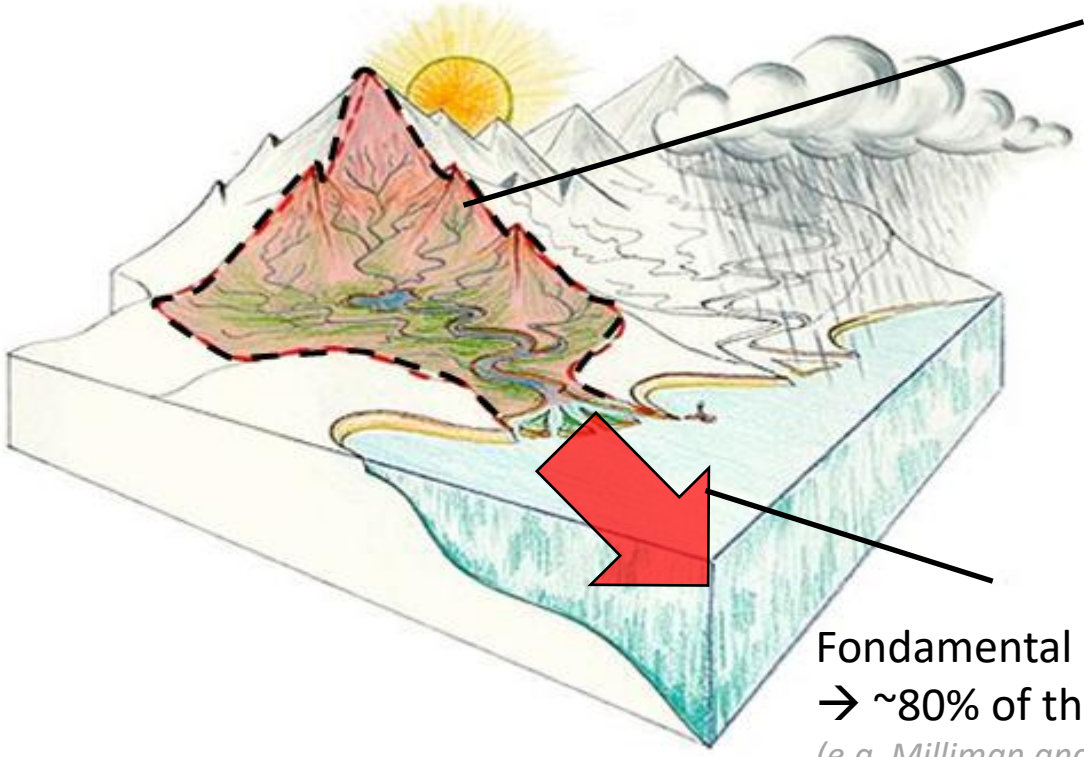
Hydrological and geomorphological control of the riverine silicon isotope composition in the Amazon basin

Moquet J-S, F. Poitrasson, E. Dantas, R. Santos, J. Viers, Y. Godderis, J. Schott, J. Bouchez, N. Filizola, J.-L. Guyot, A. Crave, N. Fernandez,

Dissolved silicon in rivers
→ earth critical zone weathering index
→ Biogeochemical cycles



Critical zone weathering index

(e.g. Bluth and Kump, 1994; White and Blum, 1995 ; Oliva et al., 2003; Hartmann et al., 2010; …)

→ Weathering laws

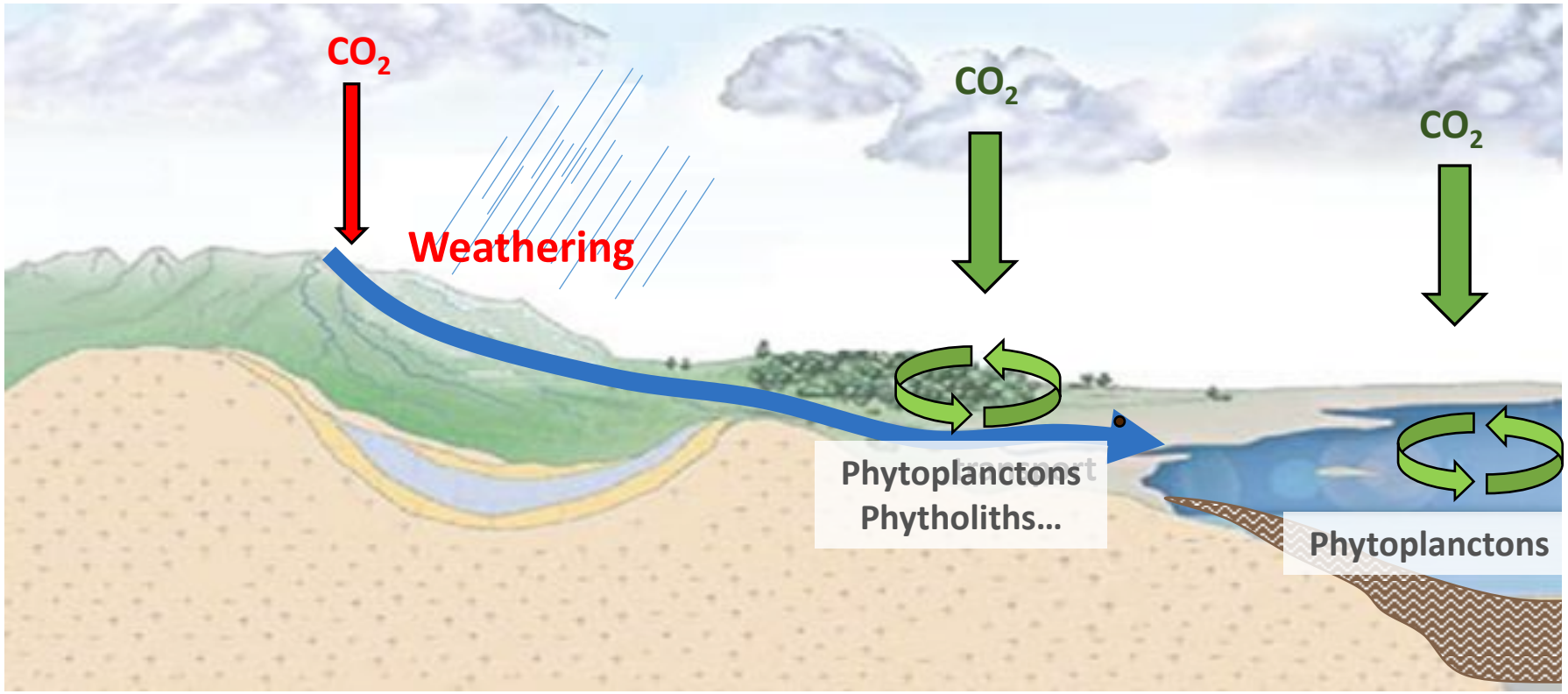
F Si = f(Runoff, T°C, lithology, slopes, …)

Fondamental role in the global biogeochemical cycles

→ ~80% of the dissolved Si of the Ocean come from rivers

(e.g. Milliman and Boyle, 1975, Tréguer et al., 1995; Bernard et al., 2009, Durr et al., 2009 ; Struft and Conley, 2012; Cornelis et al., 2012)

Silicon, an element coupled to long and short carbon cycle

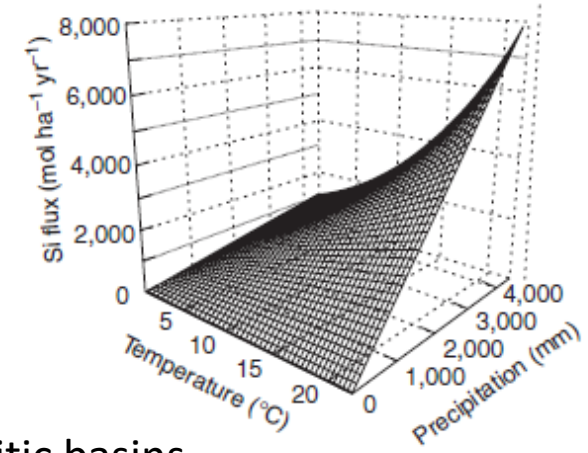


Silicates weathering $2\ KAlSi_3O_8 + 2\ CO_2 + 11\ H_2O \rightarrow Si_2O_5Al_2(OH)_4 + 4\ Si(OH)_4 + 2\ K^+ + 2\ HCO_3^-$

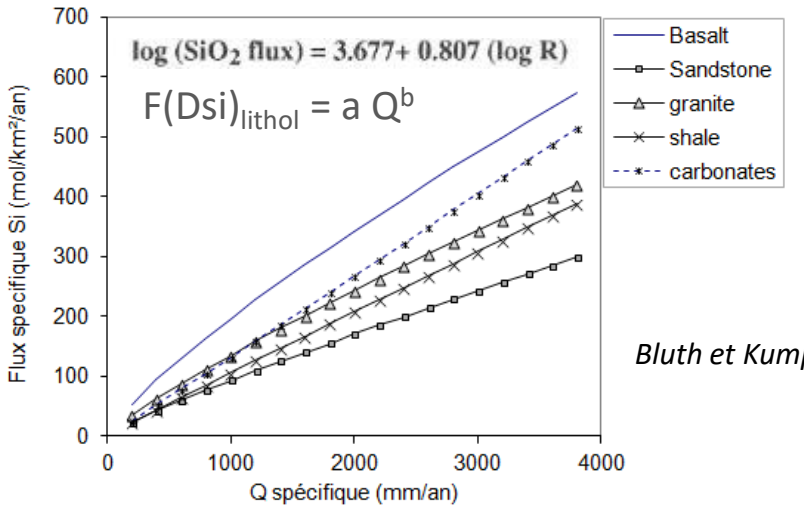
Photosynthesis (diatoms, phytoliths, …) $CO_2 + H_2O \rightarrow (CH_20) + 0_2$

Dissolved Si = a tool to define silicate weathering laws

F Si = f(rainfall, temperature)



F Si = f(Runoff, lithology)



