Sediment residence time variations in an Alpine river system inferred by uranium isotopes.

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Context

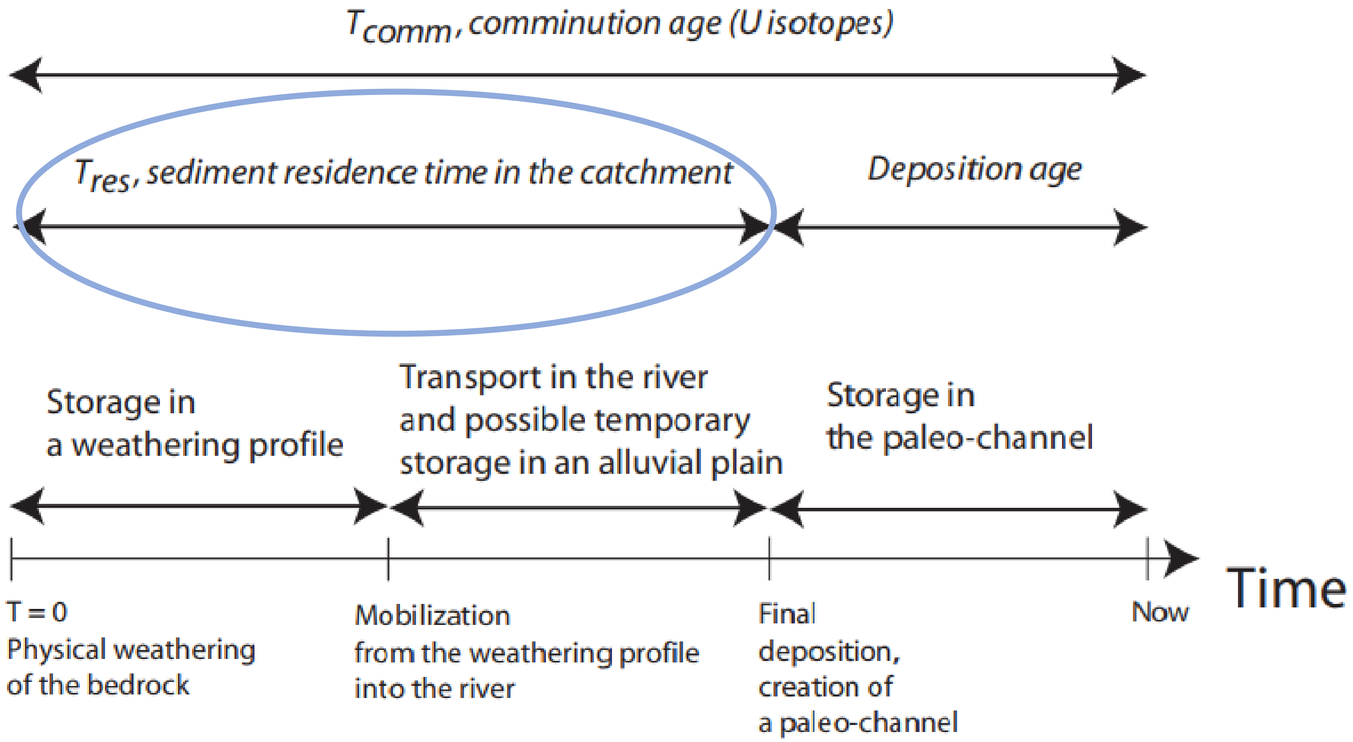
- In the context of current climate change, it is important to better understand the response of the processes (e.g. weathering, transfer, deposition) occurring in a source to sink system.

- One major challenge is to quantify the timescale of sedimentary processes such as sediment weathering and transfer. In the last decades the uranium isotope activity ratio, ($^{234}U/^{238}U$) has been used to estimate sediment residence times (i.e. the time spent by the sediment in the catchment between its formation by weathering and its deposition at the end of the system).

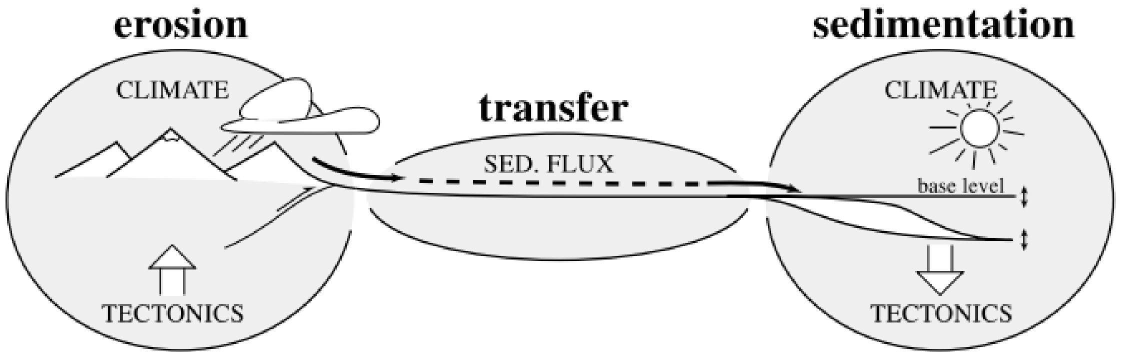
- By studying the spatial ($^{234}U/^{238}U$) variation of a modern catchment it is possible to understand how the sediment residence time evolves according to different geomorphological parameters (e.g. elevation, slope).

