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Comparison between silicate weathering and physical erosion rates in Andean basins of the Amazon river

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Abstract

From published data based on the HYBAM observatory database, we explore the relationship between silicate weathering rates and physical erosion rates over the Andean basins of the Amazon River.

No homogenous relationship between erosion rates and chemical weathering rate is observed over this area. Only the volcanic basins respond to the global relationship defined by Millot et al¹. For remaining areas, two hypotheses can explain the absence of coherence with this global empiric law: 1) The relationship between weathering and physical erosion rates need to be defined for each lithological class, and 2) For erosion rates higher than around 1000t.km⁻².yr⁻¹ the system is “weathering limited”.

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1. Introduction

At the global scale and on geological time scales, mechanical erosion and chemical weathering budgets are linked²⁻⁶. Together, these processes contribute to the degradation of the Earth's critical zone and to the biogeochemical cycles of elements. The study of the relationships between silicate weathering and physical erosion in orogenic contexts allows for a better understanding of the role of mountains belt formation in these biogeochemical cycles and in particular in the long-term carbon cycle.

At the global scale a good correlation between chemical silicate weathering and physical erosion rates has been observed for large rivers⁴ and in both basaltic and granitic orogenic domains^{1,7}. The mechanism which relates these two processes depends on the depth of the weathering zone (e.g. the soil) and hence on the geomorphological regime⁸⁻¹⁰. The thickness of the weathering zone depends on the balance between the downward propagation of the weathering front at depth and physical erosion processes at the surface. When chemical weathering at depth is the dominant process over erosion, the weathering budget can be limited by the accumulation of weathered material in deep soils, which limits the contact between primary minerals and water in soils²². This case is named erosion limited. By opposition, if the physical erosion processes are dominant, the limiting factor is kinetic because mechanical erosion allows for primary minerals to be present near the surface as the weathering rate is slower than the rate of solid matter exportation. In this case, the weathering rate depends on kinetic parameters¹¹⁻¹³.

We compare the mechanical erosion and silicate weathering rates of the Andean basins of the Amazon river determined from the large and unique hydrological, suspended sediments and geochemical database of the PHICAB and HYBAM programs. We used the published results of total suspended solid budgets¹⁴⁻¹⁶ and silicate weathering budgets¹⁷ resulting from these observatories.

2. Material and method

The silicate weathering rate is measured here using TZ_{sil}^+ values (flux of cations released by silicate weathering) and erosion rates using TSS (flux of Total Suspended Solids) in order to compare the results with the global relationship between chemical weathering and TSS rates defined by Millot et al¹. We explore here the annual TZ_{sil}^+ , TSS and runoff determined over 13 gauging stations of the PHICAB and HYBAM observatories (www.ore-hybam.org) located at the outlet of Andean headwater basins of Amazon River (see calculation methods in the respective papers¹⁴⁻¹⁷) (Figure 1). These gauging stations record the export of around 86% of the total Andean area of the Amazon basin (defined as altitude > 500 m.a.s.l).

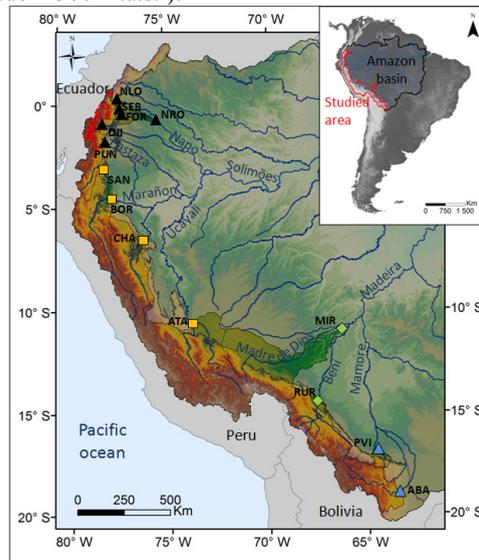


Fig. 1 : Studied area and location of the gauging stations. Red triangles represent the active volcanoes of the Amazon basin.

On the annual timescale, a south-north rainfall rate gradient is observed. This gradient is reflected in the range of annual runoff with values of 117 mm.yr⁻¹ (Rio Grande at ABA) to near 3000 mm.yr⁻¹ in the north (Upper Napo). This gradient is associated to a north-south seasonality gradient with values from 0.4, in the north, to 2.7, in the south (Seasonality Index = $\sigma[Q_{\text{month}}]/Q_{\text{mean}}$ *i.e.* standard deviation of the monthly runoff distribution divided by annual average; Figure 2A).

The Andean silicate lithology follows a north-south gradient with volcanic rocks dominating in the northern basins (Napo and Pastaza basin), mixed lithology in the central part (volcanic rocks, plutonic and metamorphic rocks, and sedimentary rocks; Maranon and Ucayali basins) and recycled sedimentary rocks in the southern Andean basins (Beni and Mamore basins).

3. Results and discussion

Chemical weathering rates display a north-south gradient. For a given runoff value, volcanic areas are more active in term of chemical weathering than others areas, *i.e.* the TZ^+_{sil} concentration released in rivers is higher in volcanic areas than other contexts (Figure 2B). This is consistent with the higher weatherability of volcanic glass¹⁸. For the others basins, it is not possible to distinguish the respective roles of lithology and runoff because the lowest chemical weathering rates are encountered for basins with both low runoff and recycled sedimentary lithology (*i.e.* the least weatherable lithology; Figure 2B).

