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ScienceDirect
Procedia Earth and Planetary Science 10 (2014) 34 – 37
Procedia
Earth and Planetary Science

Geochemistry of the Earth's Surface meeting, GES-10

Impact of vegetation and decennial rainfall fluctuations on the weathering fluxes exported from a dry tropical forest (Mule Hole)

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Abstract

The small experimental watershed of Mule Hole has been monitored for hydrology and chemistry since the last decade at hourly frequency for stream and monthly frequency for groundwater. It is covered by a dry tropical forest which generates intense evapotranspiration, limiting both runoff and groundwater recharge. Stream and groundwater fluxes are then disconnected, which provides a unique opportunity for distinguishing surficial from deep biogeochemical processes occurring in the watershed. Here, monthly monitoring of groundwater levels and chemistry were combined with hydrological modeling for studying how vegetation mediates the water stock in the vadose zone and the groundwater flux, and how this impacts the output flux of sodium by groundwater at seasonal and decadal scales. It is found that evapotranspiration intensity controls the pore water saturation with Na-plagioclase, which determines the depth of chemical weathering (soil vs saprolite). Moreover, evapotranspiration intensity regulates the water residence time in the vadose zone, from about a year downslope to 20 years upslope and the local groundwater discharge. These delays induce long term fluctuations in groundwater output fluxes and therefore in silicate weathering fluxes.

Peer-review under responsibility of the Scientific Committee of GES-10

Keywords: Vegetation cycling; silicate weathering; Tropics; nutrients; mass balance; South India

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Peer-review under responsibility of the Scientific Committee of GES-10
doi:10.1016/j.proeps.2014.08.007

1. Introduction

In weathering mass balances studies, it is often considered that vegetation only affects nutrient cycles and that cycling through vegetation is internal to the system; i.e. it would not contribute to the solute flux exported from the watershed. However, recent studies demonstrated that nutrients K, Ca and Mg partially transit through vegetation before reaching the stream, especially in tropical forests[1,2,3]. Similar behavior was also observed for silica[3,4] and alkalinity[3]. Vegetation constitutes a temporary reservoir that can enhance or mediate the exported solute fluxes and then affect the calculation of short term silicate weathering rates and associated CO_2 consumption. This is illustrated using a 10-year time series of hydrology and hydrochemistry from the small experimental watershed of Mule Hole (South India), which constitutes an extreme case of control by the vegetation of the water and solute fluxes. The intense evapotranspiration prevents the connection between groundwater and streams[5]. In this specific hydrological context, with intense vegetation cycling (canopy and litter leaching) due to tropical conditions, almost 90% of the solute fluxes exported by the ephemeral stream have transited through vegetation[3]. However, the major part of solute flux is exported by groundwater flow[6]. We present a dynamic approach for calculating the solute fluxes exported by groundwater since the last decade, in response to the rainfall variability, taking into account the evapotranspiration in the vadose zone. The long term monitoring of groundwater level and chemistry was combined with the 1D hydrological model COMFORT[7] to (1) locate the origin of solute fluxes in the regolith profile, (2) assess the role of evapotranspiration and transit time in the vadose zone and (3) establish the dynamics of solute export flux by groundwater. This abstract focuses on the processes controlling the short and long term Na export by groundwater.

2. Study site

The Mule Hole watershed is located in a sub-humid tropical climate in South India and covered by a secondary dry deciduous forest. It has been monitored since 2003 with hourly sampling of stream and monthly sampling of groundwater. According to the 2004-2006 water budget, established based on a steady state hypothesis, evapotranspiration accounts for 86% of the water budget while groundwater recharge and runoff account for only 6 and 8%, respectively[5]. We analyzed time-series of groundwater table level and chemistry in 3 piezometers: two deep (water table level ~35m) piezometers located upslope (P5) and (P6) in gneiss and amphibolite respectively and one shallow (water table level ~15m) located downslope (P10) in a mix of gneiss and amphibolite. The lumped hydrological model COMFORT[7], was calibrated on stream discharge and groundwater level for the 2003-2008 period, and used to compute water flows and residence time in the soil, saprolite and groundwater reservoirs over the last decade.