- Later, the obtained findings can be applied to sediment records to reconstructthe evolution of sediment residence time through past climate variations.

Context

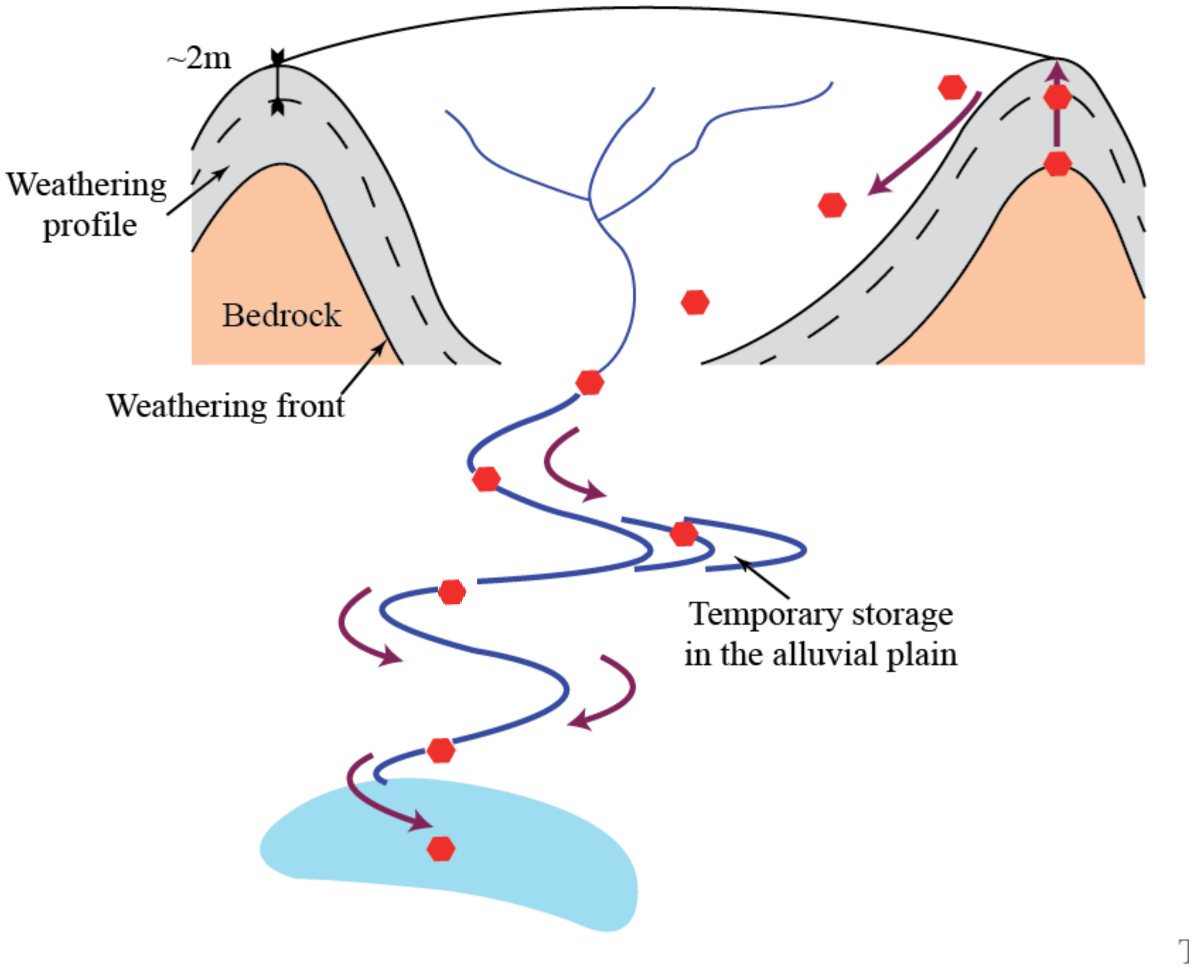


From Dosseto et al., 2010



Idealized source to sink system. From Castelltort et Van Den Driessche., 2003.

Sediment residence time



Hillslope storage

Sediment residence time

Alluvial storage

Conceptual representation of sediment (red polygone) transport from the source to the sink in a catchment.
From Dosseto and Schaller, 2016.