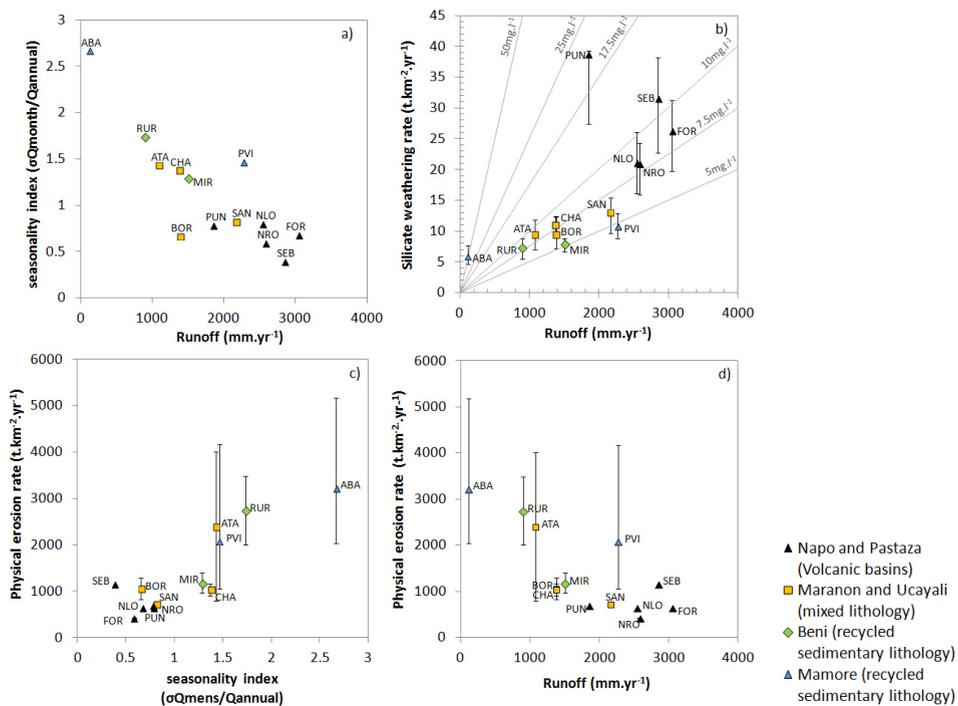


Figure 2 : Hydrological seasonality index as function of runoff (a) (HYBAM database), silicate weathering rates (TZ^+_{sil}) as function of runoff (b)¹⁷, physical erosion rates (TSS) as function of seasonality index (c) and runoff (d)^{14,15, 16}. TSS uncertainties have not been estimated for volcanic basins.

Physical erosion rates display a south-north gradient with values higher than 1000 t.km⁻².yr⁻¹ in Upper Madeira basin and values lower than 700 t.km⁻².yr⁻¹ in most of the Upper Napo basins. Throughout the study of erosion rates of Andean basins draining to the Atlantic Ocean,¹⁹ showed that this gradient is mainly related to the hydro-climatological seasonality gradient (Figure 2A). Consequently, physical erosion rates decrease with increasing runoff over the studied area (Figure 2D).

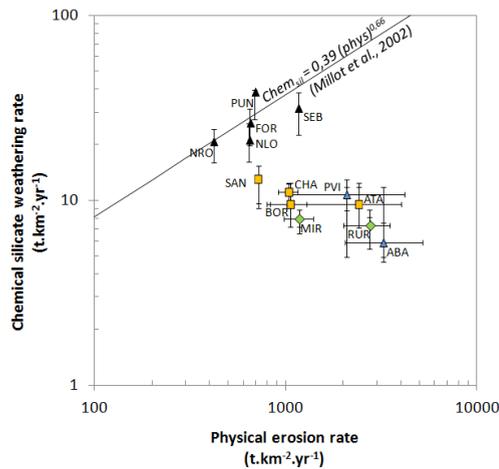


Figure 3 : Relationship between chemical silicate weathering and physical erosion rates for Andean basins of the Amazon River. The global empirical law defined by Millot et al.¹ for granitoid and basaltic basins is also shown.

Comparing the chemical weathering rate with the physical erosion rate over the studied area (Figure 3), it appears that volcanic basins (Upper Napo and Pastaza basins) respond to the global empirical law defined Millot et al.¹ based on basaltic and granitic basins over the world. The other basins do not follow this law. This observation can be explained by two hypotheses. First, it might be that a relationship between chemical weathering rate and physical erosion rate has to be defined for each lithological class (volcanic, mixed lithology, recycled sedimentary class). In this case, the regression values depend mainly on the lithology which dominates the chemical weathering rates of each class. Second, it could be argued that the relationship between chemical weathering rate and physical erosion rate crosses a threshold at high physical erosion rates. This case would correspond to the “weathering-limited” regime¹⁰. In this case reaction kinetics are a limiting factor, i.e. weathering processes are too slow to compete with solid matter exportation. However, primary material weathering processes could occur mainly in the foreland and plain sedimentary areas as suggested by Bouchez et al.²⁰ and Moquet et al.¹⁷ for the Amazon (see also Bouchez et al.²¹ in this issue). Note that these two hypotheses are not mutually exclusive.

4. Conclusion

This paper reports a synthesis of HYBAM observatory results over Andean basins. Physical erosion rates over this area have been shown previously to be mainly controlled by the hydro-climatological seasonality. Chemical weathering rates display a north-south gradient. The respective roles of lithology and runoff on this gradient cannot be determined yet. The relationship between chemical weathering and physical erosion rates is consistent with the global empiric law defined by Millot et al.¹ only for volcanic basins.

Further studies need to be carried out to better constrain the parameters controlling the weathering and physical erosion in the Andean context. This could be provided throughout a higher spatial resolution of chemical weathering and physical erosion rates in along the Andean chain, especially in high extreme erosion and rainfall contexts.

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