Quantifying the impacts of an exogenous dust input to the soil and stream chemistry of an upland Mediterranean watershed using a reactive transport modeling framework

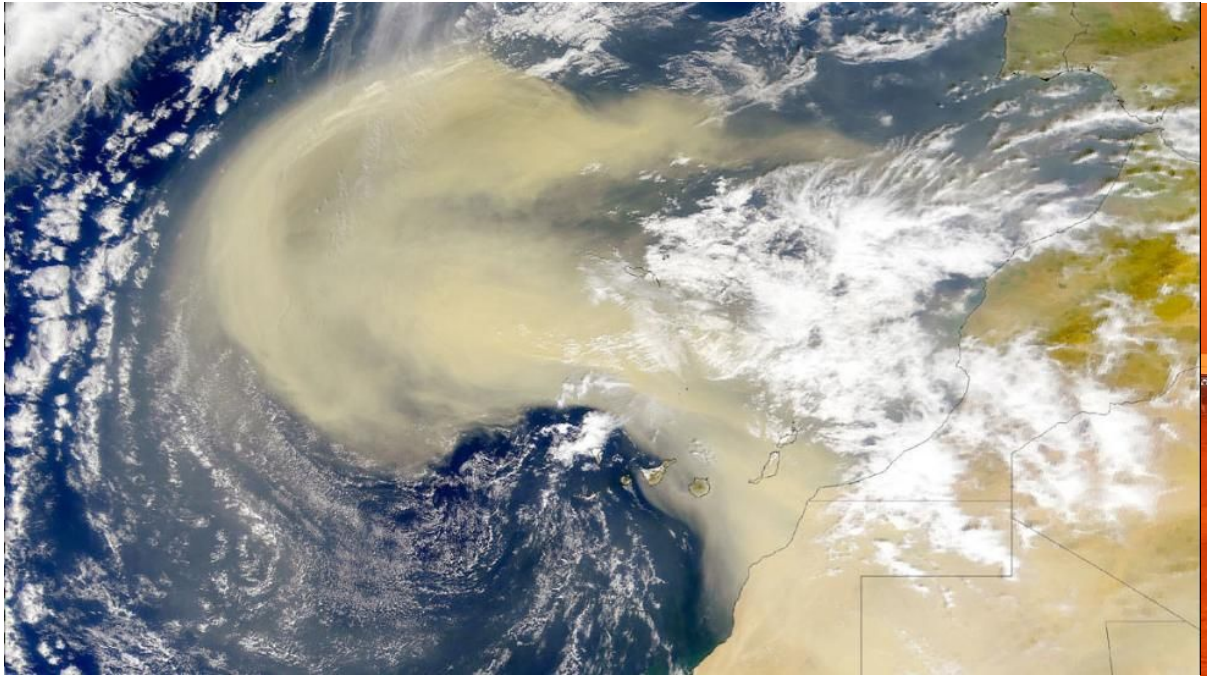
Celia Aranda Reina
CDD 2024

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

IPGP

Université Paris Cité

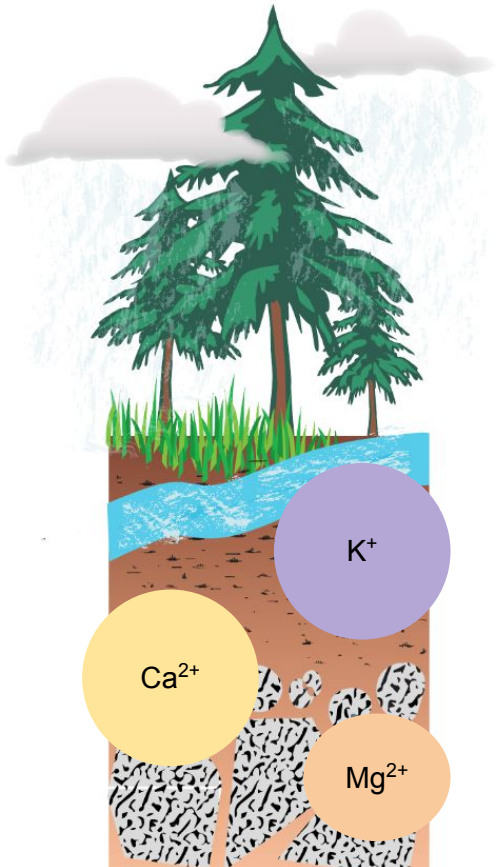
Dust impacting ecosystems



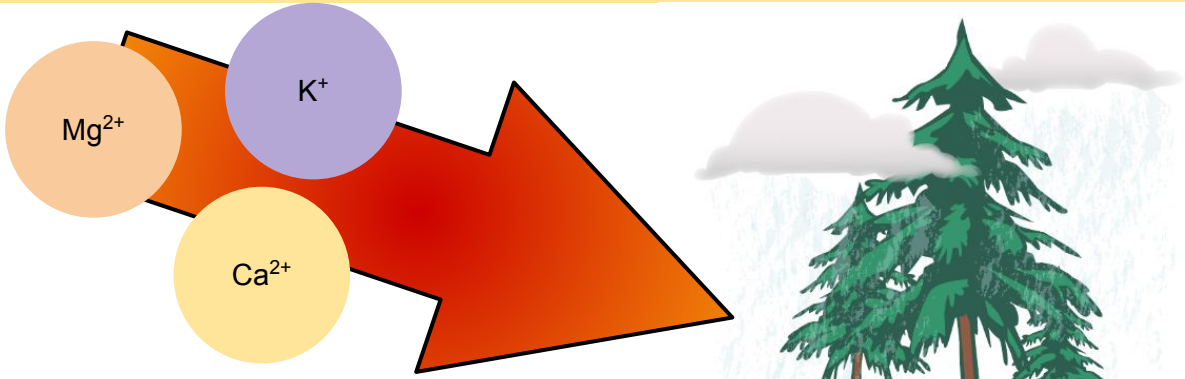
Source: https://swiftfoundation.org/saharan-desert-dust-feeds-amazon-tropical-rainforest-nasa-finds/

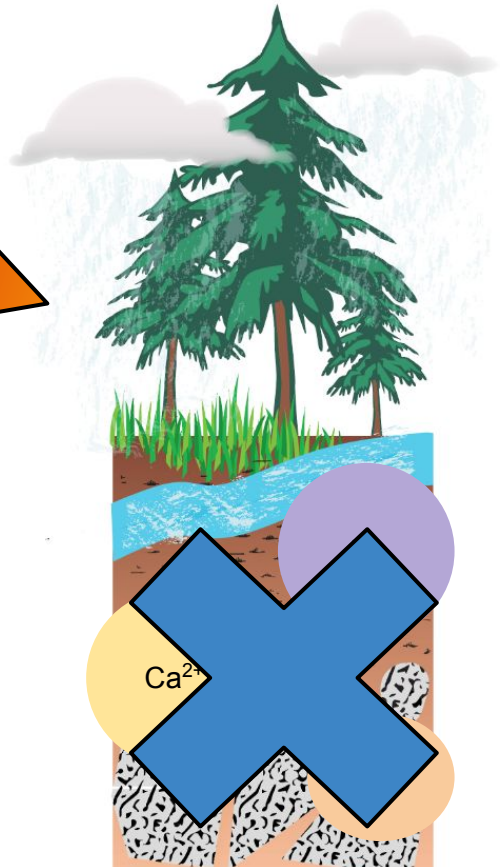
https://murciaplaza.com/los-cielos-de-murcia-se-tinen-de-naranja-por-particulas-de-polvo-en-suspension-del-sahara

