (Harford et al., 2002; Samper et al., 2009; Germa et al., 2010, 2011a) have shown large discrepancies in the results published during the 1980s (Bouysse et al., 1985; Briden et al., 1979; Gadalia et al., 1988; and references therein), likely due to the use of whole-rock K–Ar dating and/or weathered sample analyses. Consequently, no reliable ages were available to better date the eruptive phases of the intermediate arc until these recent studies. These ages are used as key parameters to better understand the variability in chemical weathering and erosion rates.

2.1. Martinique

Martinique is located in the central part of the Lesser Antilles where the arcs diverge. Martinique covers an area of 1080 km^2, in which eight volcanic units have been identified (Grunevald, 1965; Westercamp, 1972; Westercamp and Tazieff, 1980; Andreieff et al., 1988; Westercamp et al., 1989), from the basal complex and Saint Anne series (old arc), dated between 24.8 ± 0.4 and 20.8 ± 0.4 Ma (Germa et al., 2011a,b), to the active Montagne Pelée volcano.

Our study concerns northern Martinique and its four constituent parts: Mount Conil, Montagne Pelée, Piton du Carbet and Morn Jacob. Morne Jacob is the largest volcanic edifice on the island (5.1–1.5 Ma, Germa et al., 2010). The edifice is mainly andesitic, whereas its basement is basaltic. Piton du Carbet was edified later on, with an early (2 Ma) formation of andesitic composition that was later destroyed by a large flank-collapse event (Boudon et al., 1987)). Les Pitons (about 1 Ma) are andesitic lava domes. In the Piton du Carbet area, numerous ash flows are associated with the pitons. North of Piton du Carbet, Mount Conil is a recent volcanic edifice (1–0.5 Ma), composed of andesitic breccias, lava domes and lava flows (Westercamp, 1988). Montagne Pelée began forming at the end of Mount Conil's activity. The last eruptions of Montagne Pelée in 1902 produced a large accumulation of block-and-ash flow deposits (greater than 50–60 m in the Blanche River valley, which has been completely filled since that time (Boudon et al., 2005). Ashes from the 1902 eruption spread over the whole island. This recent material is particularly erodible, thus contributing to fast and high alteration.

2.2. Guadeloupe

Guadeloupe is includes two twin islands: Basse-Terre and Grande Terre. We focused our study on Basse-Terre. Basse-Terre is among the largest islands of the Lesser Antilles, i.e. 55 km long and

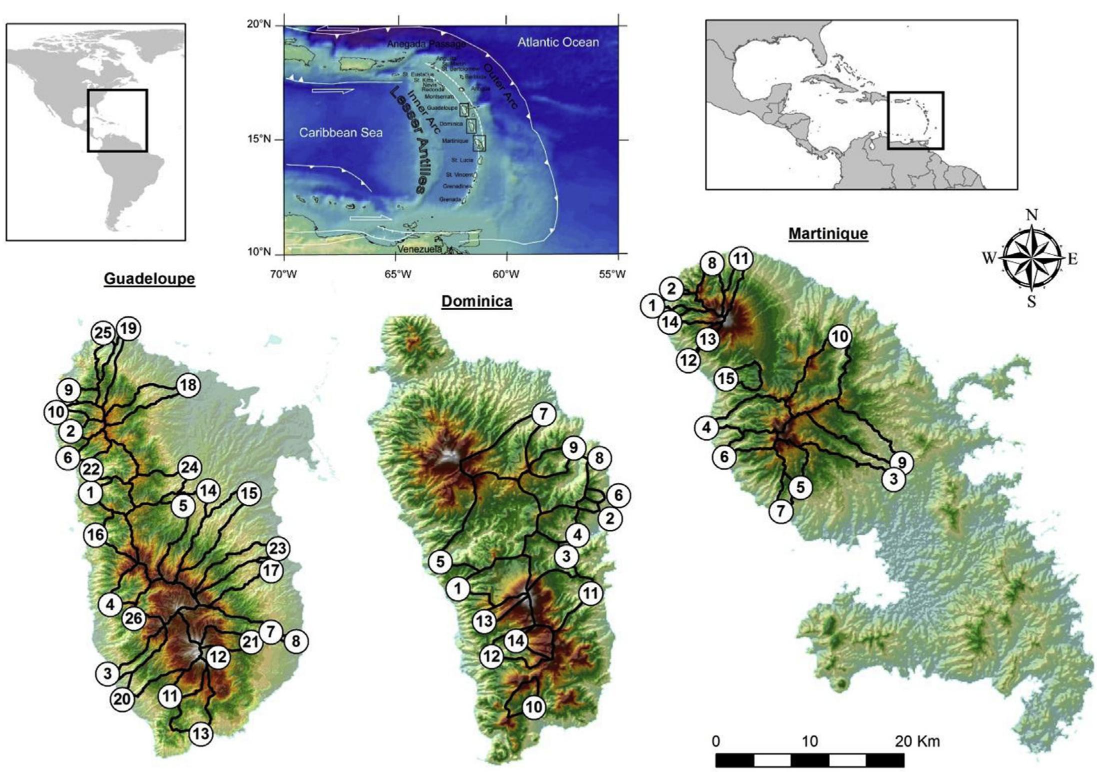

Fig. 1. Map of Martinique, Guadeloupe and Dominica in the Lesser Antilles, with the watershed locations on each island. The numbers in each basin refer to the table.