Sediment residence time

Calculated with ($^{234}U/^{238}U$)
from DePaolo et al. (2006) equation

$$t_{comm} = -\frac{1}{\lambda_{234}} ln\left[\frac{A_{meas} - (1 - f_\alpha)}{A_0 - (1 - f_\alpha)}\right]$$

- t_{comm} is the comminution age (yrs)
- λ_{234} is the ^{234}U decay constant (yrs)
- A_{meas} is ($^{234}U/^{238}U$) measured
- A_0 is ($^{234}U/^{238}U$) at t=0, in unweathered bedrock
- f_α is the recoiled fraction estimated with the specific surface area of the grain

In river sediments:

$$t_{comm} = t_{res} \qquad \textit{(deposition age = 0)}$$

Estimated from soil thickness

$$estimated\ t_{res} = \frac{denudation\ rate\ (\frac{mm}{yrs})}{soil\ thickness\ (mm)}$$

- denudation rate from Mariotti et al. (2019) on the 50-100µm fraction (or 100-250µm when not available)
- estimated soil thickness from SoilGrids (*(https://www.soilgrids.org)*

Uranium activity ratio

Bedrock
($^{234}U/^{238}U$) = 1

Weathering

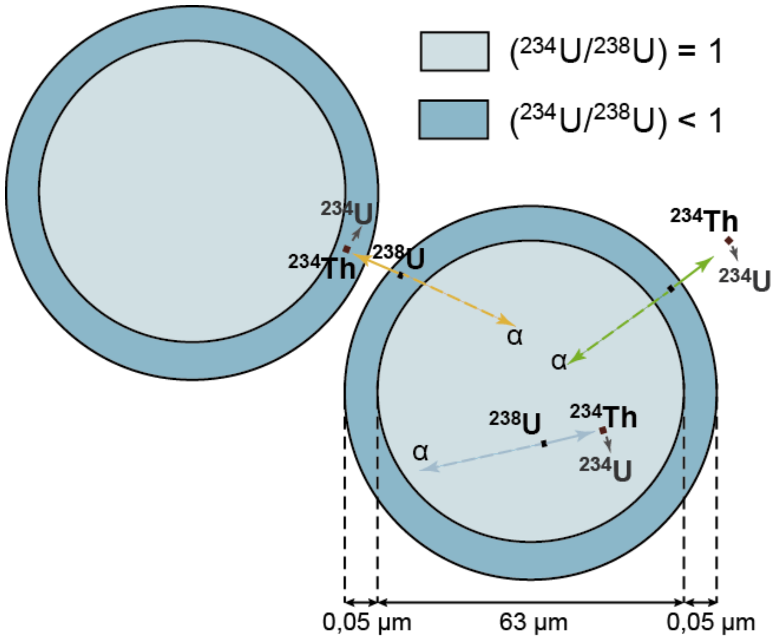
Sediments
($^{234}U/^{238}U$) < 1

River
($^{234}U/^{238}U$) >1

Chemical fractionation

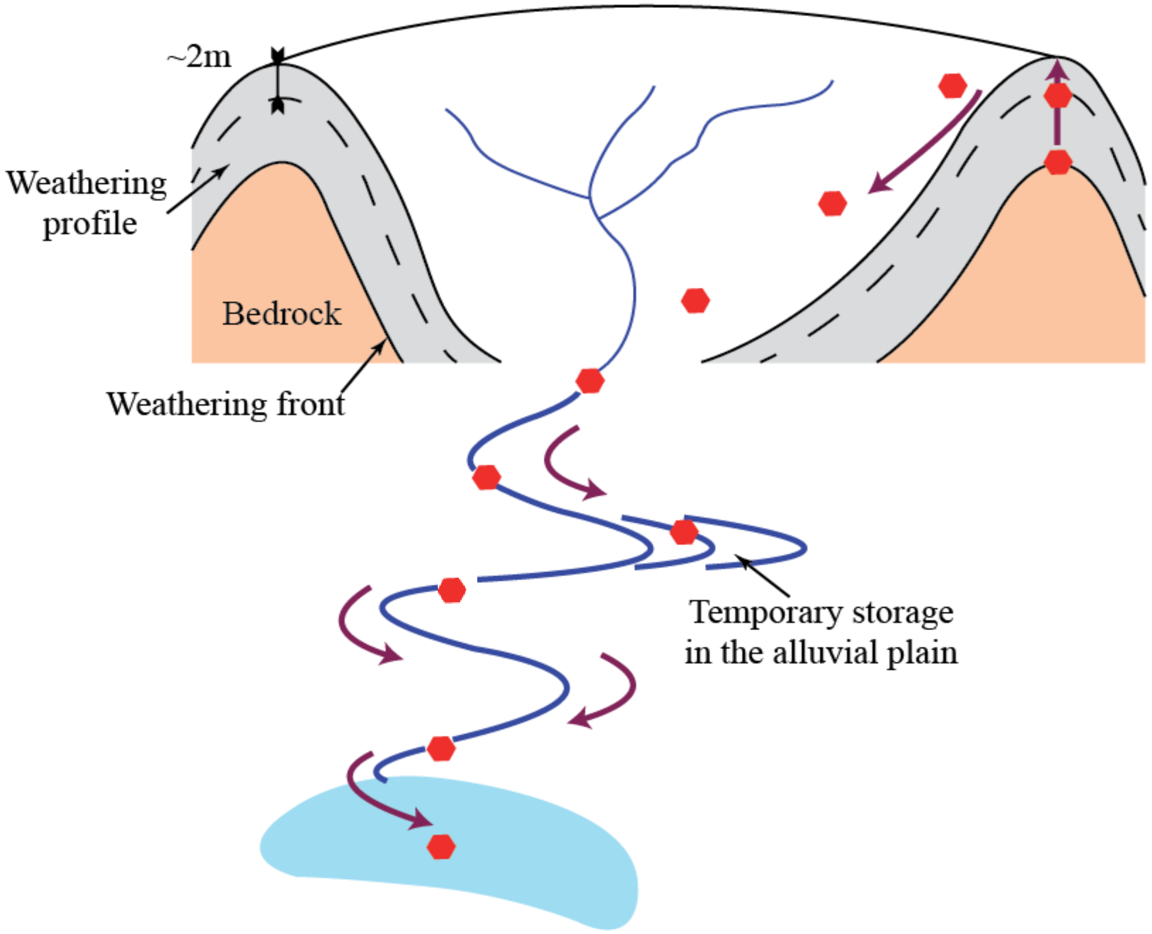
- Preferential leaching of ^{234}U compared to ^{238}U
- Preferential oxidation of ^{234}U compared to ^{238}U