Dust impacting ecosystems



Dust impacting ecosystems





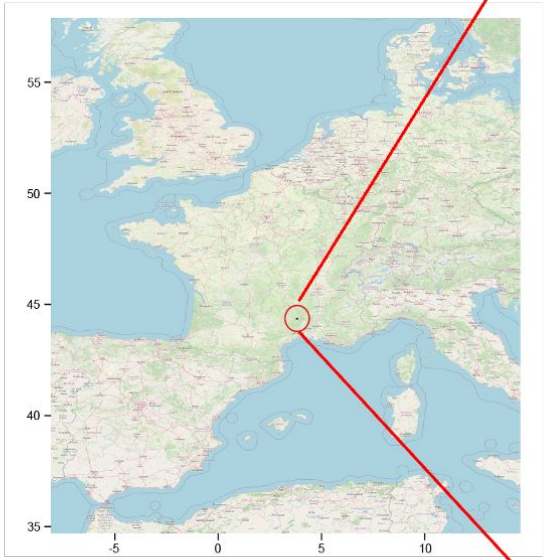
(Chadwick et al., 1999; Pett-Ridge et al., 2009a; Aciego et al. 2017)

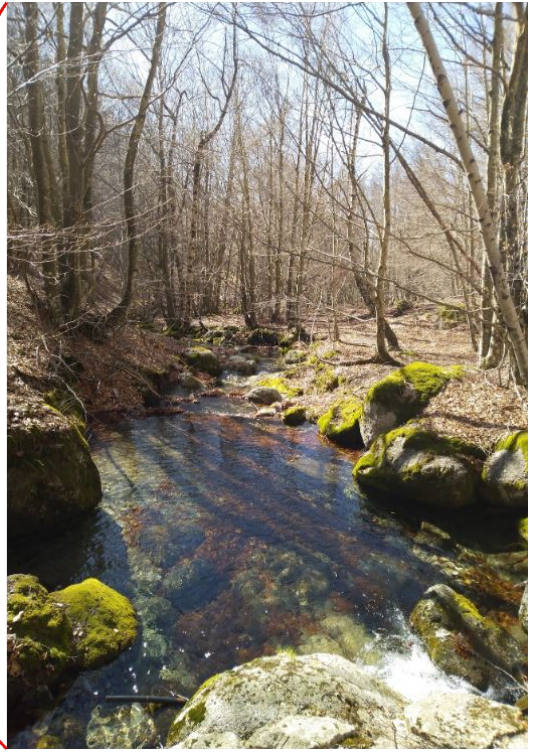
Field site: Sapine watershed, Mont Lozère

Characteristics:

- Average annual precipitation of 2000 mm.
- ET estimate of 600 mm.
- Average temperature of 8°C.
- Vegetation: beech, kept for the past 70 years.
- Stream is perennial.
- Located in corridor of Saharan dust imports.

Location: 44°37'N; 3°82'W, Mont Lozère, Parc National des Cevénnes, south of France. Mediterranean Hydrometeorological Observatory Cévennes-Vivarais (OHMCV), part of the French Network of Critical Zone Observatories (OZCAR).



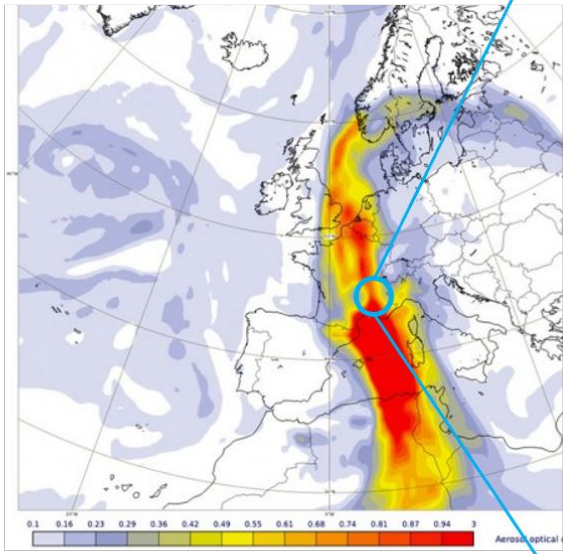


Field site: Sapine, Mont Lozère

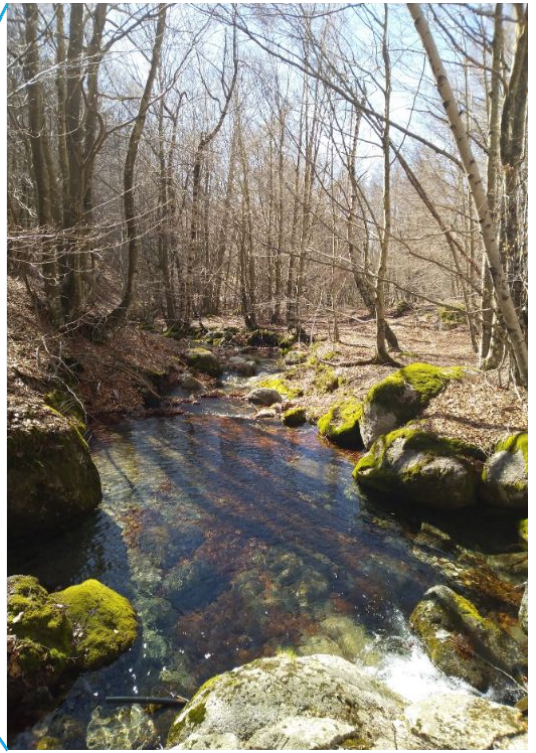
Characteristics:

- Average annual precipitation of 2000 mm.
- ET estimate of 600 mm.
- Average temperature of 8°C.
- Vegetation: beech, kept for the past 70 years.
- Stream is perennial.
- Located in corridor of Saharan dust imports.

Location: 44°37'N; 3°82'W, Mont Lozère, Parc National des Cevénnes, south of France. Mediterranean Hydrometeorological Observatory Cévennes-Vivarais (OHMCV), part of the French Network of Critical Zone Observatories (OZCAR).



Aerosol optical depth



Saharan dust plume, February 2021.
Source: severe-weather.eu

Field-based analyses

Geochemical analyses with ICP-QMS

Stream and rain water samples
Soil and bedrock samples
Plant litter and leaves

Mass-transfer coefficients

Measure of elemental gain or loss of soil compared to its parent material (usually bedrock)

$$\tau_{j,s} = \frac{C_{j,s}C_{i,r}}{C_{j,r}C_{i,s}} - 1$$

j: mobile element
i: immobile element (Ti, Zr, or Nb)
s: soil
r: bedrock
C: concentration [M M^{-1}]

(Brimhall & Dietrich 1987; Anderson et al. 2002)

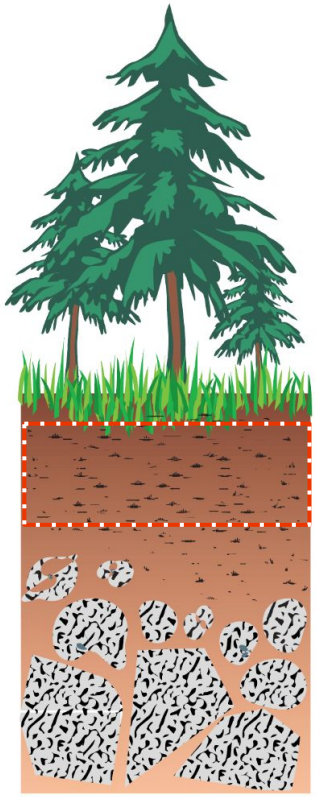
Strontium (Sr) and neodymium (Nd) isotopes