3. Results and discussion

3.1. Lag in groundwater recharge and estimated residence times

In all piezometers, the water table exhibited a rising trend over the 10 year period, with increases of about 6m. In the shallower one (P10), water table level responded every year to recharge (2-3 month periods) while in the deeper ones, two main recharge periods occurred (beginning at the end of years 2007 and 2010), spanning more than one year each. The COMFORT model suggests that the large initial lag between recharge and water table response for the deep piezometers (e.g. 3 years from 2004 to 2007) was due to the depletion of the water stock in the deep vadose zone (due to uptake by deep tree roots) during the 2001-2003 drought years. Accordingly, the first recharge event in 2007 resulted from water infiltrating over a long period (2004-2007) while the recharge event in 2010, which was more intense, was due to water infiltrating mostly during the same year.

3.2. Sources of Na in the groundwater

The solute mass balance performed at the soil-plant scale[3] indicated that only Na, and to a lesser extent Si, were released by the soil layer. About one third of the Cl input was withdrawn from the soil pore water, presumably by vegetation uptake, while evapotranspiration in the soil layer was as high as 80% of the infiltration flux. This makes

Cl the least affected of solute species in the soil. Although not fully conservative in the soil, Cl can be used to normalize cations and silica of groundwater and for locating which zones of the regolith (soil or saprolite) are contributing to chemical weathering over time. Applied to Na, this approach revealed that the zones contributing to Na release varied in space and time (fig.1). In the upslope gneiss piezometer, Na mostly originated and was transferred from the soil layer. In the upslope amphibolite piezometer, saprolite contribution dominated during the recharge event of 2007, while soil contribution dominated during the recharge event of 2010. The downslope piezometer displayed both seasonal and long term decreases of the Na/Cl molar ratio. The seasonal decrease occurred at the end of dry season and was close to the soil signatures. This suggests that for this short period the saprolite did not contribute to Na release whereas it did during the rest of the year when most of the groundwater recharge occurs. The long term decrease of Na/Cl corresponds to a long term decrease of the relative saprolite contribution to the Na flux.

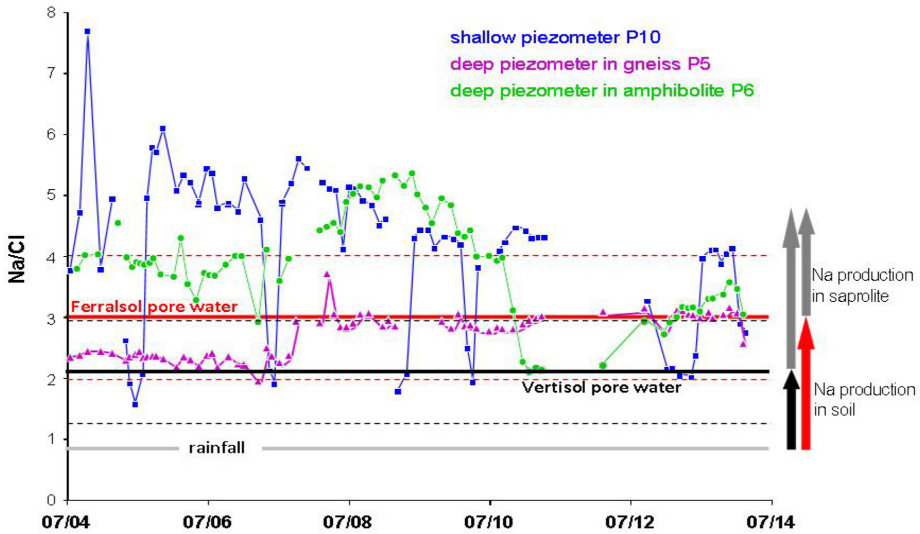

Fig. 1. Temporal evolution of the Na/Cl molar ratio in the three studied piezometers, compared with Ferralsol (red line) and Vertisol (black line) pore water compositions. Dotted lines represent the variability of soil pore water composition.