Recoil effect



Schema of recoil effect. Adapted from DePaolo et al., 2006.

Objectives



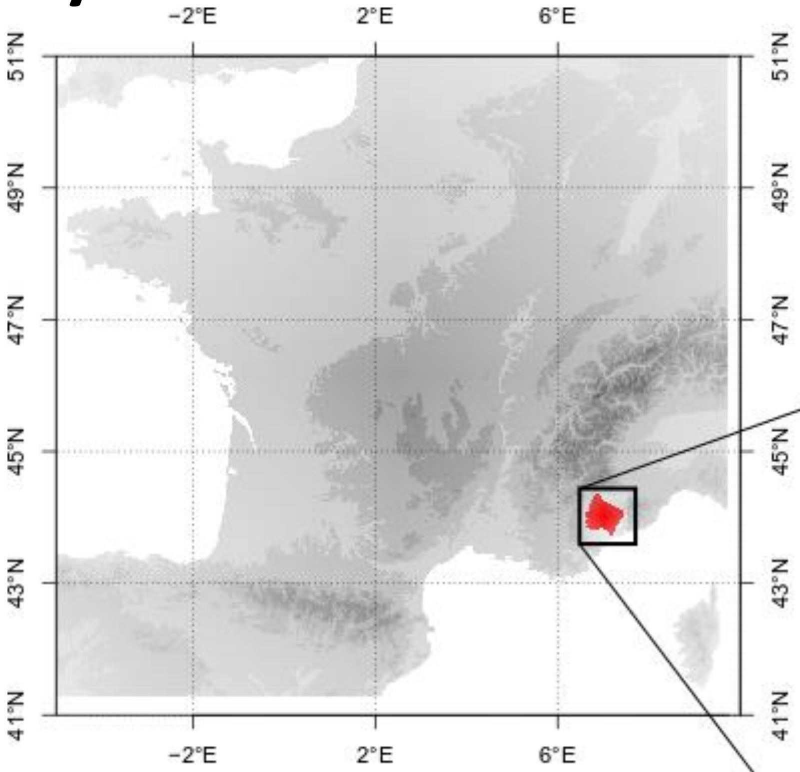
Conceptual representation of sediment (red polygone) transport from the source to the sink in a catchment.
From Dosseto and Schaller, 2016.

- To quantify the actual sedimentary residence time
→ better constrain the source to sink system