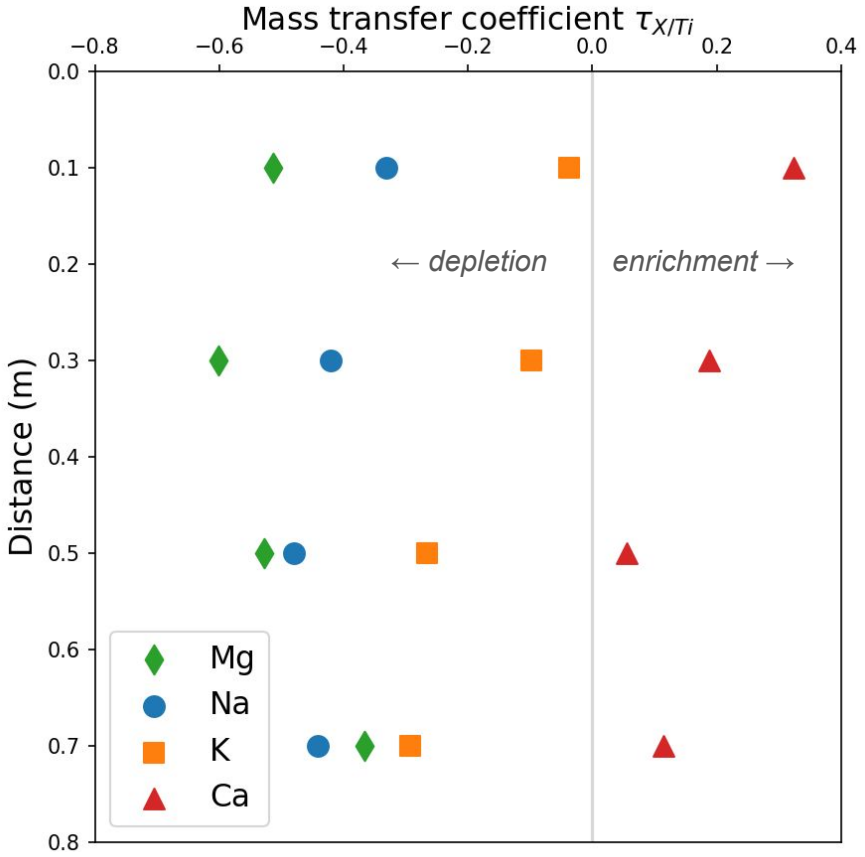
Radiogenic Sr and Nd isotopes are good source tracers

1.Chemical separation of Sr and Nd using column chemistry

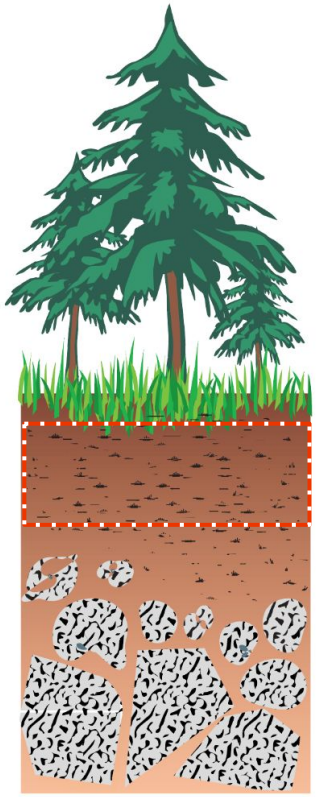
2. Isotope measurements (^{86}Sr, ^{87}Sr,^{143}Nd and ^{144}Nd) with MC-ICP-MS

