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River dissolved and solid loads in the Lesser Antilles: New insight into basalt weathering processes

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Abstract

We present here the first available estimations of chemical weathering and associated atmospheric CO_2 consumption rates as well as mechanical erosion rate for the Lesser Antilles. The chemical weathering (100–120 t/km^2/year) and CO_2 consumption (1.1–1.4 × 10^6 mol/km^2/year) rates are calculated after subtraction of the atmospheric and hydrothermal inputs in the chemical composition of the river dissolved loads. These rates thus reflect only the low-temperature basalt weathering. Mechanical erosion rates (approx. 800–4000 t/km^2/year) are estimated by a geochemical mass balance between the dissolved and solid loads and mean unaltered rock. The calculated chemical weathering rates and associated atmospheric CO_2 consumption rates are among the highest values worldwide but are still lower than those of other tropical volcanic islands and do not fit with the HCO_3^- concentration vs. 1/*T* correlation proposed by Dessert et al. (2001). The thick soils and explosive volcanism context of the Lesser Antilles are the two possible keys to this different weathering behaviour; the development of thick soils limits the chemical weathering and the presence of very porous pyroclastic flows allows an important water infiltration and thus subsurface weathering mechanisms, which are less effective for atmospheric CO_2 consumption.

Keywords: Lesser Antilles; Weathering; Basalt; Rivers; Thermal springs

1. Introduction

It is now well established that basalts are the silicate rocks with the highest weathering rates (Louvat, 1997; Dessert et al., 2003). Basalt weathering has thus to be taken into consideration in the worldwide evaluation of silicate weathering and associated atmospheric CO_2 consumption. Among all rivers draining basalts and andesite, only a few have been investigated in subduction contexts (Java: Louvat, 1997; Kamchatka: Dessert et al., 2001). This study on Caribbean Islands is one of the first on the denudation of volcanic arc relief. Besides getting a better comprehension of basalt weathering processes, we want to check how these new data fit in the law proposed by Dessert et al. (2001).

Guadeloupe and Martinique are characterised by a uniform andesitic lithology. They are located in a tropical climate with high temperatures (24–28 °C), high precipitation, very dense vegetation, sharp relief and very thick soils. Variations in runoff (4600 mm/year on the East coast, 2500 mm/year in the West Coast) and bedrock ages (0–5 Ma, North–South gradient) over short distances (<100 km) influence the weathering rates from one basin to another. Antilles rivers have a torrential hydrologic regime; their discharges can be

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multiplied by a factor 400 in less than 2 h during the rainy season (tropical storms). In such conditions, riverine transport of sediments and landslides are a major environmental concern.

In this paper, we quantify chemical and physical erosion processes by a geochemical study of river dissolved and solid materials.

2. Sampling and measurements

We have sampled the main streams of Guadeloupe, Martinique and Dominique (dissolved phases, suspended particles and sands) as well as some thermal springs and soils, in February 2003 and February 2004 (both low-water stages) and in October 2004 (high-water stage). Water samples were filtered through 0.2 μm filters. Major and trace element concentrations in soils, river sediments and dissolved phases were measured by HPLC and ICP-MS. Sr isotopic compositions of streams and thermal waters have been measured by TIMS.

3. Dissolved loads

The total dissolved solids load of Lesser Antilles rivers range from 27 to 255 mg/l for Guadeloupe (mean 68 mg/l), from 32 to 460 mg/l for Martinique (mean 79 mg/l) and from 33 to 106 mg/l for Dominique (mean 55 mg/l). Those values are high compared to major global rivers (Gaillardet et al., 1999) but lower other tropical volcanic islands as Reunion (Louvat and Allègre, 1998) and Java (Louvat, 1997). SiO_2 concentrations are homogeneous from one island to another, ranging from 213 to 1000 μmol/l. Major cation concentrations (Na, Ca, Mg, K) are within the same range for the 3 islands (respectively, 188–808 μmol/l, 32–697 μmol/l, 31–380 μmol/l and 11–56 μmol/l). Bicarbonates are the dominant anions for all islands with a mean value of 578 μmol/l. Cl concentrations (mean value of 340 μmol/l) are globally very high in comparison with other volcanic islands and their range is especially wide for Guadeloupe (150–1100 μmol/l). Rivers with the highest TDS are often located close to mapped hydrothermal activity.

Thermal springs of Guadeloupe and Martinique show a wide range of chemical compositions with contrasted SO_4/Na, Cl/Na and HCO_3/Na concentration ratios. Most of the sampled springs have relatively high SO_4 contents (19–7843 μmol/l) and low pH. Their TDS load is between 149 and 9200 mg/l. Trace elements such as Li and B are particularly enriched in thermal springs and, together with SO_4^{2-}, are good tracers of a hydrothermal contribution to the river dissolved loads (and may even serve to discover unknown or new springs).

The $^{87}Sr/^{86}Sr$ isotopic ratios of the main rivers vary between 0.70457 and 0.70514 for Guadeloupe and between 0.70413 and 0.70585 for Martinique. Basalt $^{87}Sr/^{86}Sr$ isotopic ratios of Lesser Antilles are very variable ranging from 0.70354 to 0.70624 for Martinique (Davidson, 1986) and from 0.70341 to 0.70485 for Guadeloupe (White and Dupré, 1986), which is lower than our mean value in rivers. Values of $^{87}Sr/^{86}Sr$ isotopic ratios reflect both chemical weathering of the andesite rocks and an atmospheric input of an ocean-derived Sr.

Our Lesser Antilles river data set on major and trace elements and Sr isotopes allows us to identify, in the chemical composition of the dissolved loads, the fraction derived from low-temperature alteration only. Atmospheric and hydrothermal inputs are corrected on the basis of mixing equations of X/Na concentration ratios (X being a major or trace element other than Na), which characterise the various end-members: low-temperature alteration, atmosphere (with oceanic-like X/Na ratios) and hydrothermalism (many end-members have to be defined for this input because of the variability of the thermal spring chemical compositions). Two mixing diagrams for Lesser Antilles rivers and thermal springs are illustrated in Fig. 1a and b for Guadeloupe only.

4. Solid load

The aim of our sampling for Antilles river solid loads is two-folds: to quantify the river sediment transport and to geochemically characterise its weathering state. In order to compare the river solid load chemical composition with that of local unaltered rocks, we represent their extended REE patterns normalised to a primitive mantle composition (Hoffman, 1988) (Fig. 2). The order of the elements has been chosen such that the mean unaltered rock composition has a regular decreasing pattern. For Guadeloupe and Martinique, sand samples have chemical compositions very similar to those of the volcanic rocks of those islands, but with negative anomalies corresponding to the partial dissolution of the rocks.

Fig. 2 presents extended REE patterns for one river in Guadeloupe where we have a very complete set of samples with two sands (one near the source and the other near the mouth of the river), one suspended load and one soil sample. The patterns of mean unaltered rocks (data from Samper, personal communication) and sand are very similar except for soluble elements for