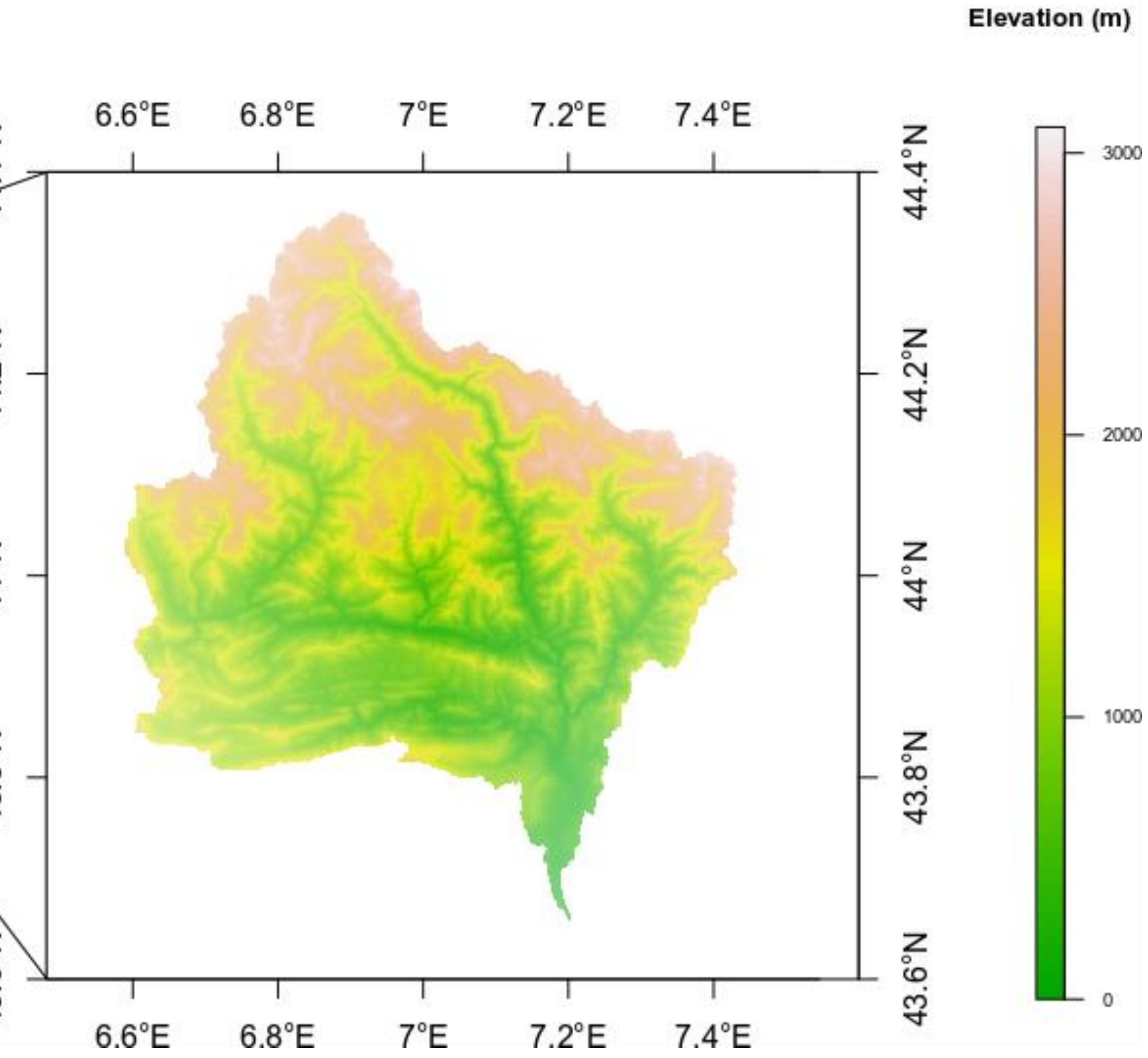
- To compute the sedimentary residence time depending on geomorphologic parameters
→ study the influence of the landscape morphology

Study site

- Mountainous sedimentary system: sedimentary transfer expected to be rapid
- No fluvial plain: no alluvial storage

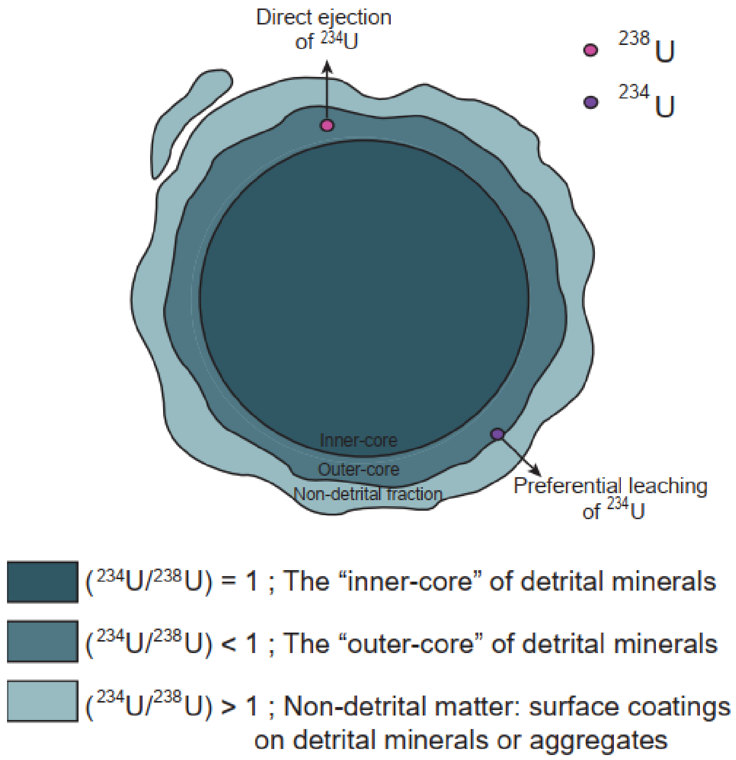


Map of the localisation of the Var catchment (France) on digital elevation model (DEM) background from ETOPO1 Global relief Model (https://www.ngdc.noaa.gov/mgg/global/global.html)