Bluth et Kump, 1994

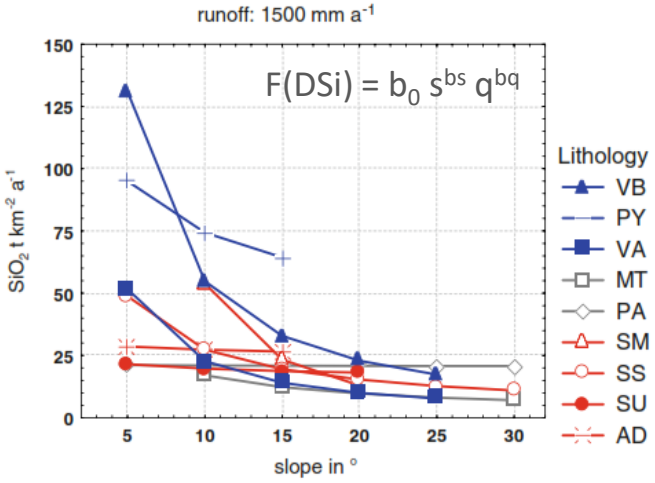
Granitic basins

White et Blum, 1995
Oliva et al., 2003

Arrhenius law

$$r_T = Ae^{(-E_a/RT)}$$

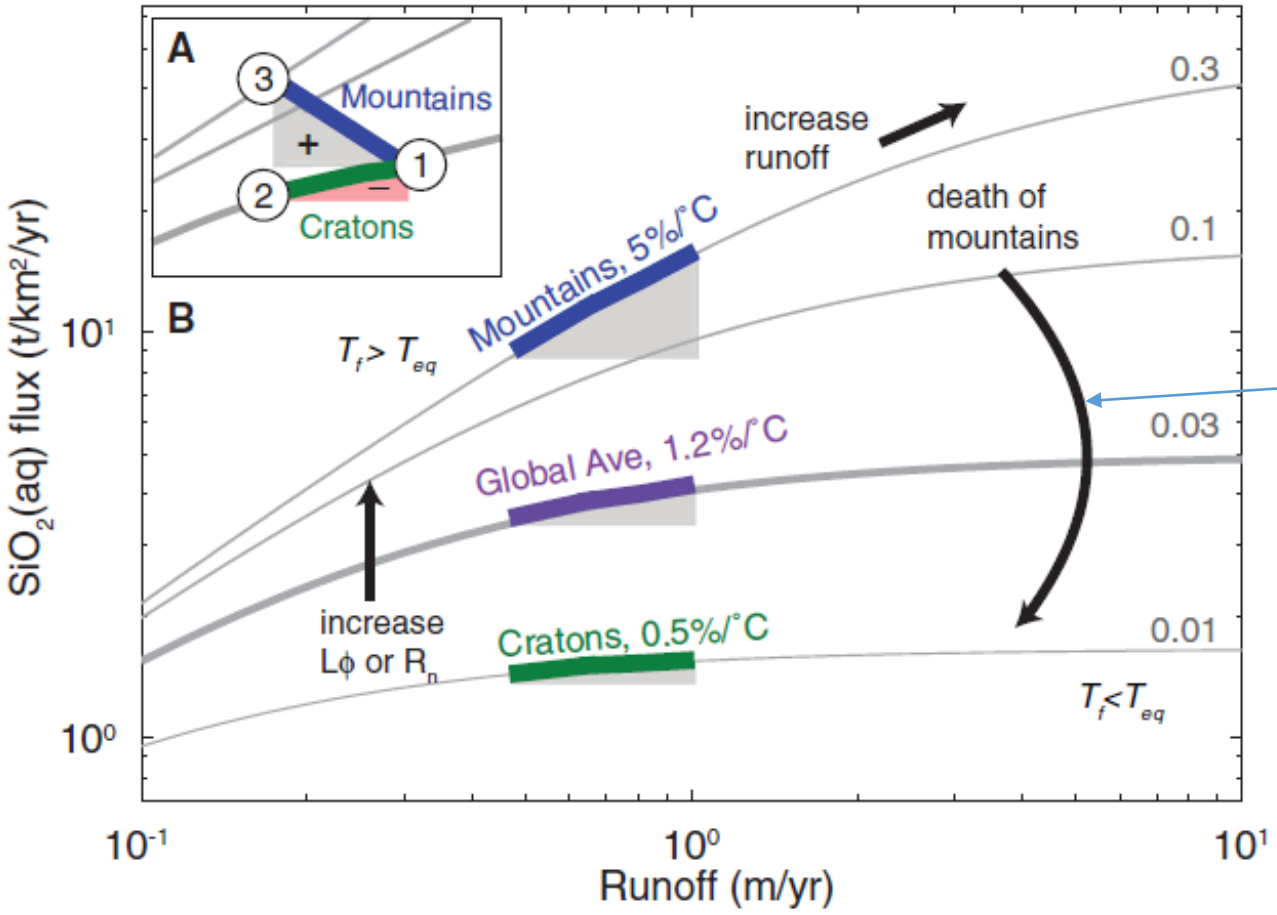
F Si = f(runoff, slopes, lithology)



Hartmann et al., 2010

Geomorphlogical control of Si production

Orogenesis and climate as drivers of the weathering



Soil age increase or/and flowpath diminution

→> 60 rivers

Maher et Chamberlain, science, 2014

Amazon basin, a privilegied study site

A major role in the main biogeochemical cycles at global scale

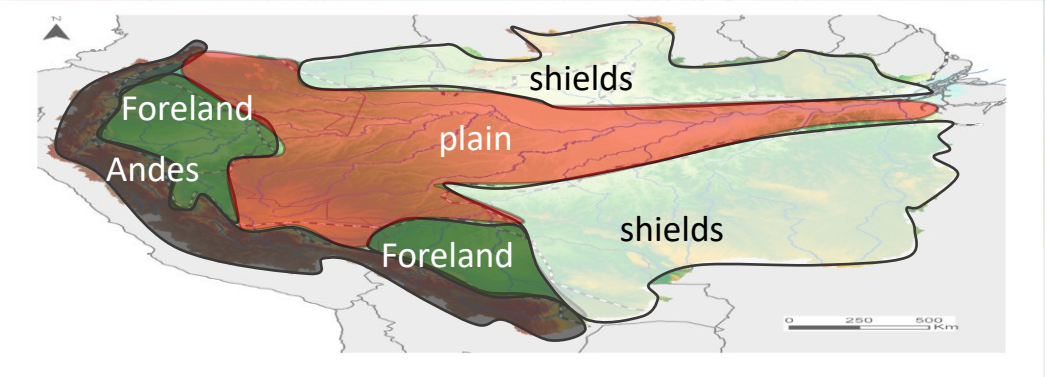
≈17% continental discharge

≈ 9% of total dissolved fluxes

≈ 15-17% of dissolved silicon fluxes

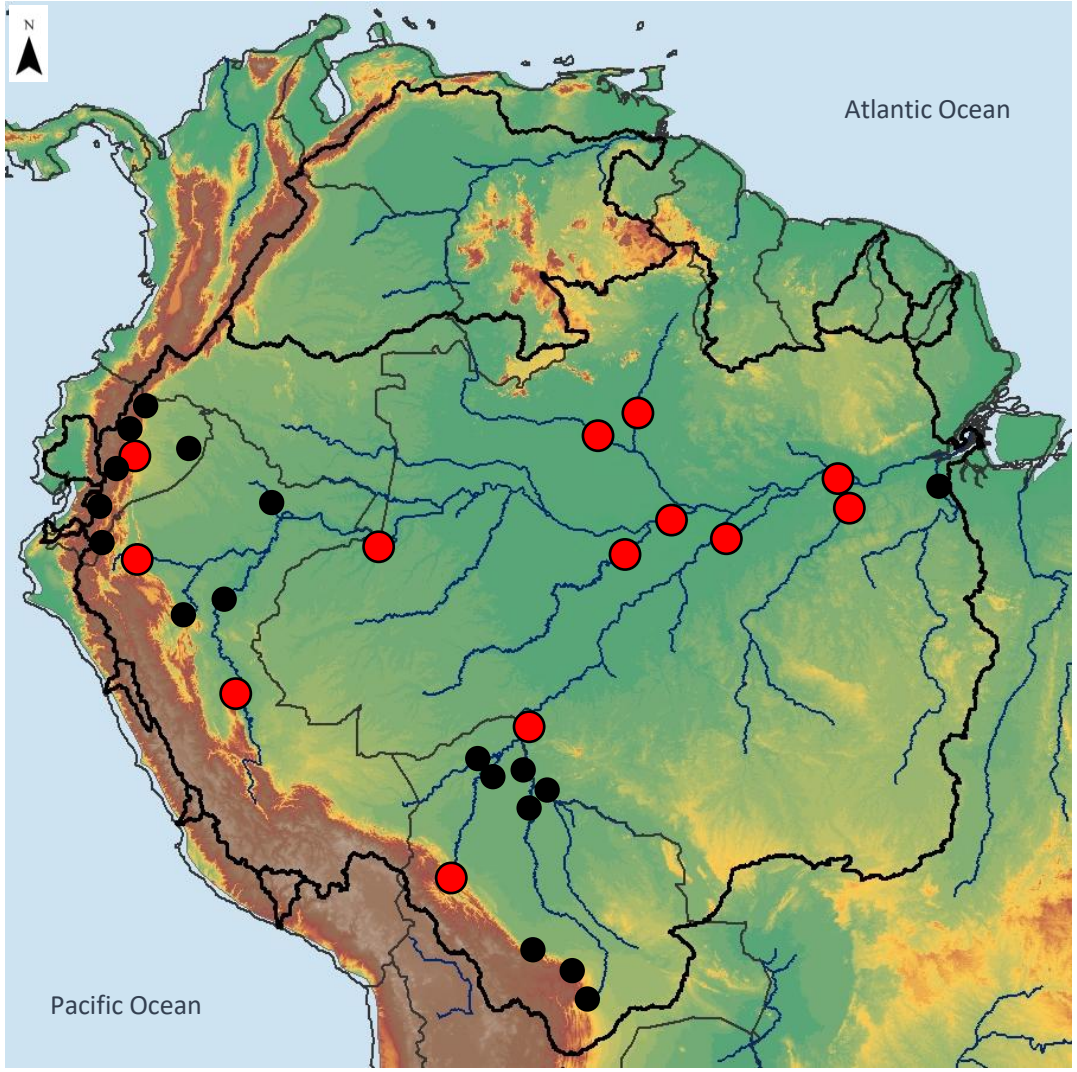
A natural laboratory

Andes sedimentary areas shields



➔What are the dissolved Si budget, origin, temporal dynamic and sources/processes of Si fluxes?