3.3. Decadal flux of Na exported by the groundwater

The COMFORT model allowed estimation of the annual fluxes of Na produced by the soil layer and comparison to the annual flux of Na leaving the groundwater upslope (P5) and down slope (P10) (fig. 2a). Specific Na fluxes varied by a factor of 3 according to the location of groundwater. The soil output flux of Na, which was consistent with the average flux calculated at the soil-plant scale[3], followed the fluctuations of the rainfall pattern: during dry years, with rainfall less than 800 mm/yr, the flux of Na towards the saprolite became negligible while it exceeded 1000 mol/ha/yr during normal years (1100 mm/yr of rainfall on average). In the shallow downslope piezometer, the delay between the increase of soil output and the increase of groundwater flux of Na was typically of 1-2 years and corresponds to the estimated residence time of water in the vadose zone (fig. 2b). However, the residence of water in the saturated zone, about 4 years according to the hydrological model, induced a nearly constant Na flux originating from the soil (fig. 2c). It should be mentioned that the hydrological model did not simulate the preferential flow at the end of the dry season, limiting the Na contribution from saprolite during this period. In the upslope piezometer, the delay between the increase of soil input and the increase of groundwater flux of Na was 3-4 years due to deep water uptake by tree roots in the saprolite. During the humid period, the increased drainage led to a decrease of the water residence time in the saprolite from 20 to 10 years, while in the saturated zone the residence time of water (~17 yr) was nearly stable (Fig 2b). These two long residence times contributed to the overall stability of the chemical composition of groundwater. Remarkably, the yearly Na flux in the recent period was about trice the yearly flux calculated for the period 2004-2006 with a steady state hypothesis.

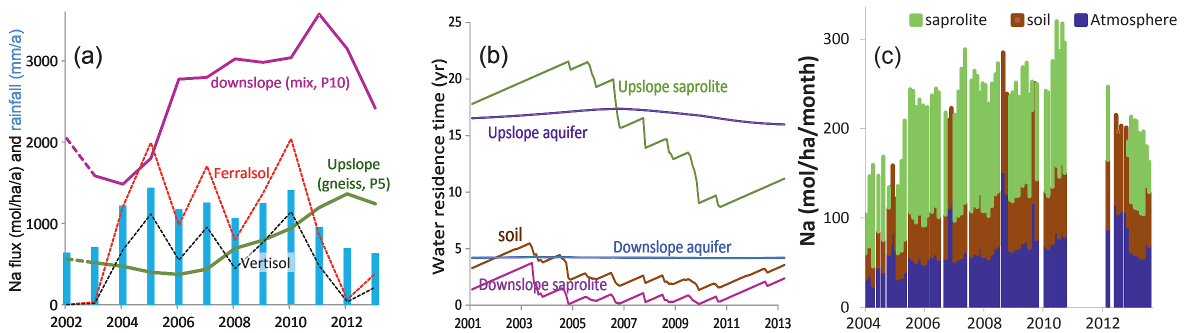

Fig. 2. (a) Annual flux of Na from different compartments compared to annual rainfall (b) residence time of water in the different compartments, (c) monthly groundwater Na flux and origin in the downslope piezometer as estimated from Na/Cl ratio.

4. Conclusion

The long term monitoring of the Mule Hole SEW allowed the assessment of the long term Na fluxes exported by groundwater, using a dynamic approach that combined monthly chemical composition of groundwater and lumped hydrological modeling. The intensity of evapotranspiration within the soil and saprolite layers controls at seasonal and decadal scales the water stock in the vadose zone, delaying and buffering the groundwater fluxes. Although Na is not affected by cycling through vegetation, its release during chemical weathering is indirectly controlled by vegetation: evapotranspiration concentrates Na in soil and saprolite pore water and then determines the depth where chemical weathering occurs, delays water transfer to the groundwater by up to several years and finally buffers the output flux by groundwater. The combination of long term groundwater monitoring with hydrological modeling provides useful, detailed information on long term chemical weathering dynamics. It can be inferred from this study that change in tropical forests, through climate change or anthropogenic activity, should strongly affect both hydrological and biogeochemical fluxes.

Acknowledgements

The monitoring of the Mule Hole SEW is part of the Environmental Observatory BVET, which is by IRD, INSU and Université Paul Sabatier (Toulouse).

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