



Where is basalt in river sediments, and why does it matter?



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ABSTRACT

Weathering, erosion and mineralogical sorting processes modify the chemical and isotopic compositions of sediments relative to those of their source rocks. The way and extent to which those processes affect the geochemistry of sediments is however not yet fully understood. Here, we report trace element data as well as Nd, Hf and Pb isotopic compositions of sediments sampled at different water depths in the Ganges, Yamuna and Chambal Rivers draining the Deccan Traps basalts and the crystalline and sedimentary rocks from the Himalayan mountain range and the northern Indian shield.

Isotopic differences between surface and bed sediments sampled at the same location reach 6 ϵ_{Nd} and about 15 ϵ_{Hf} units, suggesting that suspended loads and bedloads do not carry similar provenance information. Such differences are explained by the combined effects of differential erosion and mineralogical sorting processes during fluvial transport. Materials eroded from basalts are preferentially transported in suspension near the river surface while materials eroded from more crystalline precursors are transported near the bottom of the river. This depth-dependent provenance within the river channel leads to an overrepresentation of basaltic materials in fine-grained suspended loads that are finally delivered into the ocean and become part of the oceanic terrigenous clays. By contrast, the proportion of basaltic materials in coarser sediments such as bedloads or turbidites is underestimated.

Our results have important consequences on the use of Nd, Hf and Pb isotopic compositions of sediments as provenance proxies because they indicate that all grain-size fractions must be taken into account to properly trace source compositions. They also suggest that upper continental crust estimates derived from fine-grained sediments, such as suspended loads, may be biased towards basaltic compositions if basaltic outcrops are present in the drainage area.

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1. Introduction

River sediments are essentially mixtures of particles and minerals derived from the erosion of rocks exposed in the catchment area. Their chemical and isotopic compositions are often used to trace sources, estimate the average composition of the drained area or determine chemical and physical erosion rates in large basins (e.g. Goldstein et al., 1984; Goldstein and Jacobsen, 1988; Asmerom and Jacobsen, 1993; Allègre et al., 1996; Galy and France-Lanord, 2001; Clift et al., 2002; Singh and France-Lanord, 2002; Vance et al., 2003; Millot et al., 2004; Kamber et al., 2005; Richards et al., 2005; Roddaz et al., 2005; Belousova et al., 2006; Singh et al., 2008; Singh, 2009; Dhuime et al., 2011; Padoan et al., 2011; Lupker et al., 2011, 2012a). However, using sediments

as such proxies requires a proper understanding of biases introduced by erosion and sedimentary processes on chemical and isotopic compositions. Some studies have previously shown that the geographical extend of the source rocks in the catchment area does not always match with the proportions deduced from the isotopic compositions of sediments (Allègre and Rousseau, 1984; Goldstein and Jacobsen, 1988; Kramers and Tolstikhin, 1997; Tricca et al., 1999; Steinmann and Stille, 2008; Dhuime et al., 2011). This is because some lithologies are more erodible than others and/or are affected differently by climates that favor either chemical or physical alteration of rocks. Besides, it has been shown that the hydrodynamic sorting of particles within the water column during fluvial transport introduces large fractionation of the chemical and isotopic messages carried by bedload and suspended load sediments (Lupker et al., 2011; Bouchez et al., 2011; Garzanti et al., 2010, 2011; Garçon et al., 2013a, 2013b, 2014). Here, we go one step further and evaluate the combined effects of (a) contrasting climate and rock erodibility in the catchment area of a large river system and (b) isotopic fractionation caused by hydrodynamic

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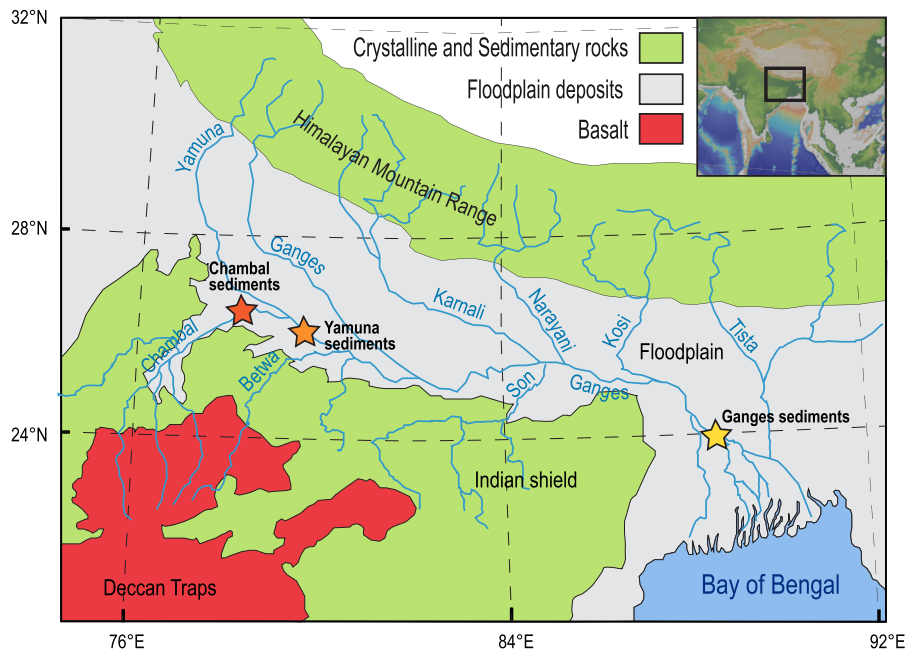


