

Silicate rock weathering and atmospheric/soil CO₂ consumed by major world river basins

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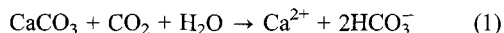
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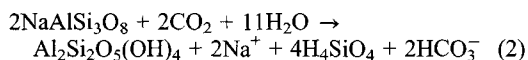
Continental erosion combines both physical and chemical processes which release organic and inorganic materials to be exported as particulate and dissolved phases by rivers into the oceans. The chemical and mechanical erosion of soil organic matter releases dissolved and particulate organic carbon, originating from atmospheric CO₂, via photosynthesis, and transported into the oceans (360 Tg C.y⁻¹, see Ludwig *et al.*, 1996). The chemical erosion of inorganic materials consists in dissolving or hydrolyzing primary minerals of rocks and soils, releasing dissolved elements which are drained into groundwater and rivers. The chemical weathering processes require CO₂ and several authors have modelled the natural weathering pathway caused by the carbonic acid reaction with

minerals to produce dissolved inorganic carbon (Garrels and Mackenzie, 1971; Amiotte Suchet and Probst, 1995):

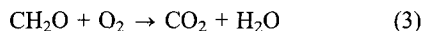
Carbonate mineral dissolution:



Silicate mineral hydrolysis:



In these above equations, the CO₂ originates from the atmosphere and is provided by soil organic matter oxidation:



For carbonate dissolution (eq. 1) only half the bicarbonate originates from atmospheric/soil CO₂, whereas for silicate hydrolysis (eq. 2), all the bicarbonate are derived from the CO₂. On a global scale, atmospheric/soil CO₂ consumed both by carbonate and silicate rock weathering amounts 230 Tg C.y⁻¹ which represents 70% of the total bicarbonate ions exported by the rivers into the oceans. The remaining 30% are supplied by carbonate dissolution (Ludwig *et al.*, this volume). By difference between the two previous values, the atmospheric/soil CO₂ consumed by silicate weathering can be estimated to 140 Tg C.y⁻¹.

As seen in Fig. 1, the fluxes of CO₂ consumed by silicate rock weathering are maximum in the tropical-

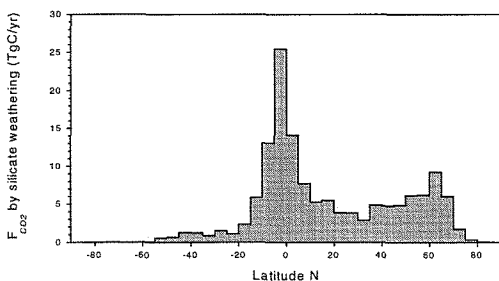


FIG. 1. Latitudinal distribution of atmospheric/soil CO₂ consumed by silicate weathering (TgC.y⁻¹).

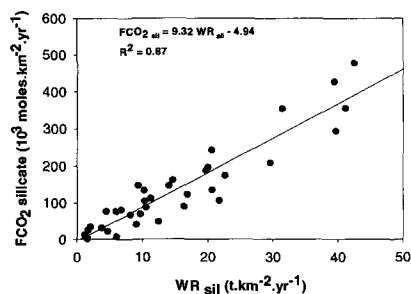


FIG. 2. Relationship between the flux of atmospheric/soil CO_2 consumed by silicate rock weathering (F_{CO_2}) and the specific silicate chemical erosion rate (WR_{sil}) for major world river basins.

equatorial regions and in high latitudes of northern hemisphere. These two peaks correspond respectively to high runoff intensity in tropical-equatorial latitudes and to largest areas of silicate rock outcrops in high latitudes (see Amiotte Suchet, 1995). The contribution of tropical-equatorial areas represents 63% of the total CO_2 consumption by silicate rock weathering. These climatic regions corresponds to the domain of lateritic soil covers (see Tardy, 1993). The silicate weathering in tundra/taiga and temperate (dry and wet) climatic areas consumes respectively 17% and 18% of the total CO_2 uptake by silicate weathering.

On a geological time scale, the flux of CO_2 consumed by carbonate dissolution on the continents is balanced by the CO_2 fluxes released to the atmosphere by carbonate precipitation in the oceans (Berner *et al.* 1983, Francois *et al.*, 1993). Whereas continental CO_2 uptake by silicate weathering is balanced on a steady state by CO_2 released in the atmosphere by volcanic activity, metamorphism and carbonate precipitation too. Then, during the geological times, the atmospheric CO_2 is partly controlled by the equilibrium between silicate rock erosion and tectonic activity as these two processes have been fluctuating. Therefore, it is important to consider not only the total CO_2 flux consumed by the total continental erosion but above all, the CO_2 uptake by silicate rock weathering. With regard to the global carbon cycle, the fluxes of CO_2 consumed by silicate rock weathering represent a non-negligible sink of CO_2 for the atmosphere.

The CO_2 fluxes consumed by silicate weathering have been calculated for about forty large river basins by Amiotte Suchet (1995) from river fluxes of alkalinity (data from the literature) using a geochemical modelling (MEGA) based on the stoichiometry of

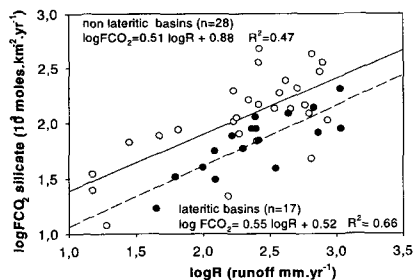


FIG. 3. Relationships between CO_2 flux consumed by silicate weathering and annual runoff for large river basins in lateritic (black circles) and non-lateritic (white circles) areas. For details and basic data, see Boeglin and Probst (1998).

the chemical reactions which control the dissolution and hydrolysis of the different minerals and on the ionic ratios in streamwater draining major rock types (see also Amiotte Suchet and Probst 1996; Probst *et al.* 1994 and 1997; Boeglin and Probst, 1998). As shown in Fig. 2, the flux of CO_2 consumed by silicate weathering is directly proportional to the silicate rock weathering rate (total dissolved elements released by chemical erosion of silicate rocks and expressed in $\text{t.km}^{-2}.\text{y}^{-1}$).

As previously shown by different authors, climate (e.g. precipitation, runoff and temperature) is one of the main factors controlling silicate rock weathering and consequently, atmospheric/soil CO_2 fluxes (Velbel, 1993; Amiotte Suchet and Probst, 1993; White and Blum, 1995). As can be seen in Fig. 3, there are good linear relationships between CO_2 fluxes and runoff for the major world river basins. Nevertheless, this Fig. clearly shows that, for similar runoff, the CO_2 flux consumed by silicate weathering is lower for lateritic drainage basins than for non-lateritic ones. For a mean runoff of 250 mm.y^{-1} , the chemical weathering of silicate consumes a specific CO_2 flux about 1.8 times higher in lateritic drainage basins than in non-lateritic ones. It is important to consider such a difference because the lateritic covers occupy 33% of the whole continental areas (Tardy, 1993). However, this difference cannot necessarily be attributed to lower weathering intensity in lateritic regions, but also to other parameters such as relief, mineralogical weathering stage or thickness of soil profiles.

All these controlling factors must be now studied in detail in small watersheds, particularly in lateritic areas, as well as in large river basins to better understand silicate weathering processes at such scales and to simulate silicate weathering rate, CO_2 flux and alkalinity inputs to the oceans during geological times.