Observatory
SNO-HYBAM (since 2003) + PHICAB (Bolivia 1980-1990)



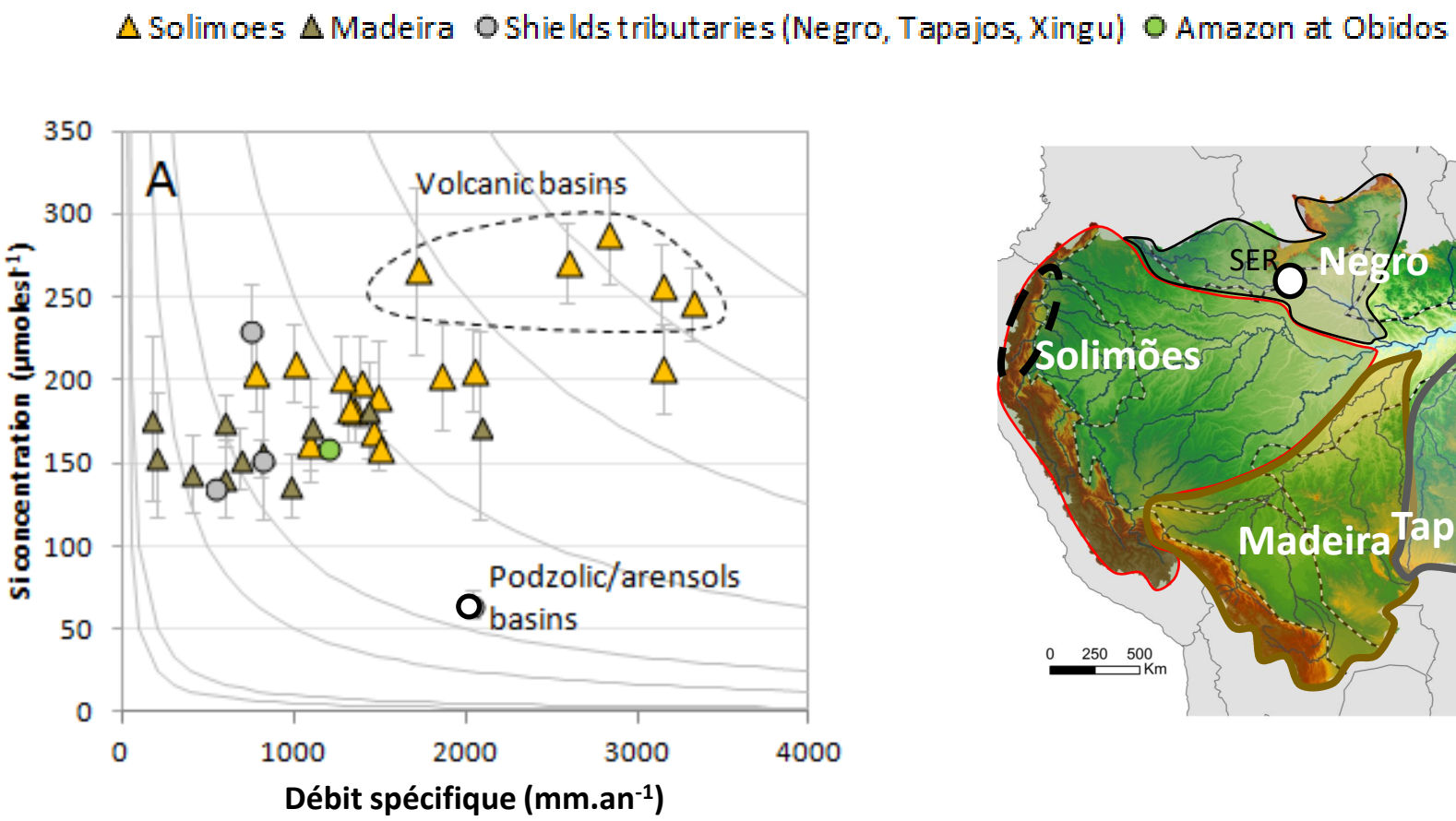
13 SNO stations : ●
18 « reference » stations : ●

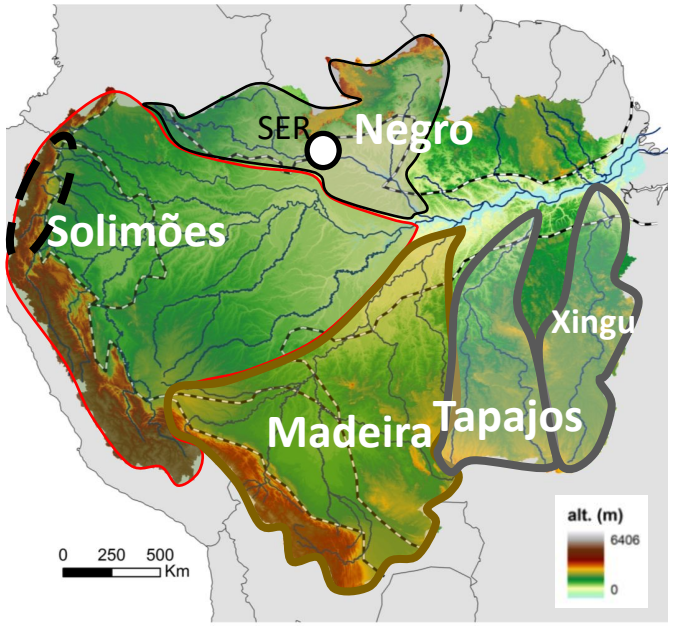
- **daily discharge**

- **monthly hydrochemistry: major elements (including dissolved Si)**
>5000 analyses

➔ Flux = concentration x discharge
➔ spatial variability Si concentration and fluxes
➔ seasonal variability
➔ budget

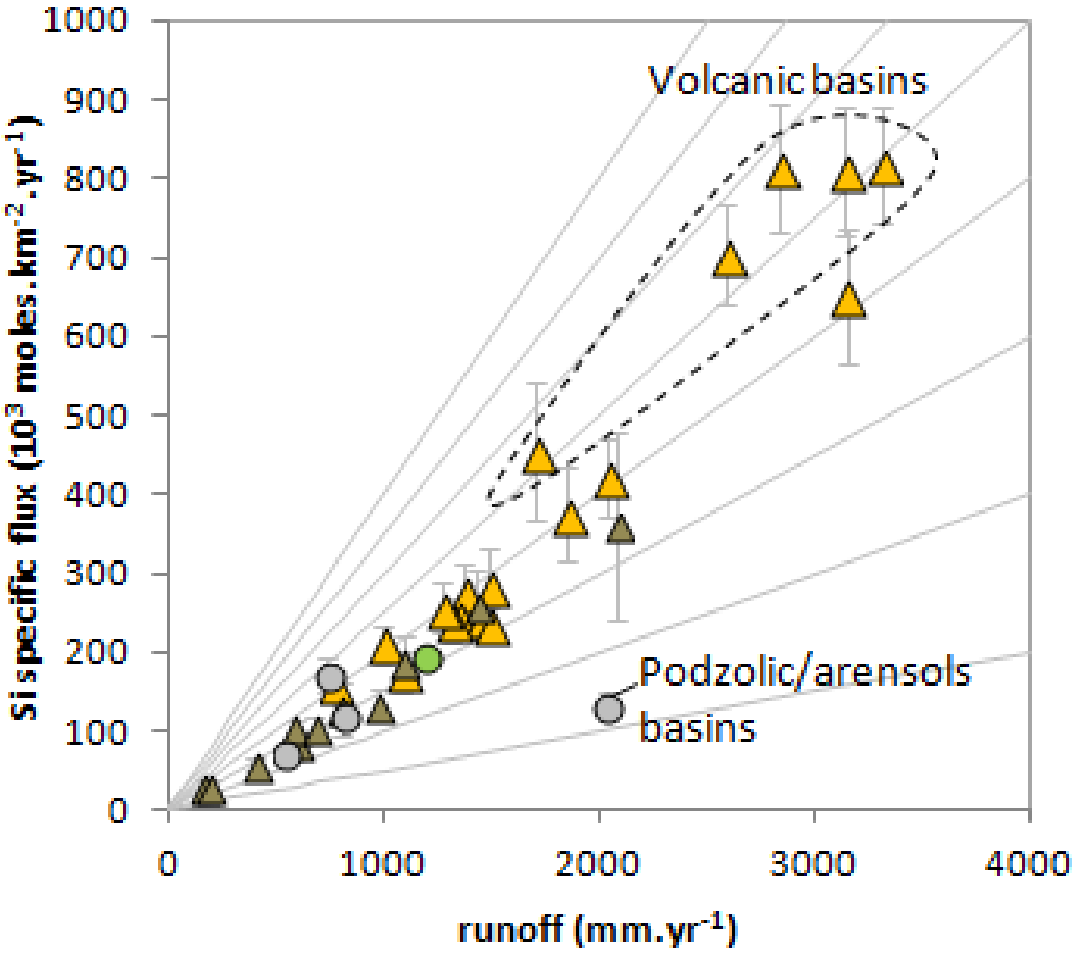
Spatial repartition of dissolved Si concentration





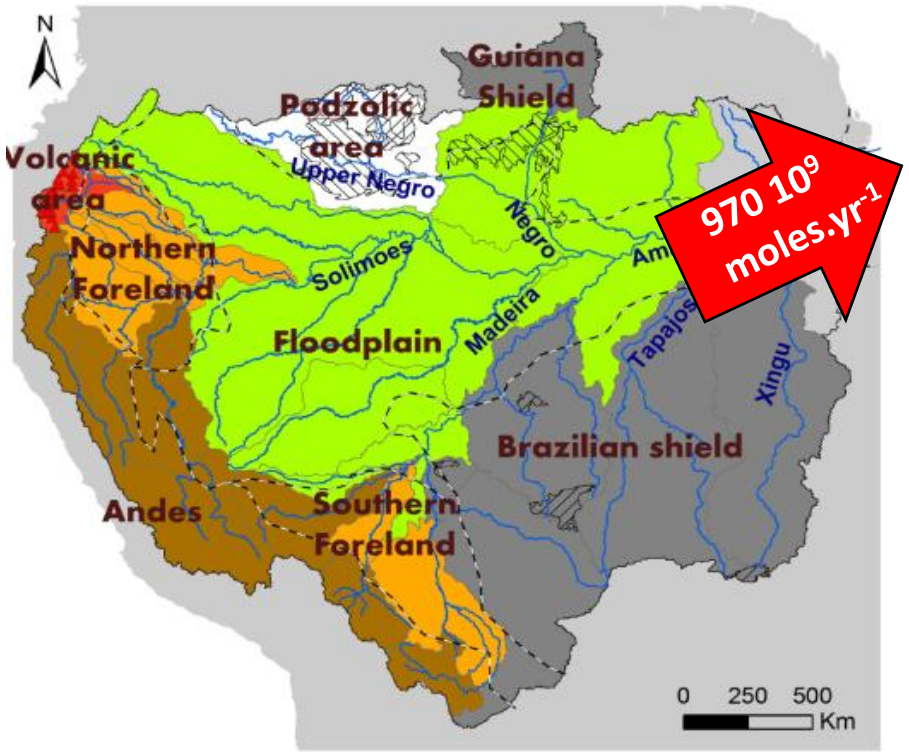
➔ 3 domains :
- volcanic basin (Napo)
- podzolic basins (Upper Negro)
- Other basins (80% of the Amazon)