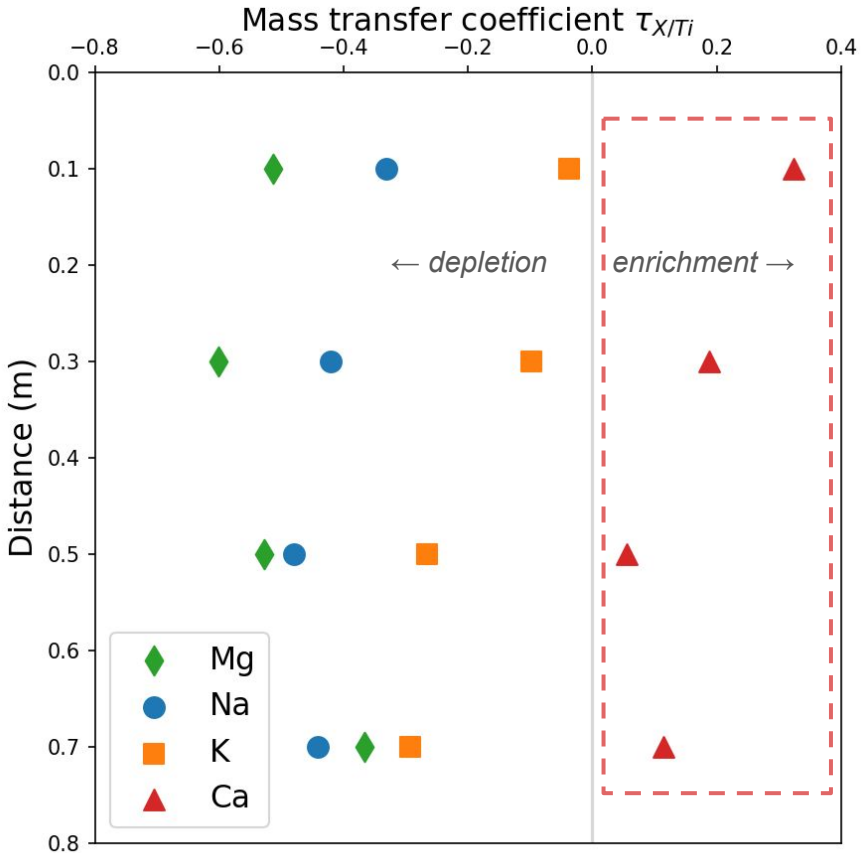
Mass-transfer coefficients



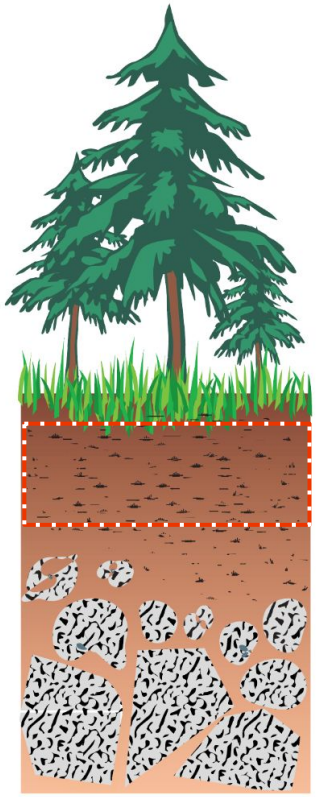


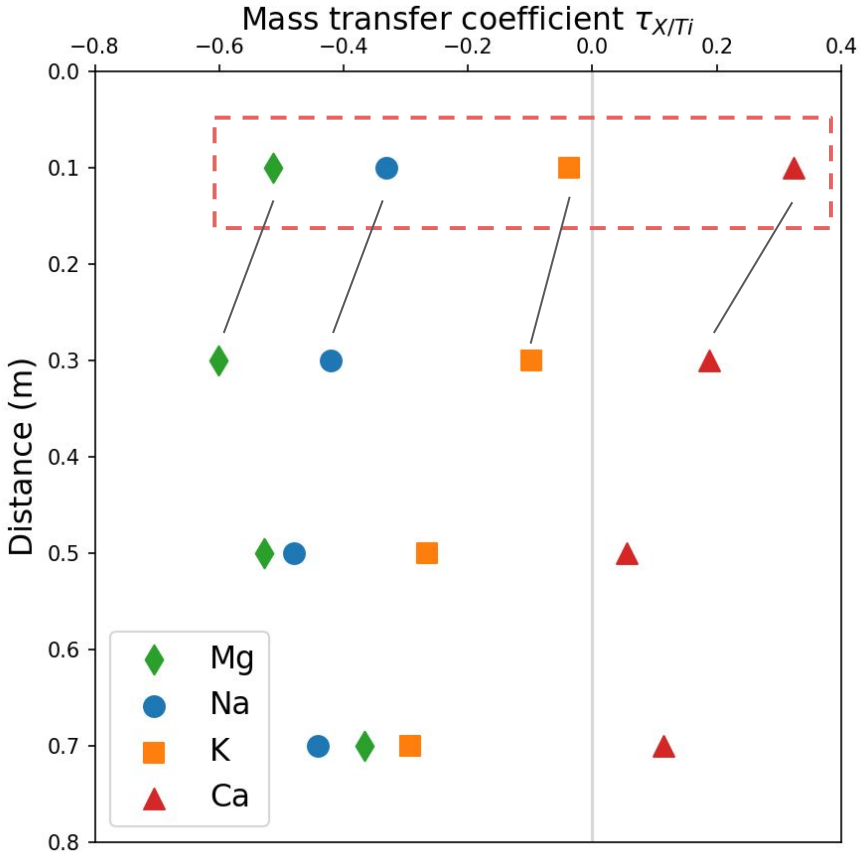
Mass-transfer coefficients



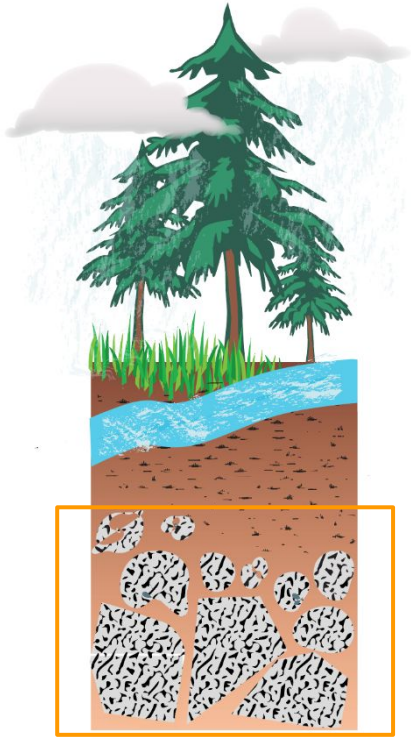


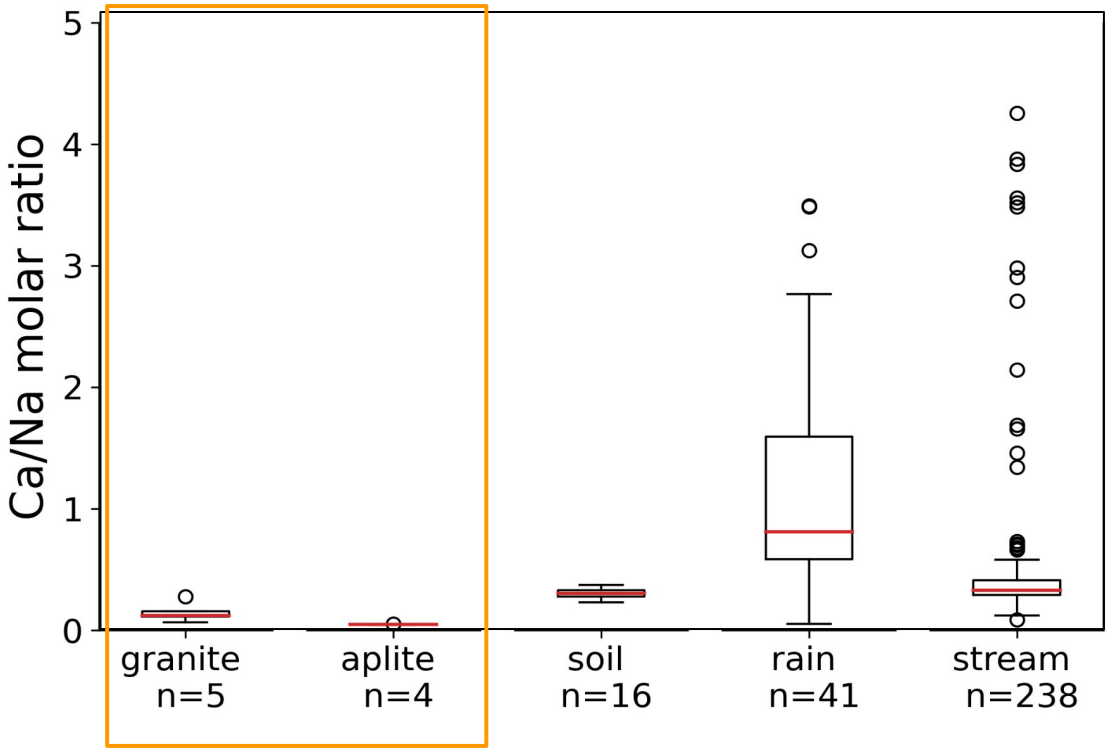
Mass-transfer coefficients



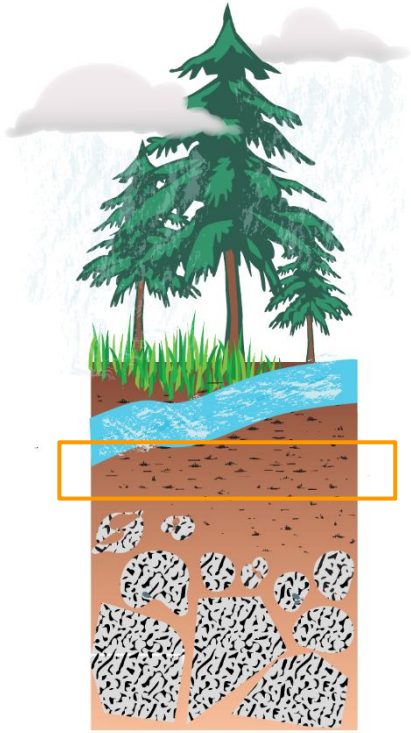