Fig. 1. Map of the Ganges fluvial system showing where crystalline, sedimentary and basaltic rocks occur in the drainage basin. Modified after Galy et al. (2010). Stars indicate the sampling locations of the sediments discussed in this study. See Table 1 for additional information on the location and nature of the different samples.

sorting in the water column during fluvial transport. We discuss trace element concentrations and Nd, Hf, Pb isotopic compositions of sediments sampled at different water depths in the Ganges fluvial system that drains the Deccan Traps basalts and the crystalline and sedimentary rocks of both the Himalayan range and the northern Indian shield. We show that bedloads and suspended loads carry different provenance information and discuss potential implications for worldwide terrigenous sediments.

2. Geological setting and sampling

Sedimentary material was recovered at three different sampling sites along the Ganges fluvial system (Fig. 1). Samples include bedload and suspended load sampled at different water depths in the Yamuna and Ganges Rivers as well as bank sediments and surface suspended loads from the Chambal River. All samples were recovered at high flow during the monsoon season (July to September) from 1996 to 2009. Bank sediments were sampled on the river shore while bedloads were dredged up from the bottom of the rivers. Suspended loads were sampled at the same location than bedloads, at the water surface or at different depths within the river channel. They were recovered after filtration of about 5 L of river water under pressure through 0.2 μm filters. Detailed sampling techniques can be found in Galy et al. (2008) and Lupker et al. (2011).

The first sampling site is located in Bangladesh at the outflow of the Ganges River (Fig. 1); given its location, it integrates all sediments transported by the Ganges and its tributaries. The drainage basin covers about one million km^2 and includes Quaternary fluvial deposits from the Indo-Gangetic floodplain, variably metamorphosed crystalline and sedimentary rocks from both the Himalayan mountain range and the northern Indian shield, and few basaltic rocks from the Deccan Traps (Le Fort, 1975; Krishnan, 1982). At this location, the Deccan Traps basalts represent only 4% of the total drained area. Major and trace element concentrations, as well as Nd, Hf and Pb isotopic compositions of sediments sampled at this location have been previously published by Lupker et al. (2011) and Garçon et al. (2013a, 2013b) but are reported for convenience in Table 1.

The two other sampling sites are both located upstream in the floodplain, in the Yamuna and in the Chambal Rivers. At the Yamuna sampling site, the drainage basin consists of $\sim 20\%$ of basalts from the Deccan Traps, $\sim 40\%$ of crystalline and sedimentary rocks from both the Himalayan mountain range and the northern Indian shield and $\sim 40\%$ of Quaternary floodplain deposits, mostly derived from the erosion of the Himalayas (Fig. 1). At the Chambal sampling site, the Deccan Traps basalts constitute 30% of the basin area, the crystalline and sedimentary rocks from the Indian shield represent $\sim 60\%$ and the remaining 10% consists of Quaternary floodplain deposits containing the erosion products of both the Deccan Traps basalts and the Indian shield (Fig. 1).

3. Analytical techniques

All samples were powdered in agate bowls using a planetary ball mill. They were pre-treated for 2 days in HNO_3 14N on a hot plate at 130°C , then evaporated and digested in a HF-HClO_4 mixture in PARR® bombs for 6 weeks at 140°C or one week at 200°C . After complete dissolution, trace element concentrations and Nd–Hf–Pb isotopes were measured following the procedures described by Chauvel et al. (2011). Repeated measurements of BR or BR-24 rock standards were used to calibrate trace element concentrations. The validity and reproducibility of the trace element data is estimated to be better than 5% for most elements based on the analyses of several complete duplicates and repeated measurements of international rock standards as unknown samples, including sedimentary materials such as JSd-2 (see Supplementary Table 1 for more details). Neodymium, Hf, and Pb were isolated using ion chromatography (Chauvel et al., 2011). Total procedural blanks were less than 100 pg for Nd, Hf and Pb. Isotopic compositions were measured on a Nu Plasma HR MC-ICP-MS at the ENS Lyon (France). For Nd and Hf, mass bias corrections were performed using $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$ and $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$, respectively. The reproducibility (2σ) of the Ames-Rennes Nd and Ames-Grenoble Hf reference standards run every two or three samples was better than 40 ppm for $^{143}\text{Nd}/^{144}\text{Nd}$ and $^{176}\text{Hf}/^{177}\text{Hf}$ ratios. The analytical drift was corrected using the recommended values of 0.511961 for the

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