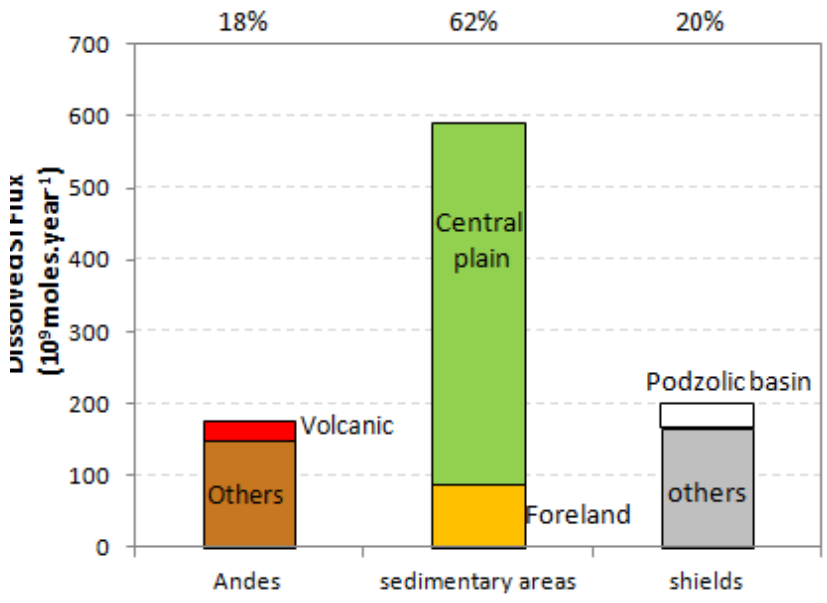
Spatial repartition of dissolved Si fluxes

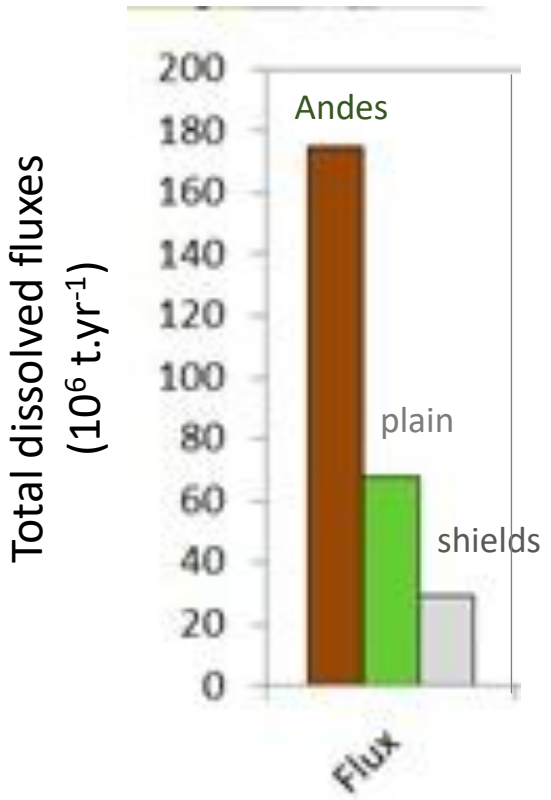


➔ Main controling factor of Si flux repartition = discharge repartition

Dissolved Si budget





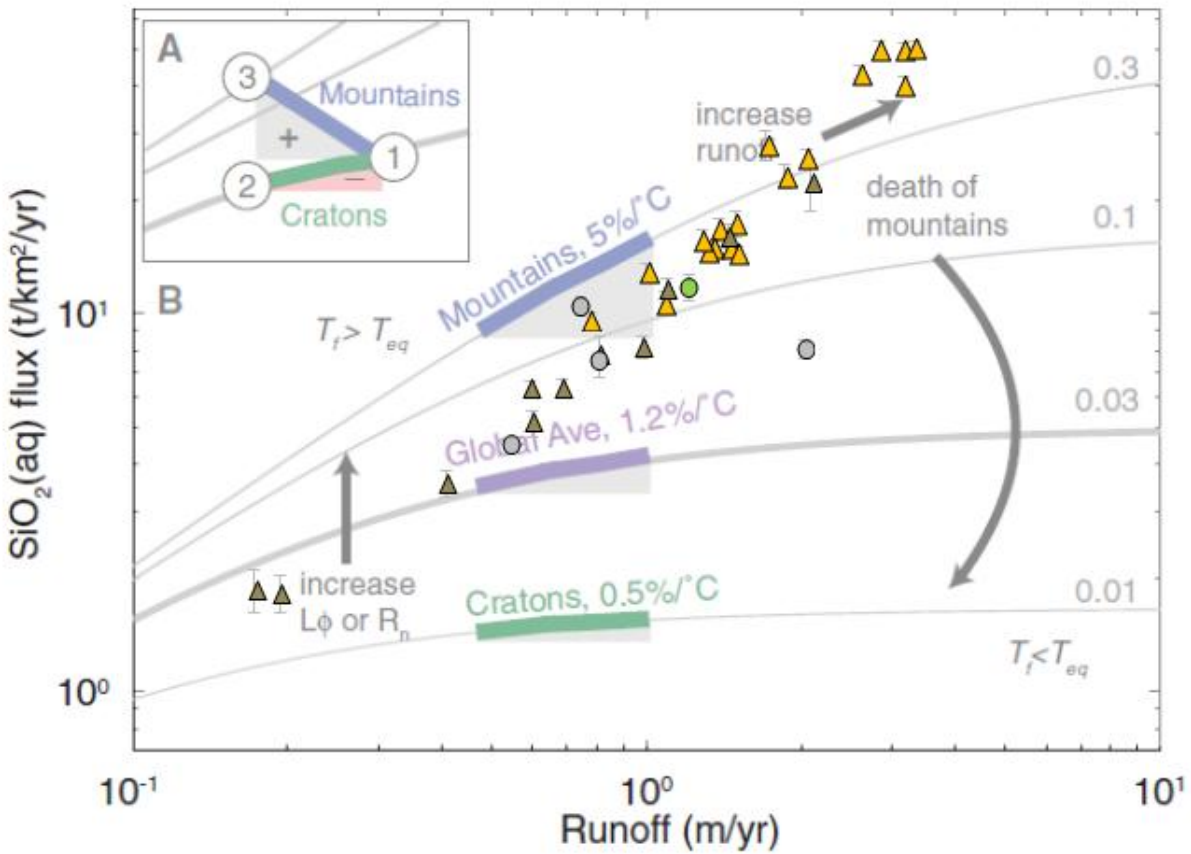


Moquet et al., ESPR, 2016

➔ Si flux Amazon = 15-17% Si flux continents → oceans (Beusen et al., 2009)

➔ Main source of Si = sedimentary areas

Comparison with empirical laws



Maher et Chamberlain, Science, 2014

➔ Si fluxes doesn't respond to geomorphology vs weathering empirical laws

(Ex : Stallard, 1985; Gaillardet et al., 1999; West et al., 2005; Maher et Chamberlain, 2014)

Seasonal variation of dissolved Si

5 caracteristic basins

C = a Q^b (34 stations)

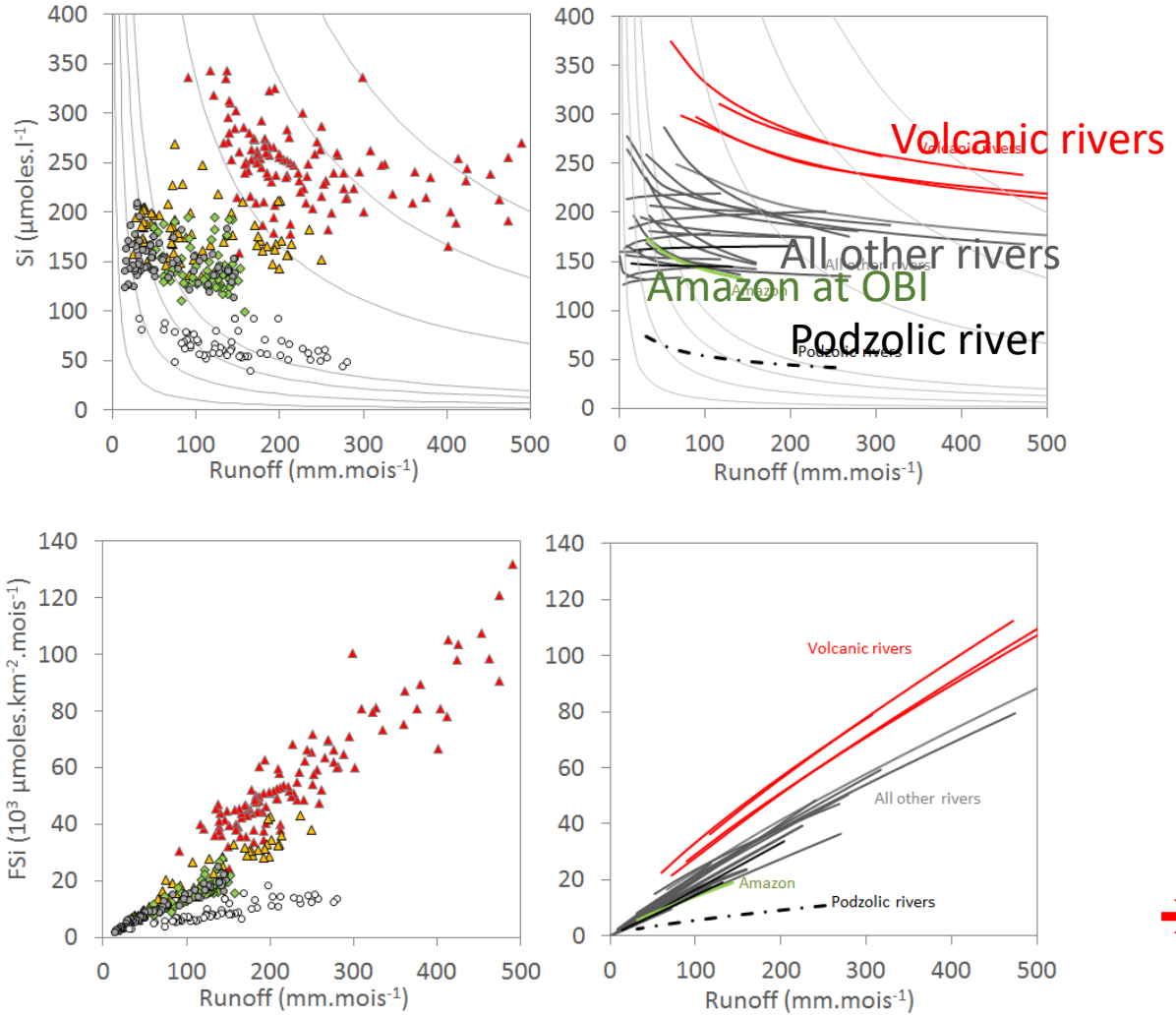
▲ Volcanic basin (FOR)