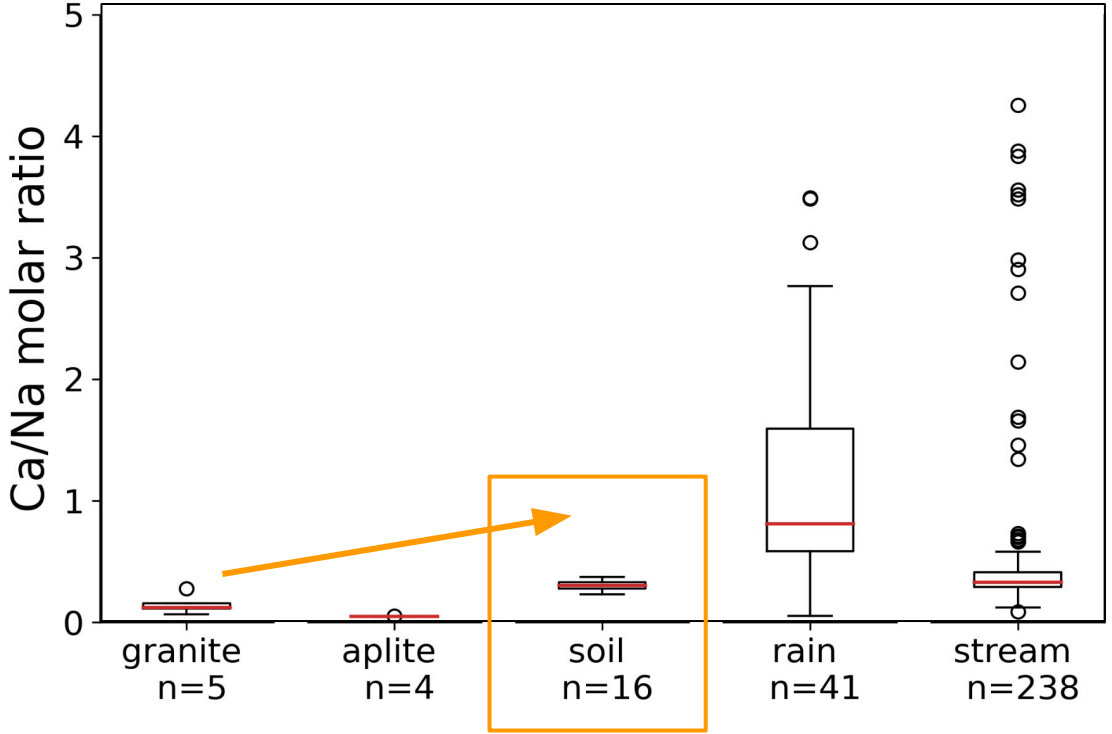
Ca/Na molar ratios



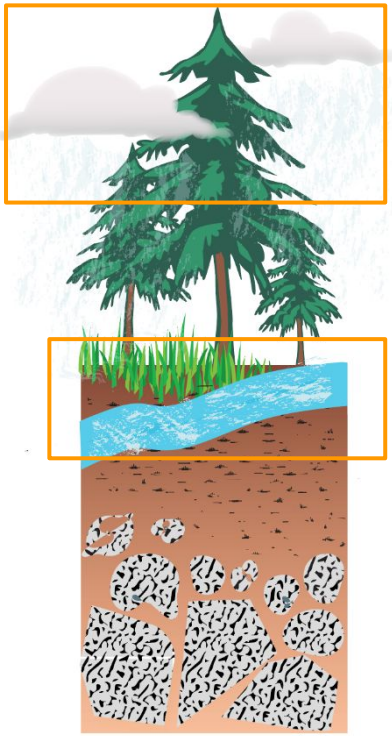


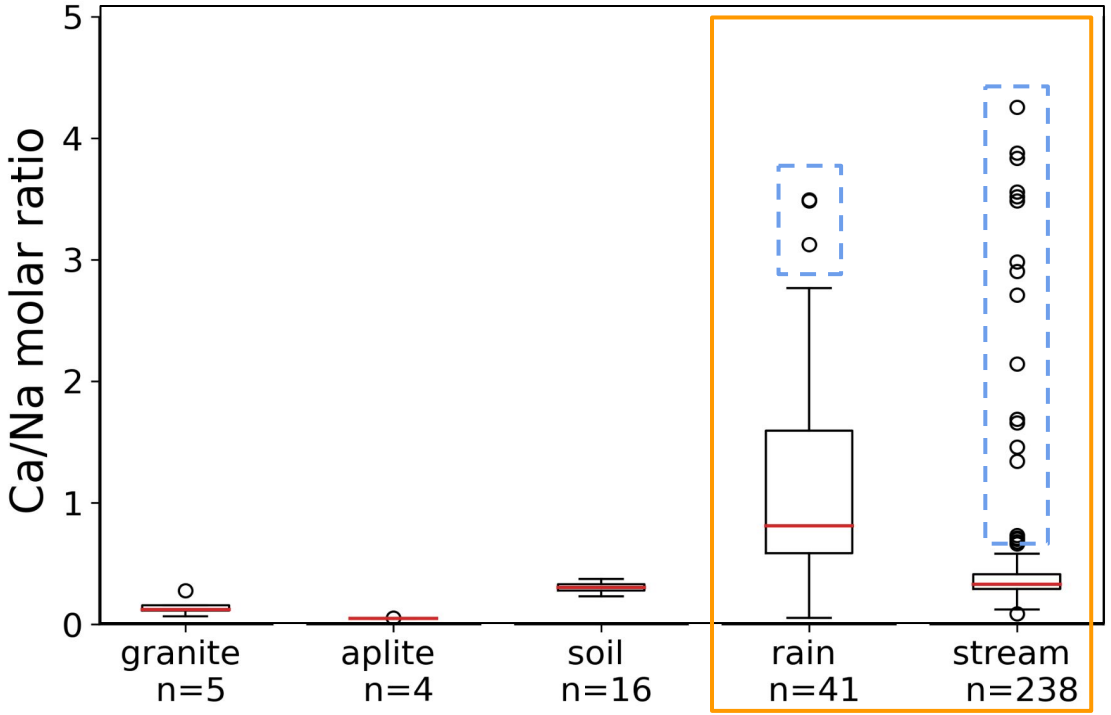
Ca/Na molar ratios



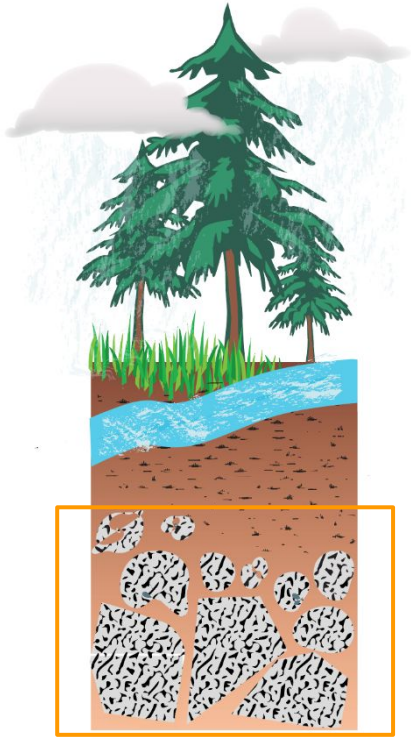


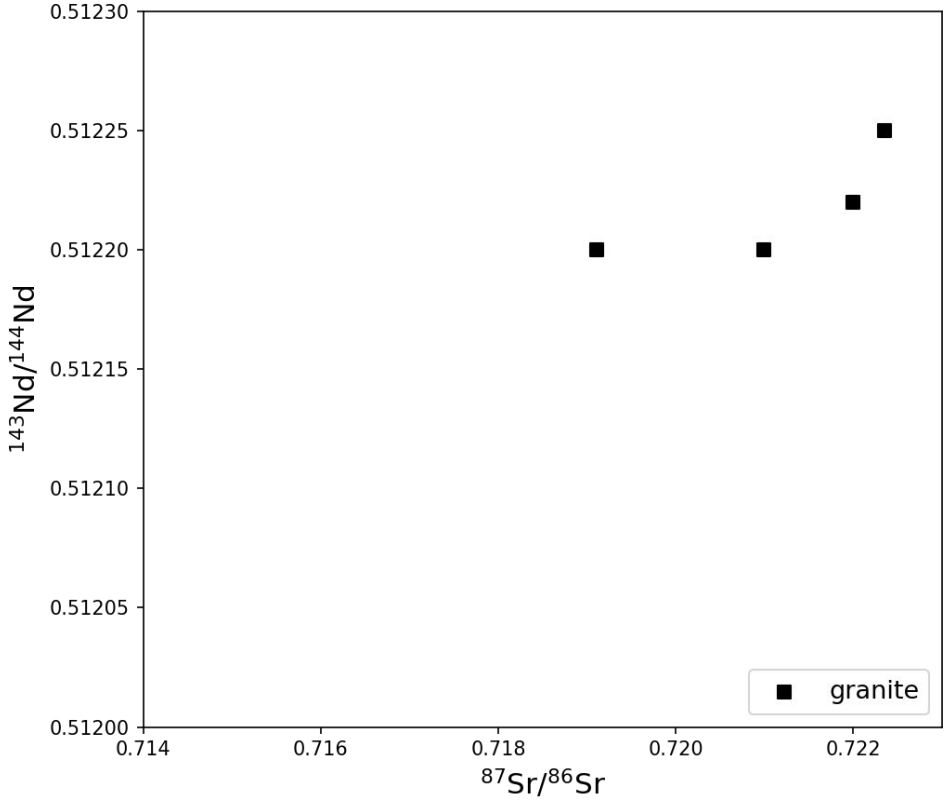
Ca/Na molar ratios



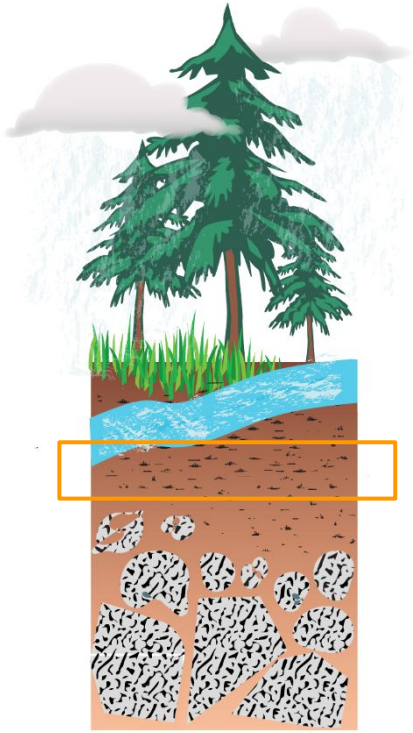


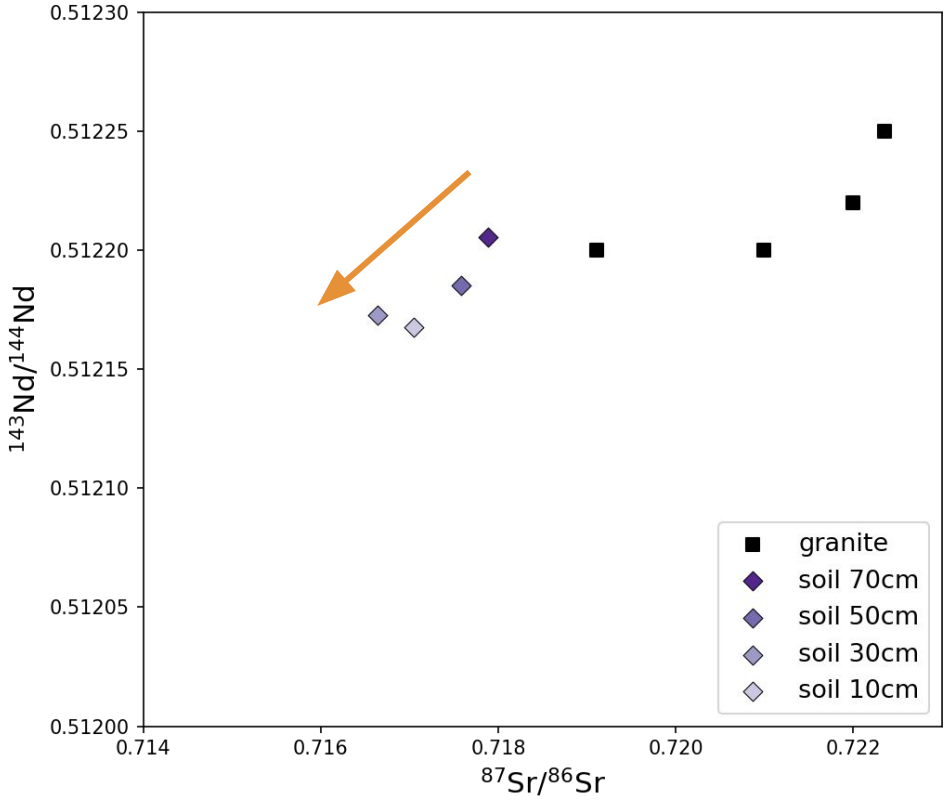