Digital elevation model (DEM) of the Var catchment at a resolution of 5m (DEM "RGE ALTI" produced by the French Institut National de l'Information Géographique et Forestière)

Methods



The sedimentary grains can be separated in three different parts based on their respective ($^{234}U/^{238}U$) activity ratio.
Adapted from Martin el al., 2015.

SIEVING

Isolation of the finest fraction (<63µm)

LEACHING

Removal of the non detrital matter

(protocol from Francke et al., 2018)

BET analyses

Measurement of the specific surface area

DIGESTION

Conventional HF-HCl remineralization

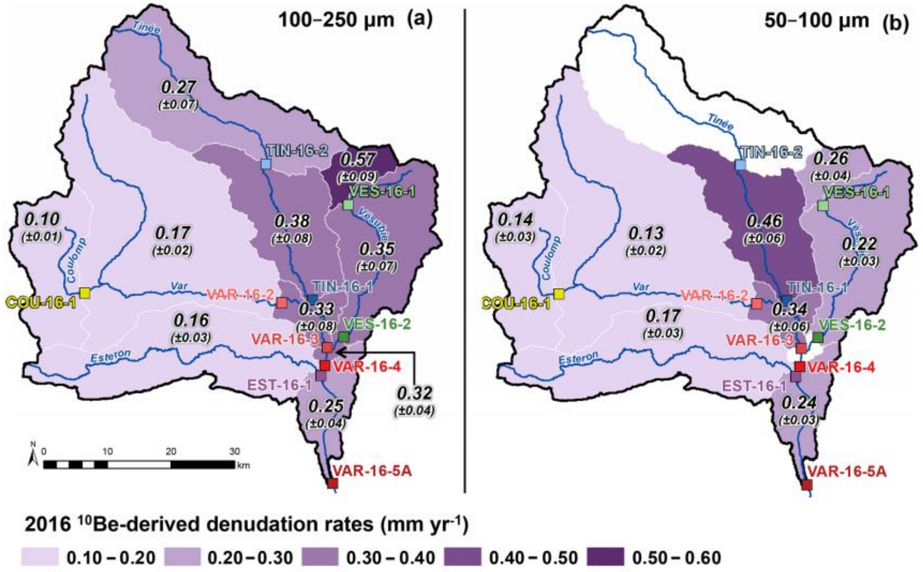
U ELUTION

Chromatographic separation of U fraction from the matrix

ISOTOPIC MEASUREMENTS

by MC-ICP-MS

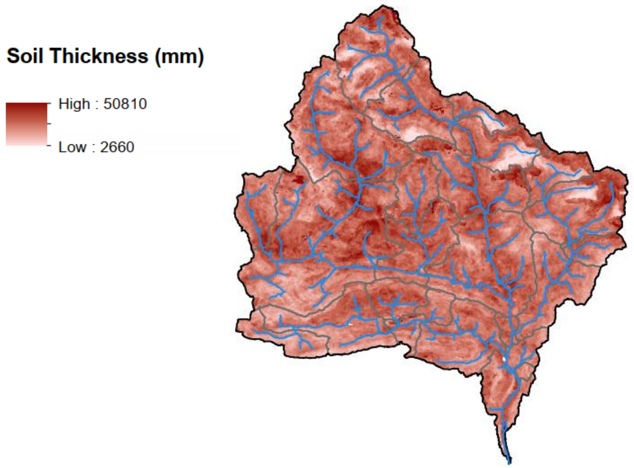
Methods



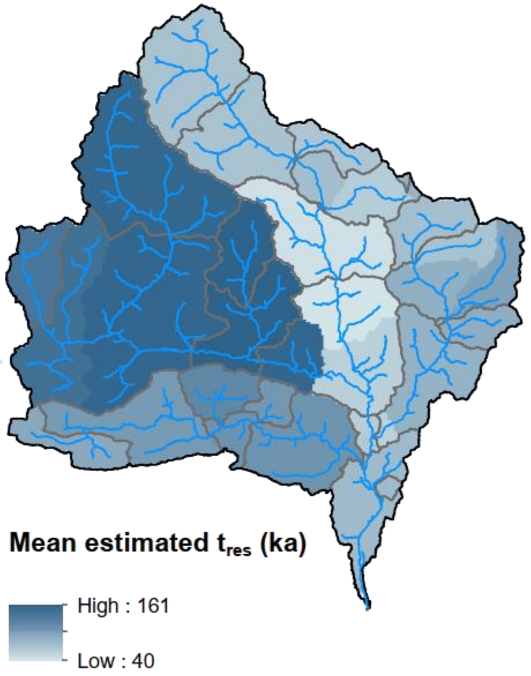
Denudation rate inside the Var cachment on two sediments size fractions (Mariotti et al., 2019)

$$estimated\ t_{res} = \frac{denudation\ rate\ (\frac{mm}{yrs})}{soil\ thickness\ (mm)}$$