△ Andes (ATA)

◆ Amazon (OBI)

● Shields (ITA)

○ Podzolic area (SER)



➔ FSi =f(Q) spatially and temporally

Seasonal variation of dissolved Si

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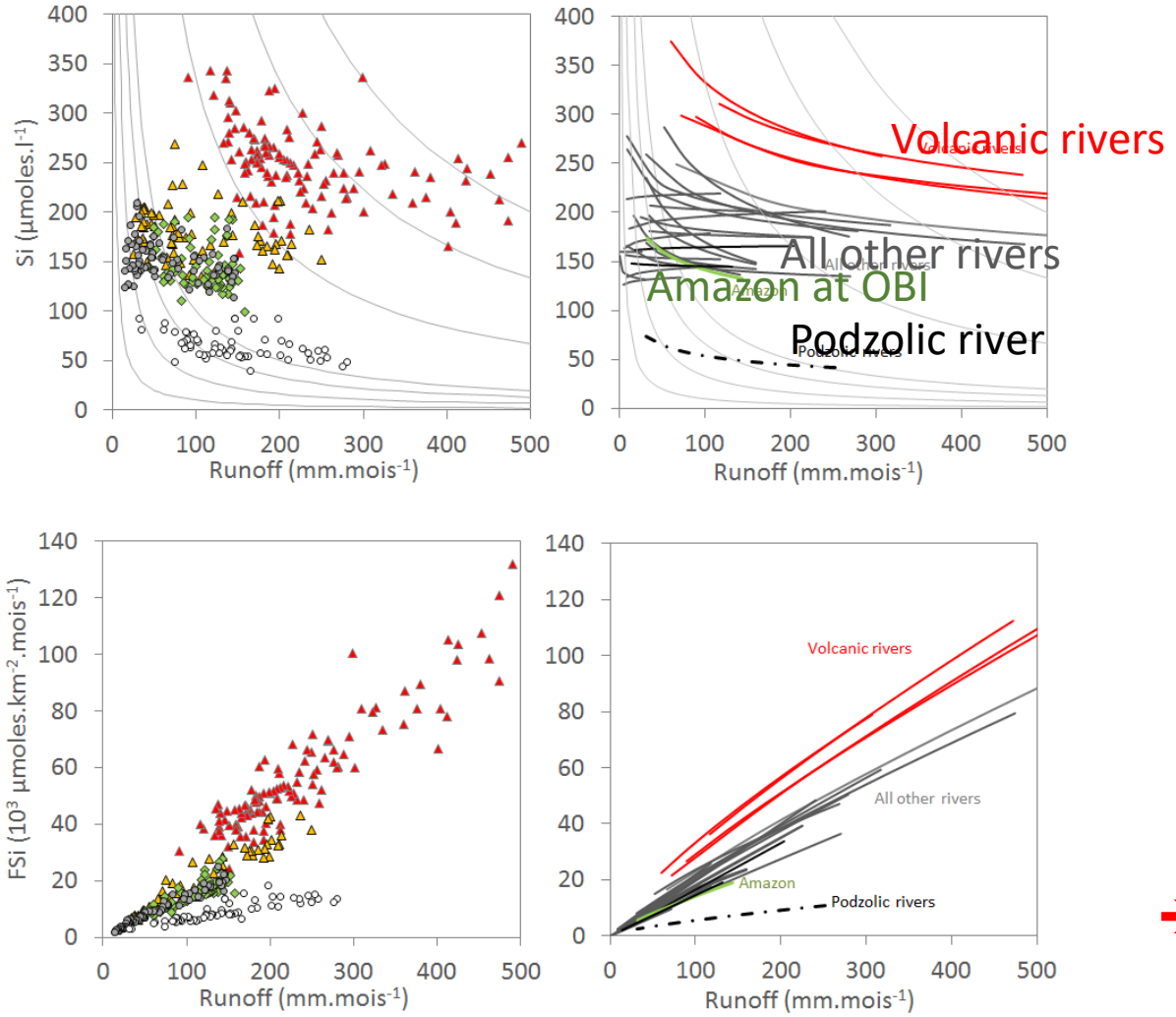
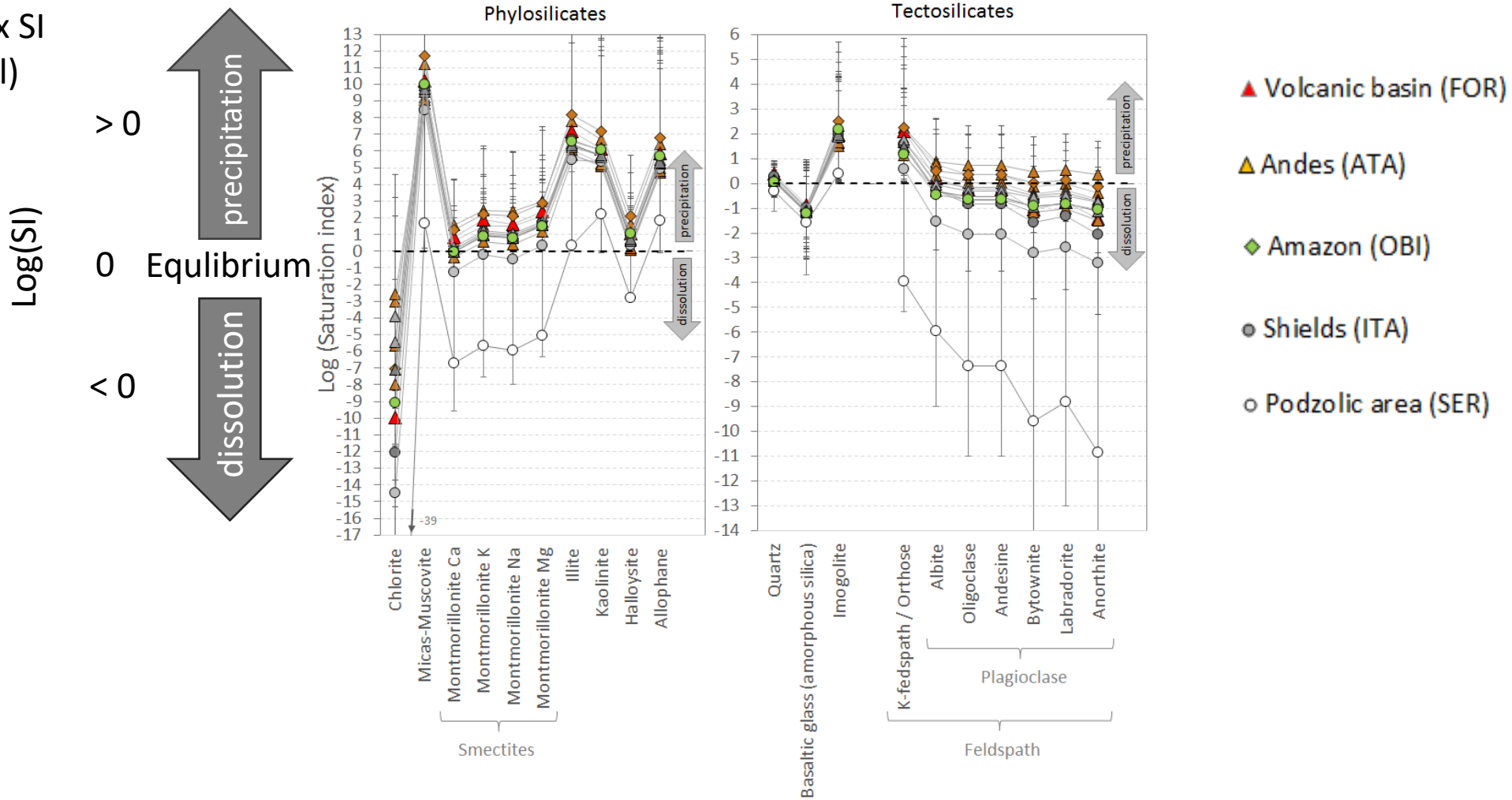


➔ FSi =f(Q) spatially and temporally

How to explain homogenous spatial and seasonal Si concentration : homogenous or heterogenous source/processes?

Thermodynamical equilibrium mineral vs water

Saturation index SI
(WITCH model)



→ Upper Negro (podzolic basin) = under-saturated respective to most minerals.

→ Other rivers = saturated or over saturated respective to clays

→ Fast or slow thermodynamical equilibrium with 1 or various clays can explain an homogenous Si concentration.