Strontium (Sr) and Neodymium (Nd) isotopes



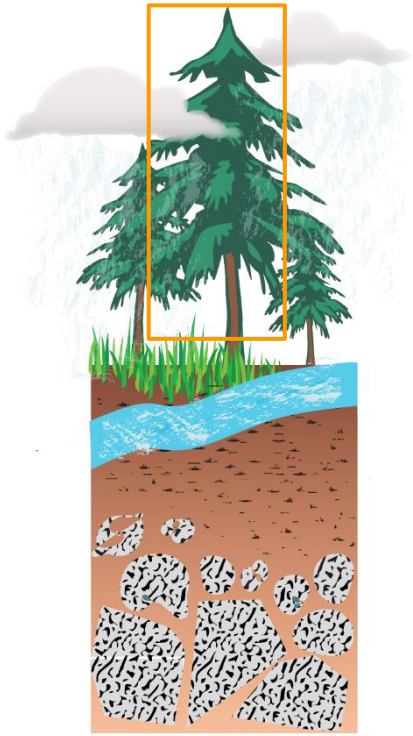


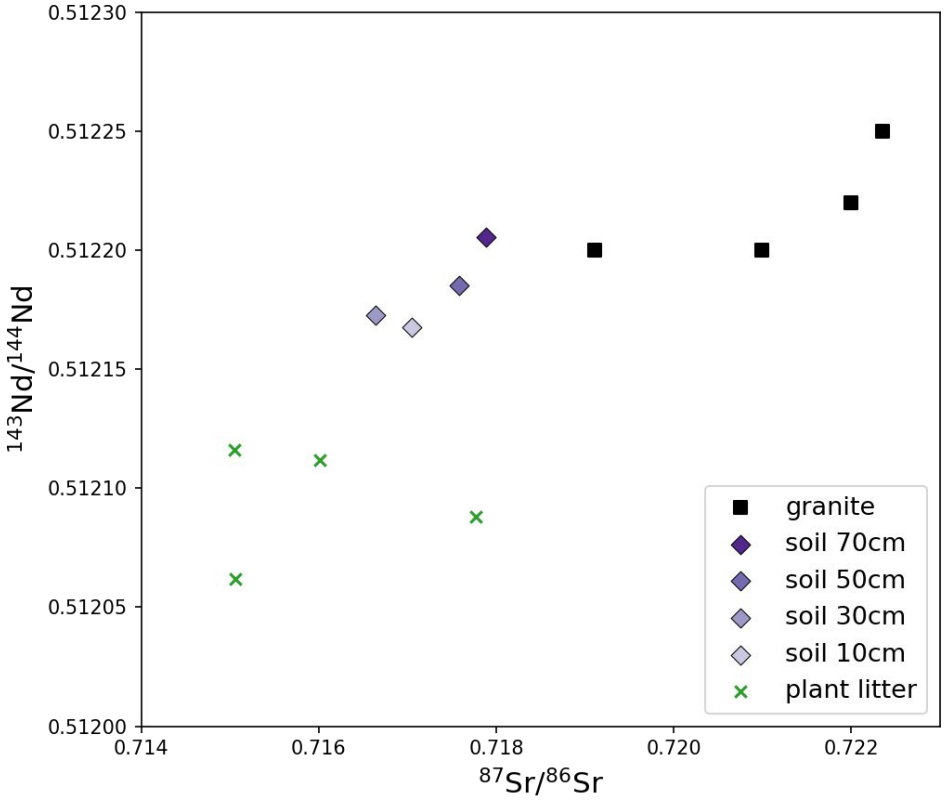
Sr and Nd isotopes



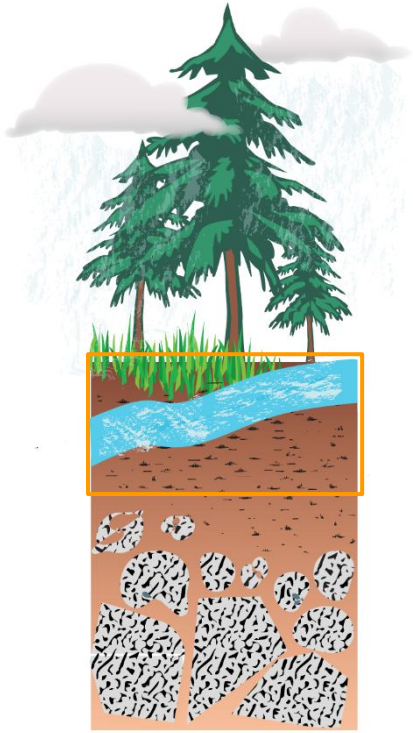


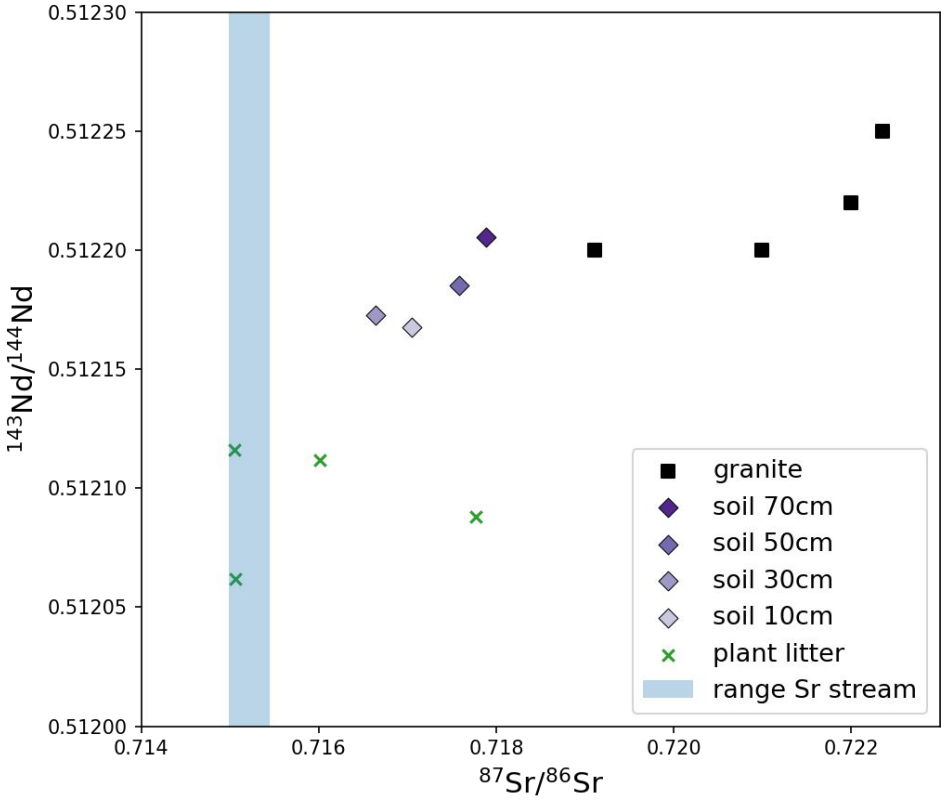
Sr and Nd isotopes





Sr and Nd isotopes





Field evidence of dust deposition

- Gained solid-phase calcium (mass-transfer coefficients)