Soil thickness data processes for each mean, maximum and minimum values for each subcatchment given **mean**, **maximum** and **minimum** estimated residence time

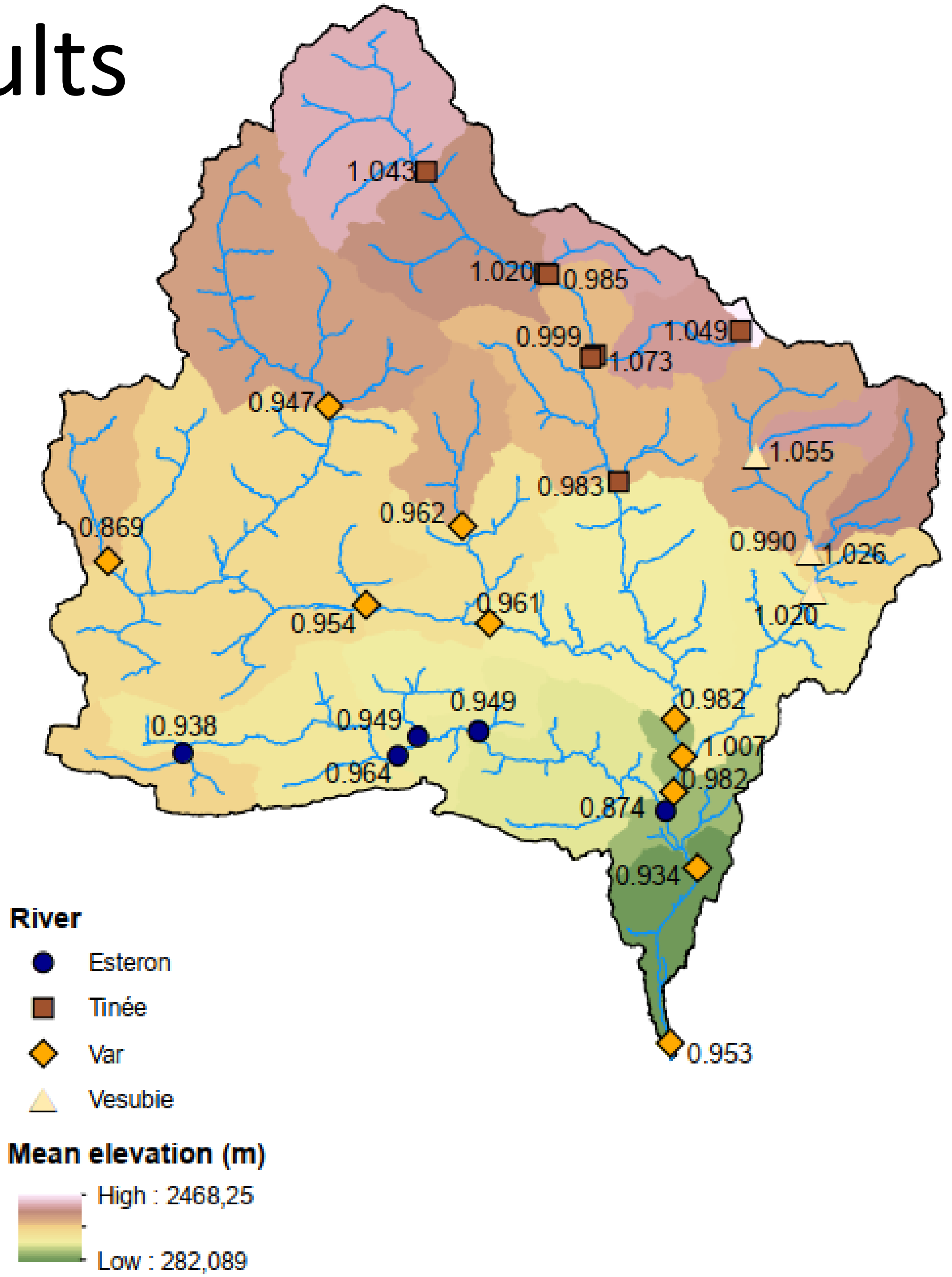


Estimated depths to bedrock (mm) from the soilGrids database used as soil thickness data for the study