→ Possible explaination

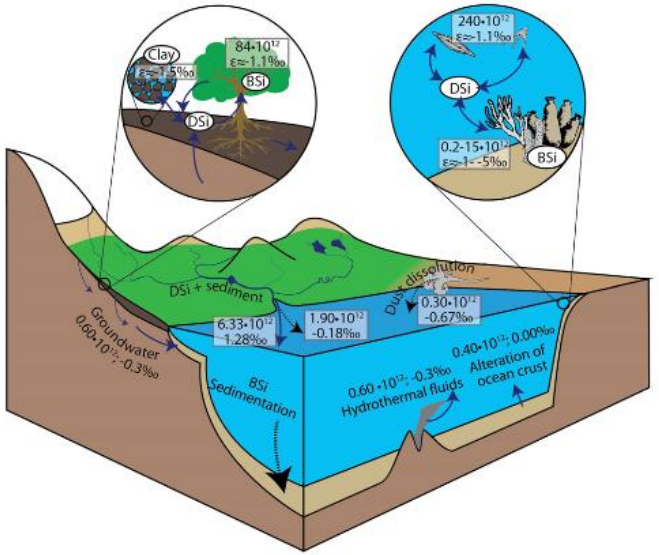
→ Does not indicate processes or sources homogeneity or hetrogeneity

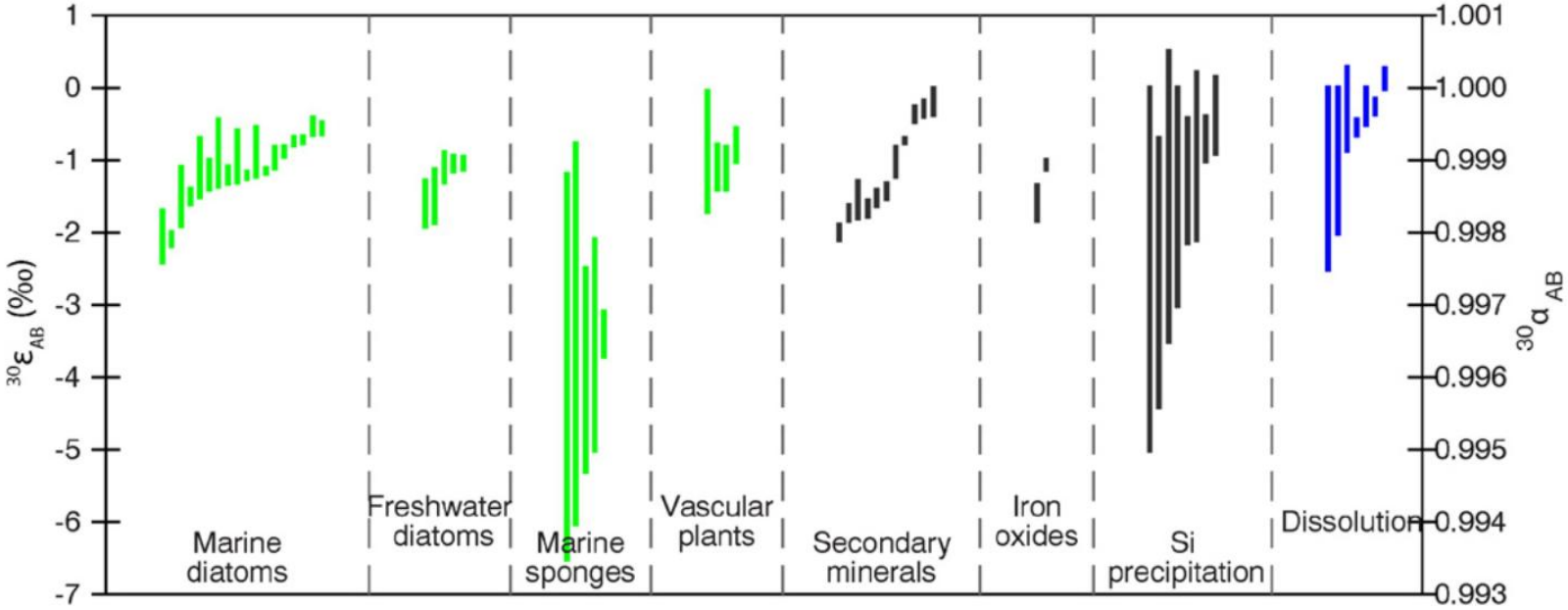
Si stable isotopes : a tool to track weathering and biological processes

^{30}Si, ^{29}Si, ^{28}Si

$$\delta^{30}Si(‰) = \left(\frac{^{30}Si/^{28}Si_{sample}}{^{30}Si/^{28}Si_{standard}} - 1 \right) \times 1000$$

Standard : NBS28



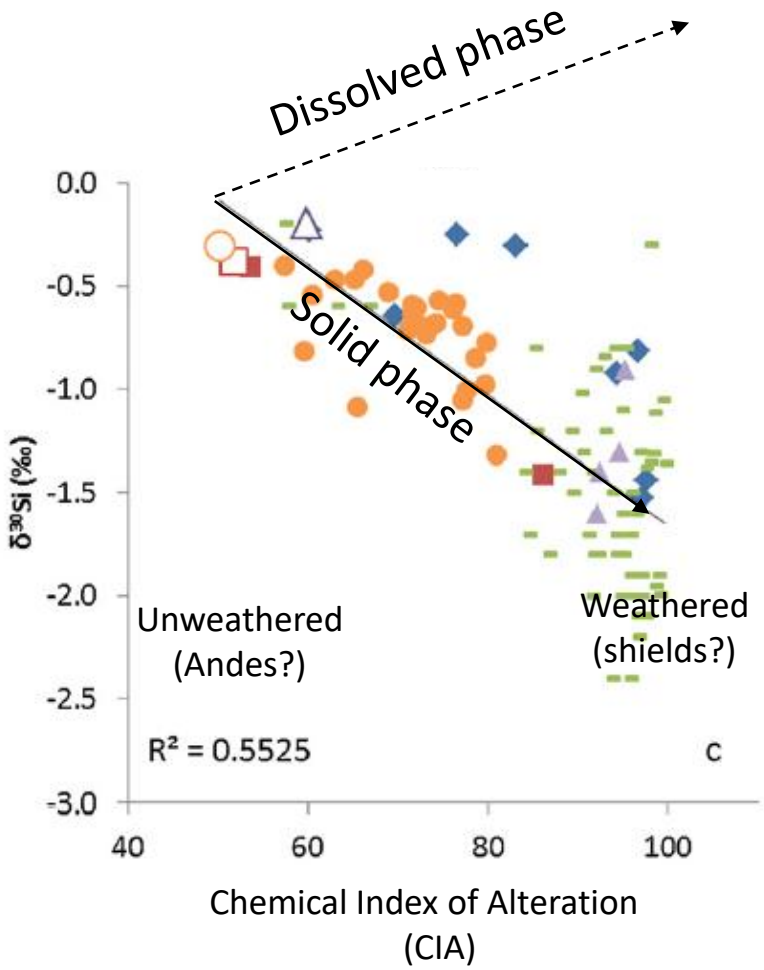


Frings et al., Chem. Geol., 2016

Si stable isotopes : a tool to track weathering and biological processes

Weathering processes

(*ex : Georg et al., 2006, Cardinal et al., 2010; Ding et al., 2011*)

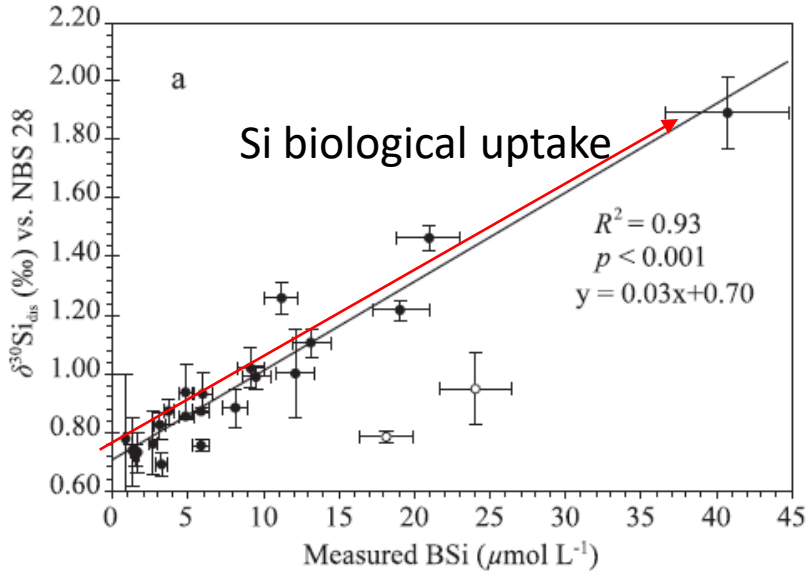


Opfergelt et al., GCA, 2012

Biological processes

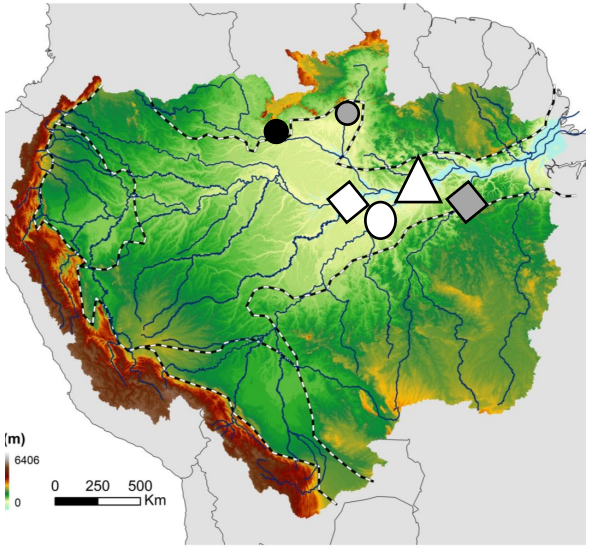
(ex : *Ding et al., 2004; Hughes et al., 2011; Frings et al., 2014*)