Field evidence of dust deposition

- Gained solid-phase calcium (mass-transfer coefficients)
- Episodically increased Ca/Na molar ratios in stream water

Field evidence of dust deposition

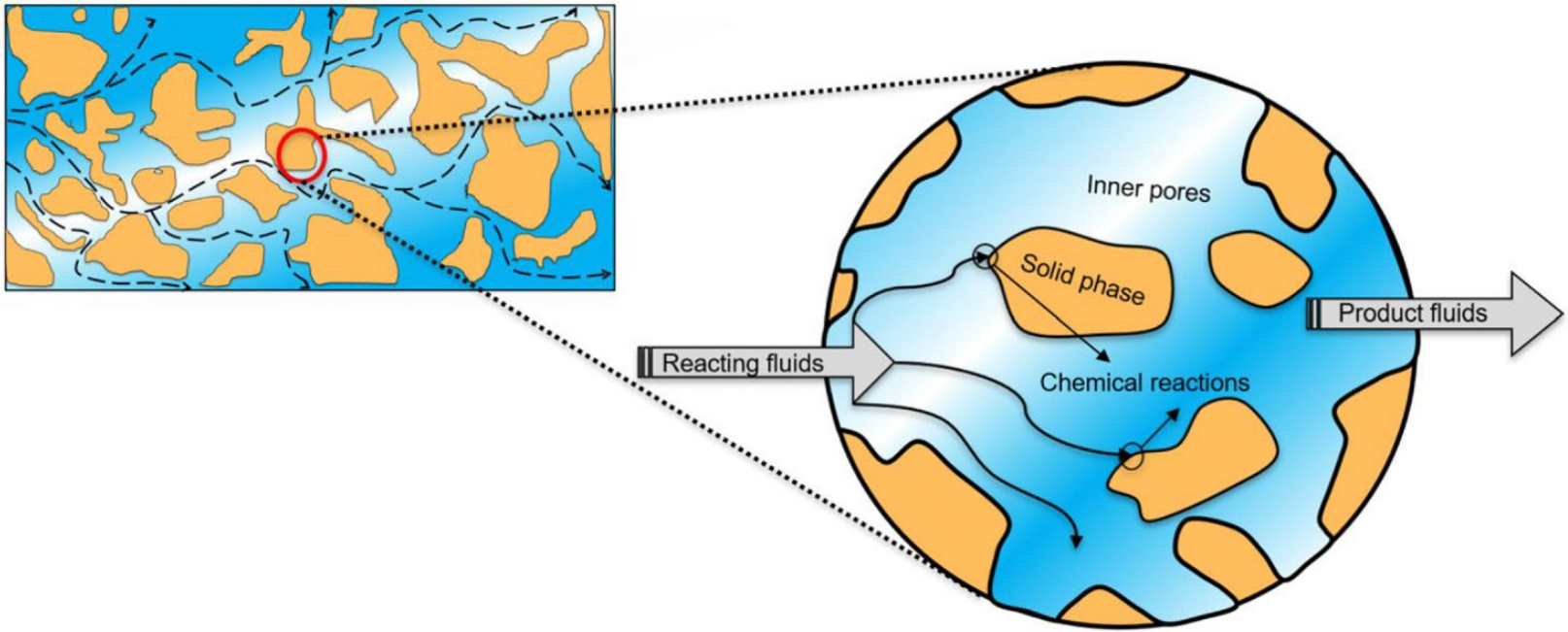
- Gained solid-phase calcium (mass-transfer coefficients)
- Episodically increased Ca/Na molar ratios in stream water
- Departure from bedrock Sr and Nd signatures

Field evidence of dust deposition

- Gained solid-phase calcium (mass-transfer coefficients)
- Episodically increased Ca/Na molar ratios in stream water
- Departure from bedrock Sr and Nd signatures

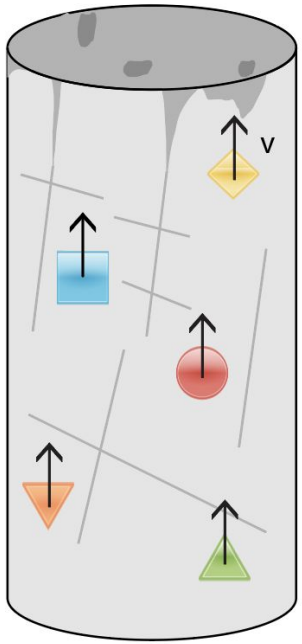
Question: **How does this exogenous source of mass affect the geochemistry of the system?**

Reactive transport model



Abd, A. S., & Abushaikha, A. S. (2021).

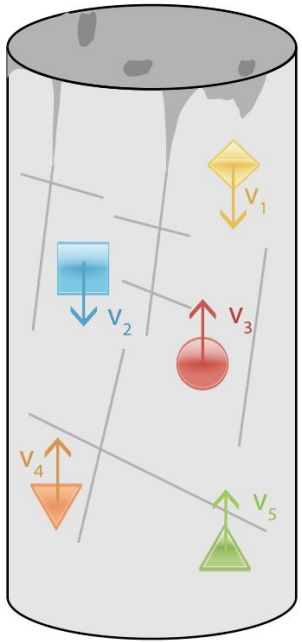
Dust implementation into a reactive transport framework



modified from Golla et al. (2024)

In the distributed version of CrunchTope, all minerals travel collectively at a constant rate in the same direction

Dust implementation into a reactive transport framework

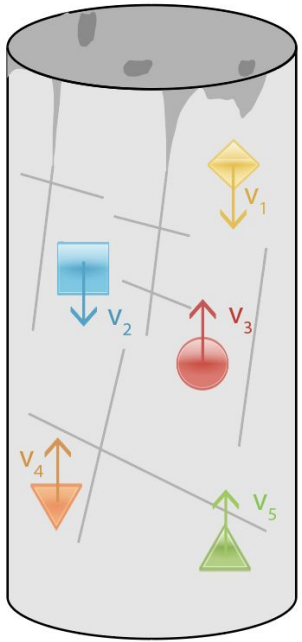


modified from Golla et al. (2024)

In our new version of the code,
each mineral can be assigned a velocity individually:

- upwards for uplift
- downwards for burial

Dust implementation into a reactive transport framework



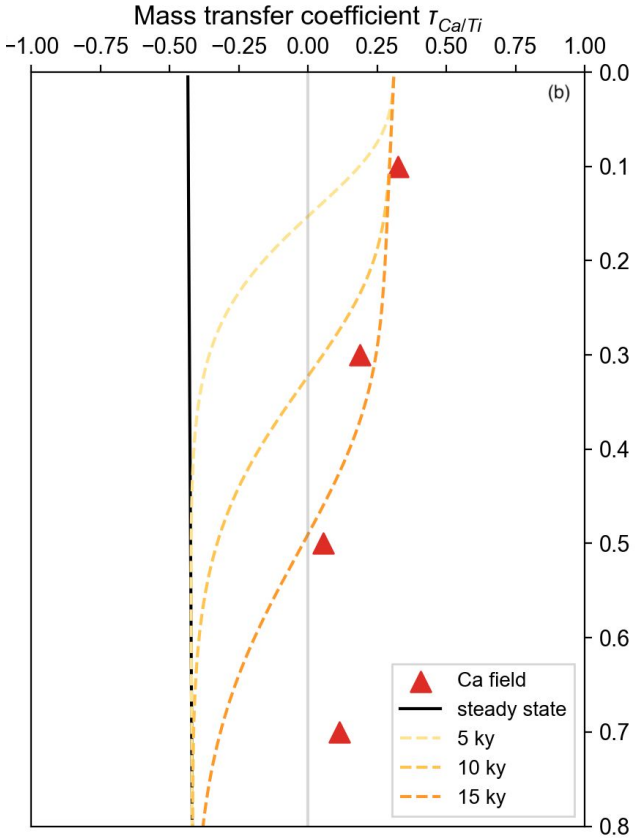
modified from Golla et al. (2024)

In our new version of the code,
each mineral can be assigned a velocity individually:

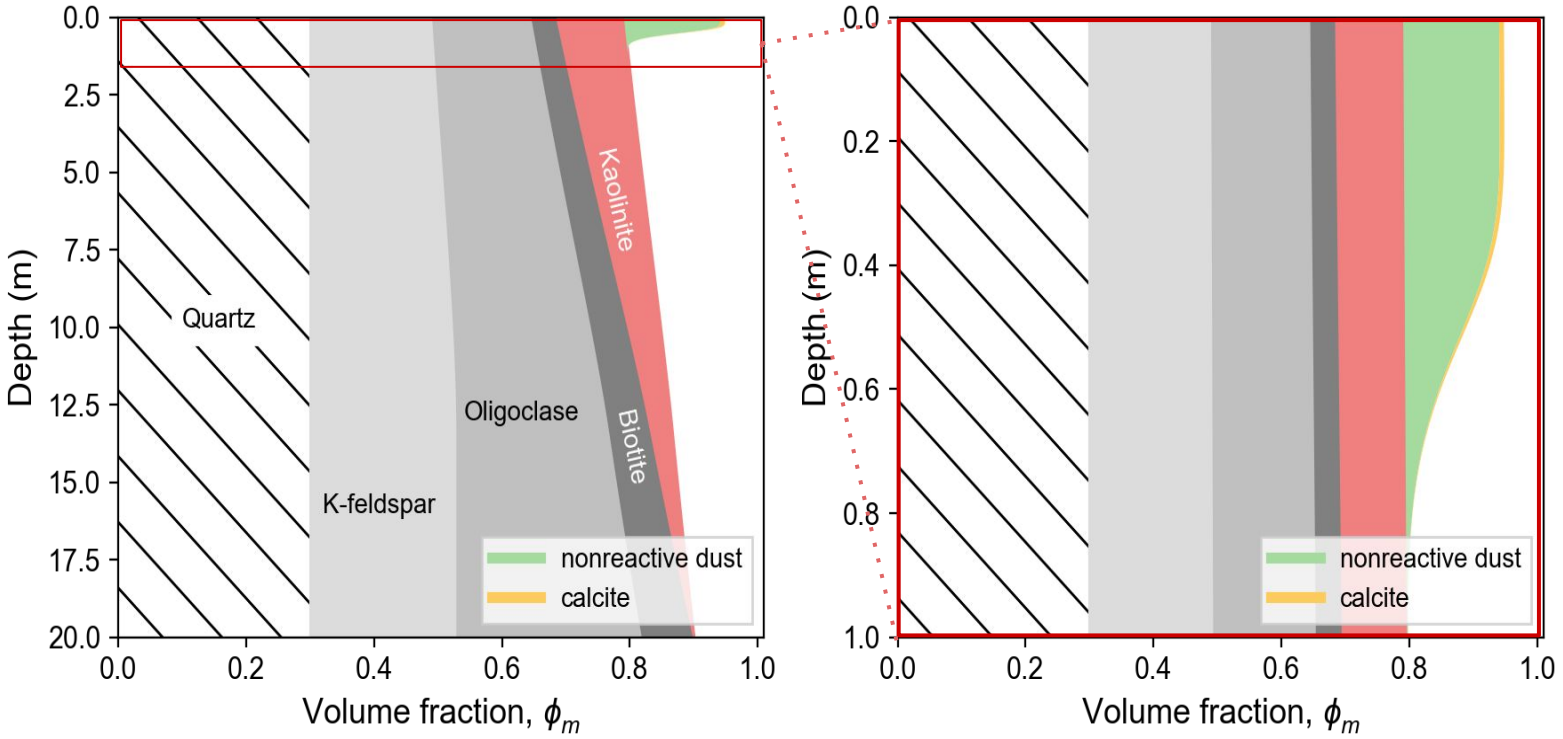
- upwards for uplift
- downwards for burial

We use this capability to implement dust to the actively weathering and uplifting profile in Sapine.

Sapine model results: mass transfer coefficients



Sapine model results: depth of dust transport



Slow down of reaction rates

Conclusions

Questions?

References

Abd, A. S., & Abushaikha, A. S. (2021). Reactive transport in porous media: a review of recent mathematical efforts in modeling geochemical reactions in petroleum subsurface reservoirs. In SN Applied Sciences (Vol. 3, Issue 4). Springer Nature. https://doi.org/10.1007/s42452-021-04396-9

Aciego, S.M., C.S. Riebe, S.C. Hart, M.A. Blakowski, C.J. Carey, et al. 2017. Dust outpaces bedrock in nutrient supply to montane forest ecosystems. Nat Commun 8. doi: 10.1038/ncomms14800.

Anderson, S.P., W.E. Dietrich, and G.H. Brimhall. 2002. Weathering profiles, mass-balance analysis, and rates of solute loss: Linkages between weathering and erosion in a small, steep catchment. GSA Bulletin 114(9): 1143–1158. doi: 10.1130/0016-7606(2002)114<1143:WPMBAA>2.0.CO;2.

Brimhall, G.H., and W.E. Dietrich. 1987. Constitutive mass balance relations between chemical composition, volume, density, porosity, and strain in metasomatic hydrochemical systems: Results on weathering and pedogenesis. Geochim Cosmochim Acta 51(3): 567–587. doi: 10.1016/0016-7037(87)90070-6.

Chadwick, O. A., Derry, L. A., Vitousek, P. M., Huebert, B. J., & Hedin, L. O. (1999). Changing sources of nutrients during four million years of ecosystem development. Nature, 397(6719), 491–497. https://doi.org/10.1038/17276

Golla, J.K.K, Bouchez, J., Kuessner, M.K., Ayral, PA., Druhan, J. (2024) Weathering incongruence in mountainous Mediterranean climates recorded by stream lithium isotope ratios.

Guinoiseau, D., S.P. Singh, S.J.G. Galer, W. Abouchami, R. Bhattacharyya, et al. 2022. Characterization of Saharan and Sahelian dust sources based on geochemical and radiogenic isotope signatures. Quat Sci Rev 293. doi: 10.1016/j.quascirev.2022.107729.

Pett-Ridge, J. C., Derry, L. A., & Barrows, J. K. (2009). Ca/Sr and 87Sr/86Sr ratios as tracers of Ca and Sr cycling in the Rio Icacos watershed, Luquillo Mountains, Puerto Rico. Chemical Geology, 267(1–2), 32–45. https://doi.org/10.1016/j.chemgeo.2008.11.022

Vincent, J., B. Laurent, E.B. Nguyen, B. Nguyen, J. Vincent, R. Losno, et al. 2015. Variability of mineral dust deposition in the western Mediterranean basin and South-East of France PEACETIME : ProcEss studies at the Air-sEa Interface after dust deposition in the MEditerranean sea View project Variability of mineral dust deposition in the western Mediterranean basin and south-east of France. Atmos. Chem. Phys 16: 8749–8766. doi: 10.5194/acpd-15-34673-2015.