Distribution of physical erosion in Himalaya from river particle geochemistry

A. Galy
C. France-Lanord
CRPG-CNRS, BP 20, 54501 Vandoeuvre-les-Nancy, France

J.-E. Hurtrez
UMR 5573, Laboratoire Géophysique et Tectonique, Université Montpellier II case 060, 34095, Montpellier Cedex 5, France

The Himalayan range is exposed to a large variety of erosion processes such as glaciation, landsliding and soil development under varying climatic regimes. While it is clear from river profile geometry that intense physical erosion is concentrated on the south flank of the high range (Seeber and Goernitz, 1983) the proportion of erosion between the different zones (North Himalaya, High Himalaya, Lesser Himalaya) remains largely unknown, as do the importance of the different erosion processses. The study of eroded material in river loads or sedimentary basins is one way to adress these problems. The overall composition of the different Himalayan formations are similar, primarily variably metamorphosed mixed clastic and carbonate strata. Lithology does not provide diagnostic test for the origin of river particles. In contrast several geochemical tracers have distinct values in different formations which acan be used to decipher the origin of detrital particles. We present a geochemical study of river bedload and suspended load in rivers from the Narayani watershed in Central Nepal Himalaya and Ganges and Brahmaputra in Bangladesh.

The geochemical characteristics of the main geological formations are mostly known from previous geochemical studies. Small watersheds draining single geological formations have been sampled to improve our understanding of the end members. Main rivers in Nepal have been sampled from their source in Tibet down to the floodplain. For bedload samples, analyses have been caried out on whole decarbonated bedloads, leachable fractions, and <2μm clay fractions. Analyses includes major and trace elements, Sr, Nd and O isotopic compositions.

Himalayan sediment sources

In the Himalaya, the main geological formations follow more or less the main geomorphologic divisions. The north basins and part of the high range belong to the Tethyan Sedimentary Series (TSS). They are mostly composed of carbonate and clastic platform sediments, more or less metamophosed. The isotopic characteristics of the silicate rocks are $^{87}Sr/^{86}Sr \sim 0.725 \pm 0.01$, ε_{Nd} varies from -16 to -12. Most of the south flank of the range is composed of the High Himalaya Crystalline (HHC), highly metamorphosed paragneisses and migmatites . Average $^{87}Sr/^{86}Sr \sim 0.75 \pm 0.02$ and $\varepsilon_{Nd} \sim -15 \pm 2$. The Lesser Himalaya (LH) is mostly composed of schist, quartzite and minor limestone, variably metamorphosed. $^{87}Sr/^{86}Sr$ is higher than 0.85, $\varepsilon_{Nd} \sim -25$, and metamorphic ages are from 1.5 to 2.0 Ga. Each formation is heterogeneous which reduces the accuracy of the source quantification. The isotopic signature of bedload from tributaries that only drain a single formation are indistinguishable with those of the local source rocks.

Bedload origin

In Central Nepal, along the Kali-Gandaki profile, $^{87}Sr/^{86}Sr$ and ε_{Nd} of bedload sands covary with the distance to the source and are interpreted in terms of proportions of the different sources of particles (Fig. 1). The head of the basin erodes mainly TSS and some HHC-derived leucogranites. As soon as the river reaches the HHC, the suspended load becomes completely dominated by these rocks. This change corresponds to a zone of rapid incision as shown by the steepening of the river profile. Downstream the respective proportion of each formation in the bedload (TSS, HHC and LH) is around 25, 45 and 30% whereas their relative outcrop areas in the basin are 27, 15 and 57%. We find similar results for other major Himalayan rivers sampled in Nepal. The HHC appears as the dominant source of detrital material. This likely result from the distribution of precipitation and preferential uplift in the high range. Precipitation on the northern basin is only about 1/20 of that on the south flank. To the south the preponderance of HHC in the river load over LH is

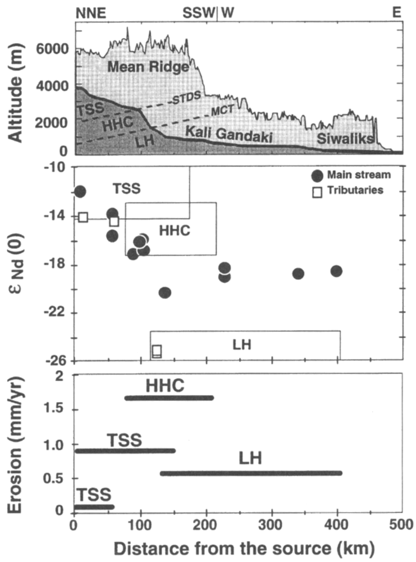

FIG. 1. Variation of the isotopic composition of Nd in the silicate fraction of the bedload along the Kali Gandaki profile. While the basin has a 42% area in the LH formation, bedloads are mostly composed of HHC-derived materials. This translates into contrasted rate of erosion between the different formations.

consistant with the higher relief of the HHC, probably in response to preferential uplift in this zone (Pandey *et al.*, 1995). The predominance of the HHC in the detrital load is observed in the Ganges and Brahmaputra in Bangladesh as well as in the Bengal Fan (France-Lanord *et al.*, 1993).

Himalayan erosion rate

For the whole Narayani watershed, which drains *c.* 10% of the Himalaya, the flux of suspended particles is around 80 × 10^6 tons/yr. The relative contribution of each formation (TSS, HHC and LH) is respectively 25, 45 and 30% for relative basin areas around 31, 27 and 42%. This indicates erosion rate for these 3 formations of 0.8, 1.6, and 0.6 mm/yr respectively. In the Trisuli basin, the TSS are restricted to the north of the high range but still represent 50% of the drainage area. The erosion rate of the TSS is only 0.1 mm/yr. All these values are underestimated since they depends on suspended load fluxes whereas the bedload flux is also very important in this type or river. Assuming that bedload fluxes double the suspended load fluxes, calculated erosion rates are in agreement with long term erosion rates from cooling ages (e.g. Harrison, 1997).

Seasonal variability

Seasonal variations are observed at a given location for $^{87}Sr/^{86}Sr$ of detrital carbonates as well as for ε_{Nd} of detrital silicates. For the Brahmaputra the HHC dominate during the monsoon ($\varepsilon_{Nd} = -16.9$), but a northern Himalayan source is resolvable 6 months later ($\varepsilon_{Nd} = -13.6$). These results indicate that during the dry season more material from the northern terranes is transported by the rivers. A similar tendency is observed in the dissolved load. The observation of this seasonal variability in the Brahmaputra implies that the turnover of the bedload is extremely rapid. Such variability is not observed for the Ganges.

Grain size variability

Clay fractions corresponds to 1–2% of the bedload and 60-80% of the suspended load. Clay fractions of major Himalayan rivers as well as Ganges and Brahmaputra have ε_{Nd} 1 to 3 ε unit higher than their correspondent whole bedload. The proportion of HHC material is therefore 10–20% higher in the clay fraction than in the silt fraction. Similar differences were observed between silt and clay on Miocene sediment from the Bengal Fan (Galy *et al.* 1996). This result appears surprising because soils are much thicker in the LH than in the HHC. It shows that in Himalaya, other processes of clay production like physical grinding in glaciers and during transport are important sources of very fine particles. The chemical composition of clays from river load support this interpretation as the chemical alteration index is lower in river clays than in soils from LH or HHC. Physical processes clearly prevail over alteration and soil development in Himalayan erosion.

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