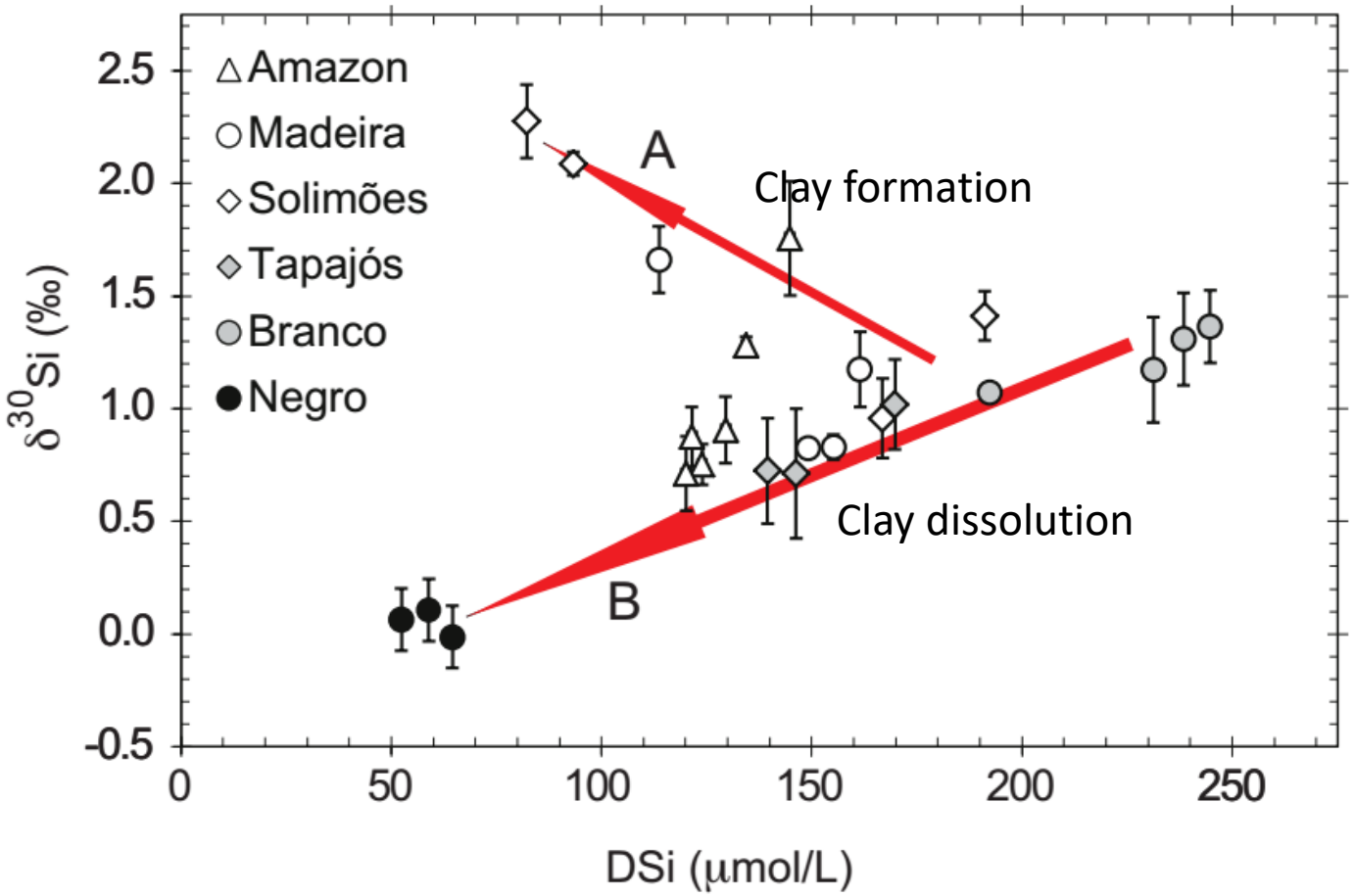
Congo river



Hughes et al., Limnology and Oceanography, 2011

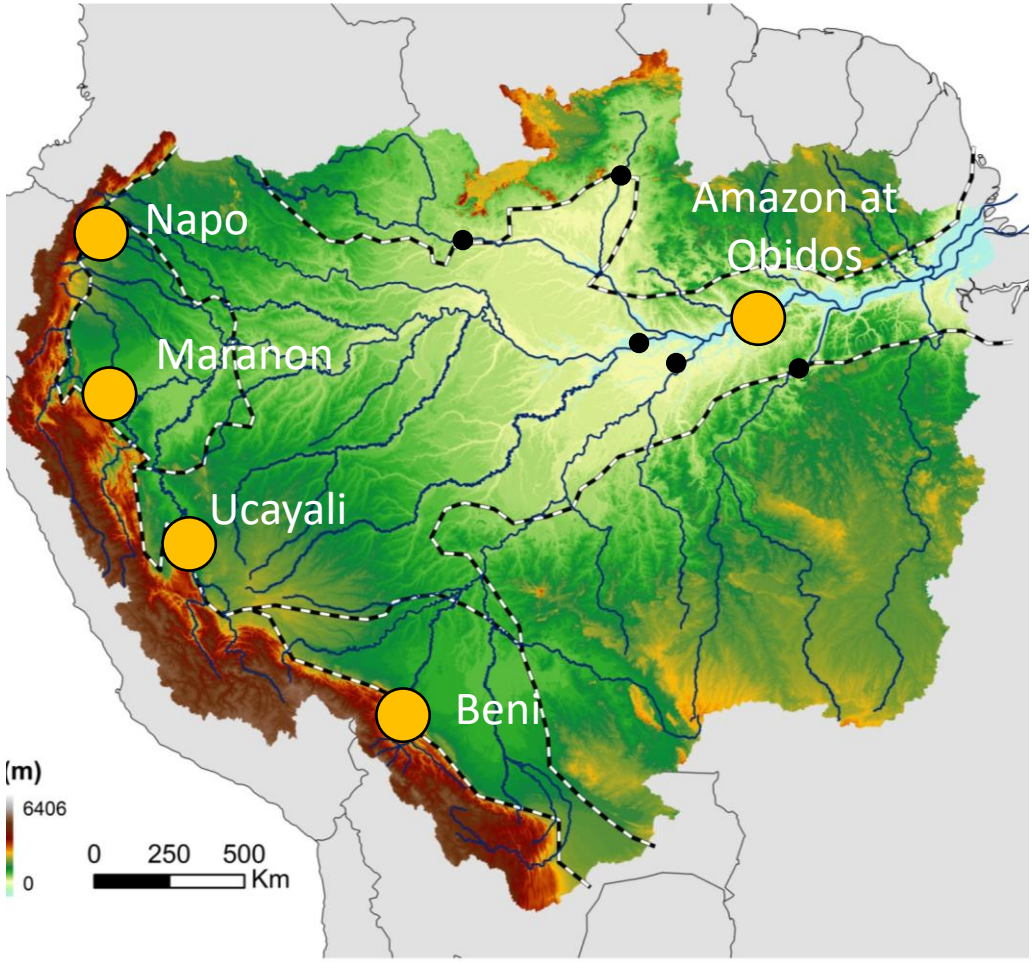
Si stable isotopes in the Amazon basin





Hughes et al., 2013
extracted from Poitrasson, 2017

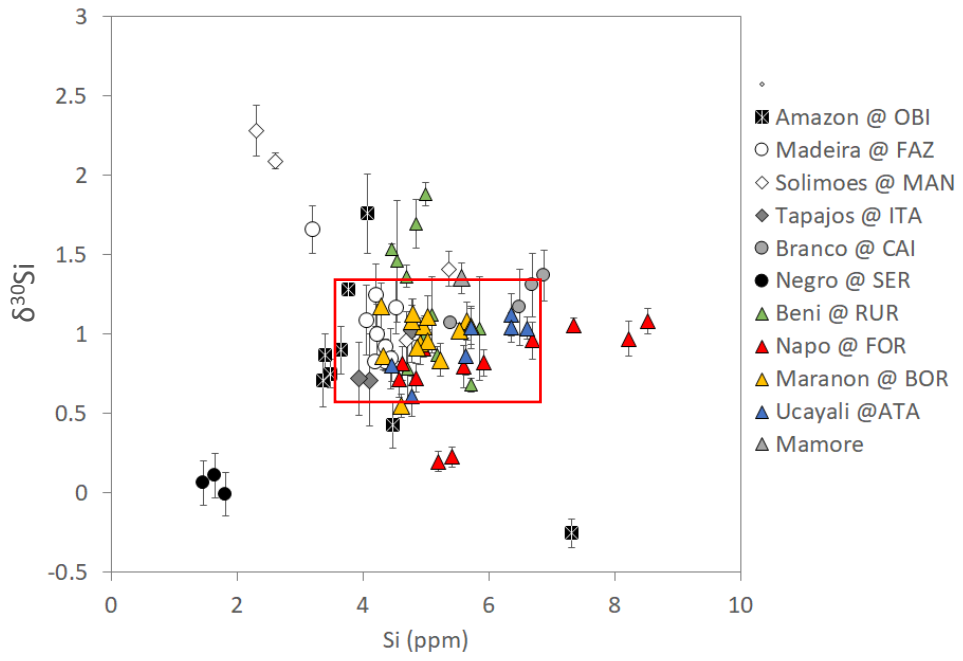
Si stable isotopes in the Amazon basin



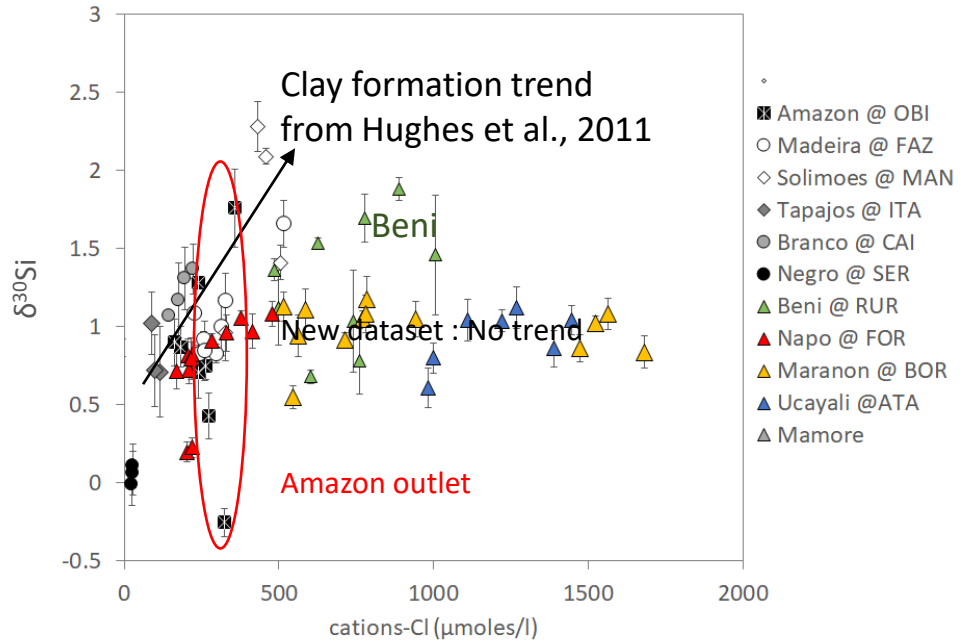
Archived Hybam samples :
Hydrological years: 2015 or 2016
→ Si stable isotopes on monthly samples

δ^{30}Si Andes > δ^{30}Si plaine?
δ^{30}Si behavior along the hydrological cycle?

Si stable isotopes in the Amazon basin



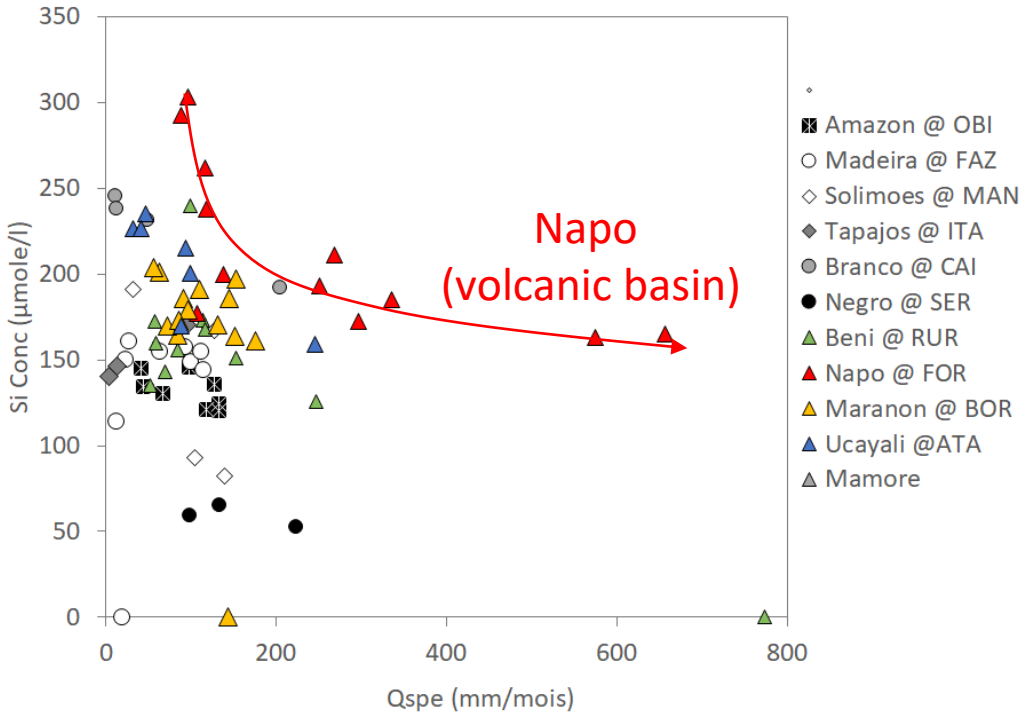
→ Differences with previous Amazon data
→ Low mean δ^{30}Si variability for the new data

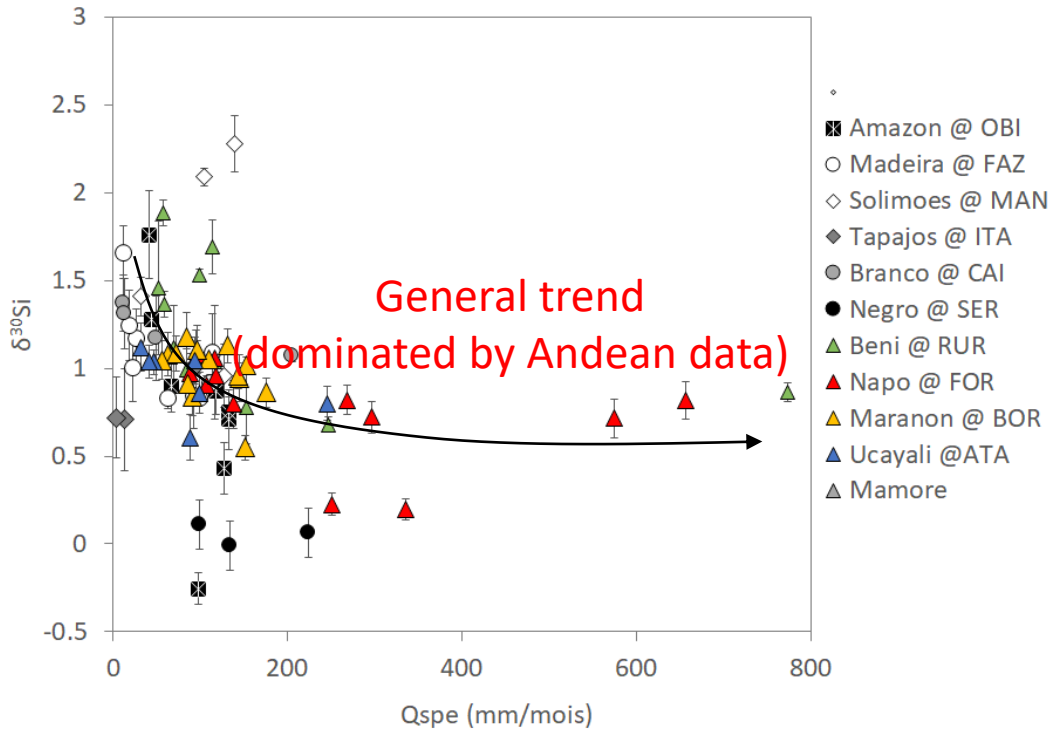


Beni river : higher δ^{30}Si → higher clay formation rate / more weathered?

Amazon at the outlet → high δ^{30}Si variability
→ No relationship with discharge/weathering processes
→ Biological activity?

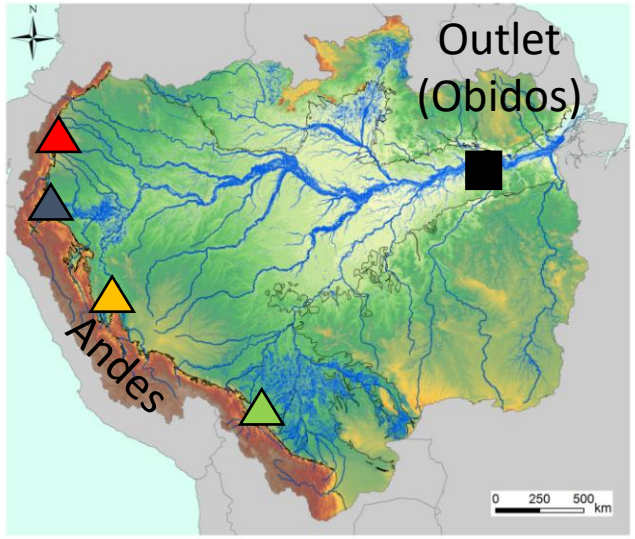
Hydrological control of Si concentration and $\delta^{30}Si$

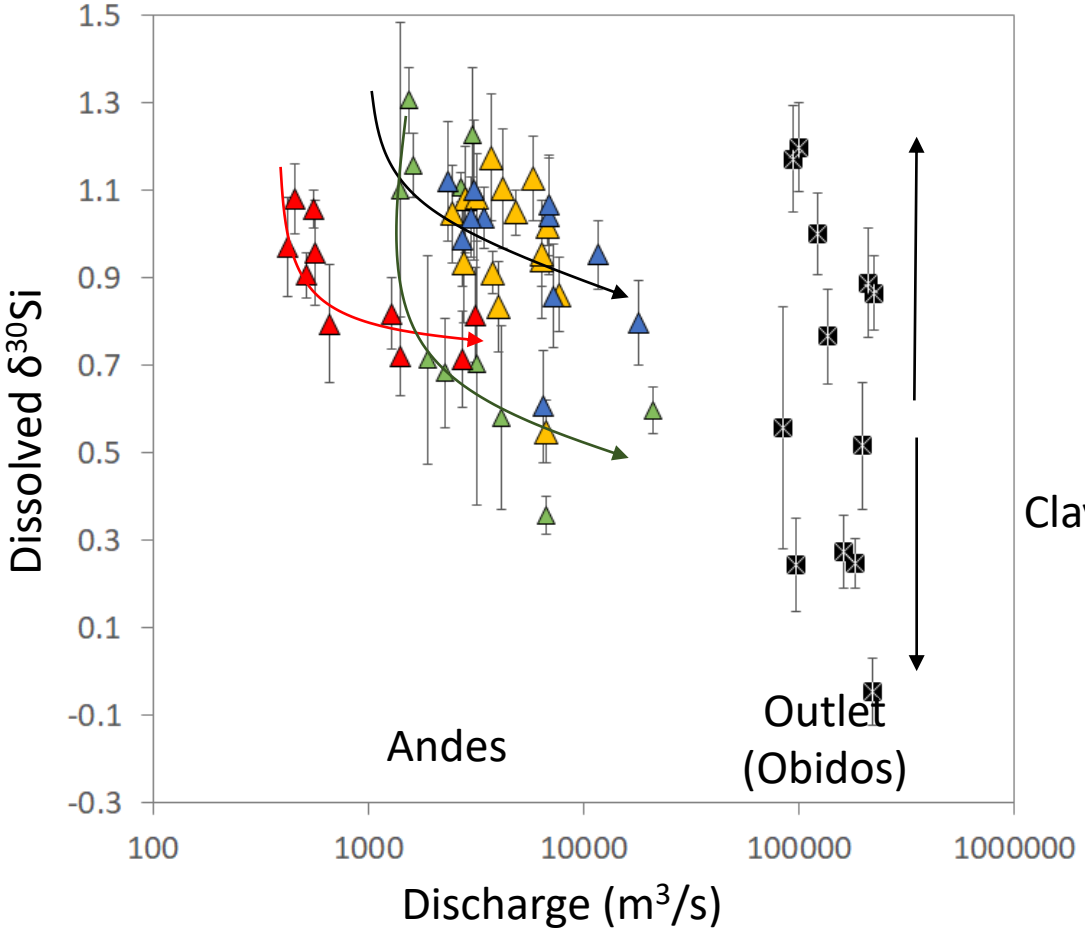




➔ At first order : hydrological variability seems to be related with specific discharge for Andean basins

Synthesis and preliminary interpretation





Source/clay formation
+ biological effect?

Clay dissolution?

➔ In the Andes, δ^{30}Si depend o hydrological conditions
➔ chenal hypothesis vs aquifer hypothesis

➔ δ^{30}Si variability : plain exutory >> Andes

Low water → High water
Aquifer effect : residence time higher
River chenal : higher clay content

Conclusion

- **Spatially** → 3 Si concentrations ranges :
  - Volcanic basins
  - Podzolic basin
  - Other basins (80% of the Amazon)

  → No geomorphological control on Si fluxes

- **Seasonally :** chemostastic behavior (constant concentration) is observed at all stations

  → The hydrologic flux control the dissolved Si flux

  → Clay/water thermodynamic equlibrium can explain Si concentrations.

  → Climate control on Si fluxes

- **Processes/sources** : δ^{30}Si variability

  → **Andes : Hydrological control** → Weathering or hydrological processes (mixing model)

  → **Amazon outlet : high variability** → Not related with the hydrological cycle → Biological activity?

  → Geomorphological control on δ^{30}Si vs discharge relationships

→ **Observatory strategy : importance of the samples archivage**


Merci
Thank you
Obrigado
Gracias
Rio Napo