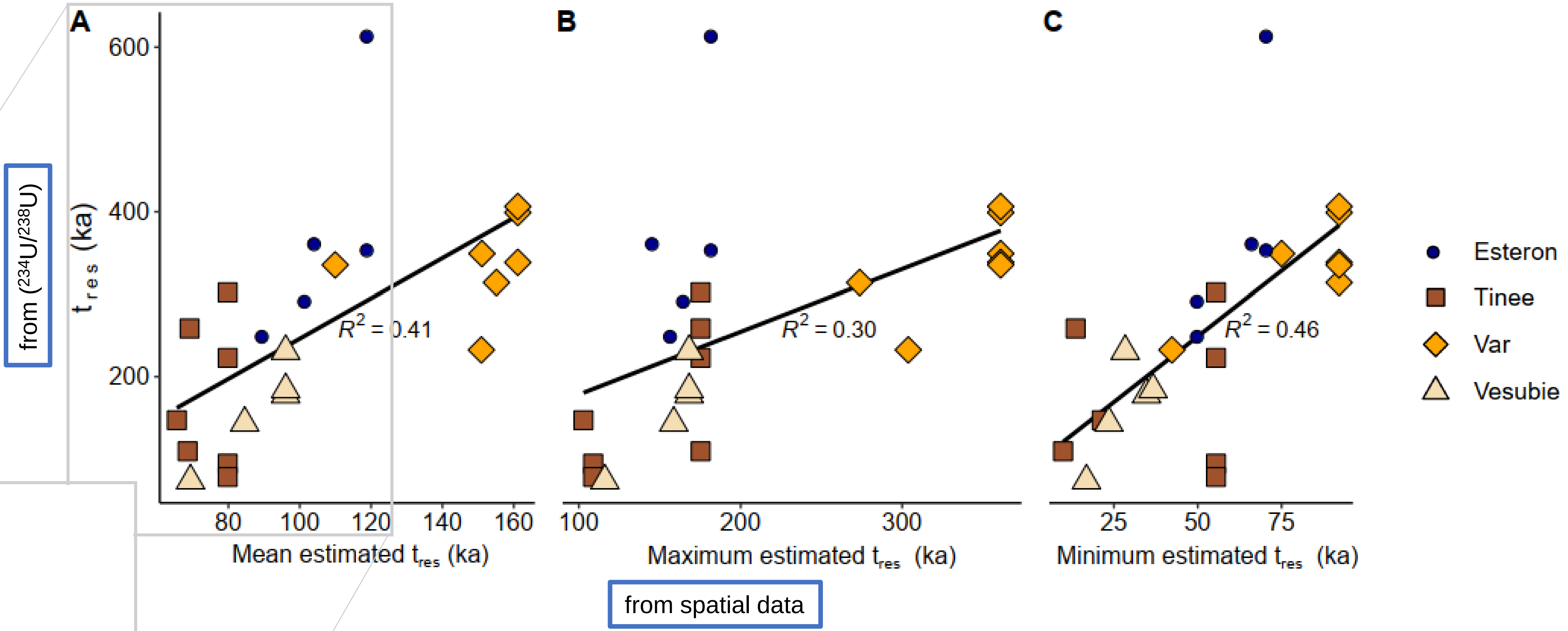
Exemple of the mean estimated residence time (ka) calculated for each subcatchment

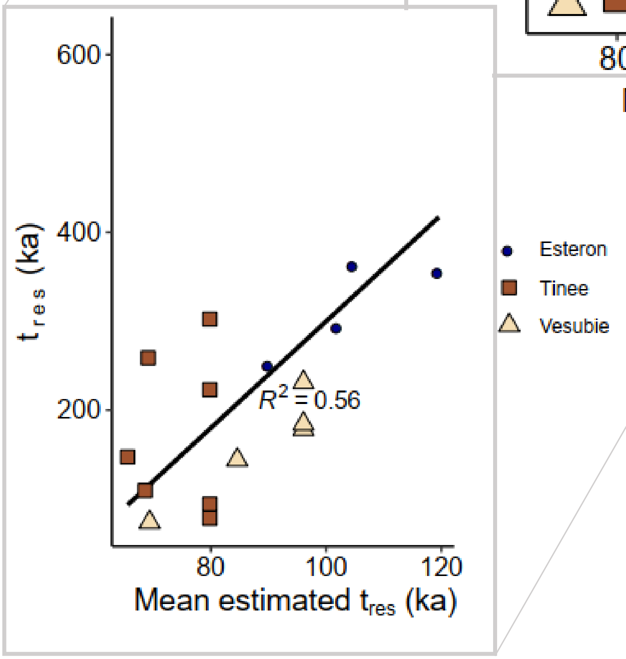
Results



- High ($^{234}U/^{238}U$) values for Esteron and Tinée river sediments
- Low ($^{234}U/^{238}U$) values for Var and Vesubie river sediments

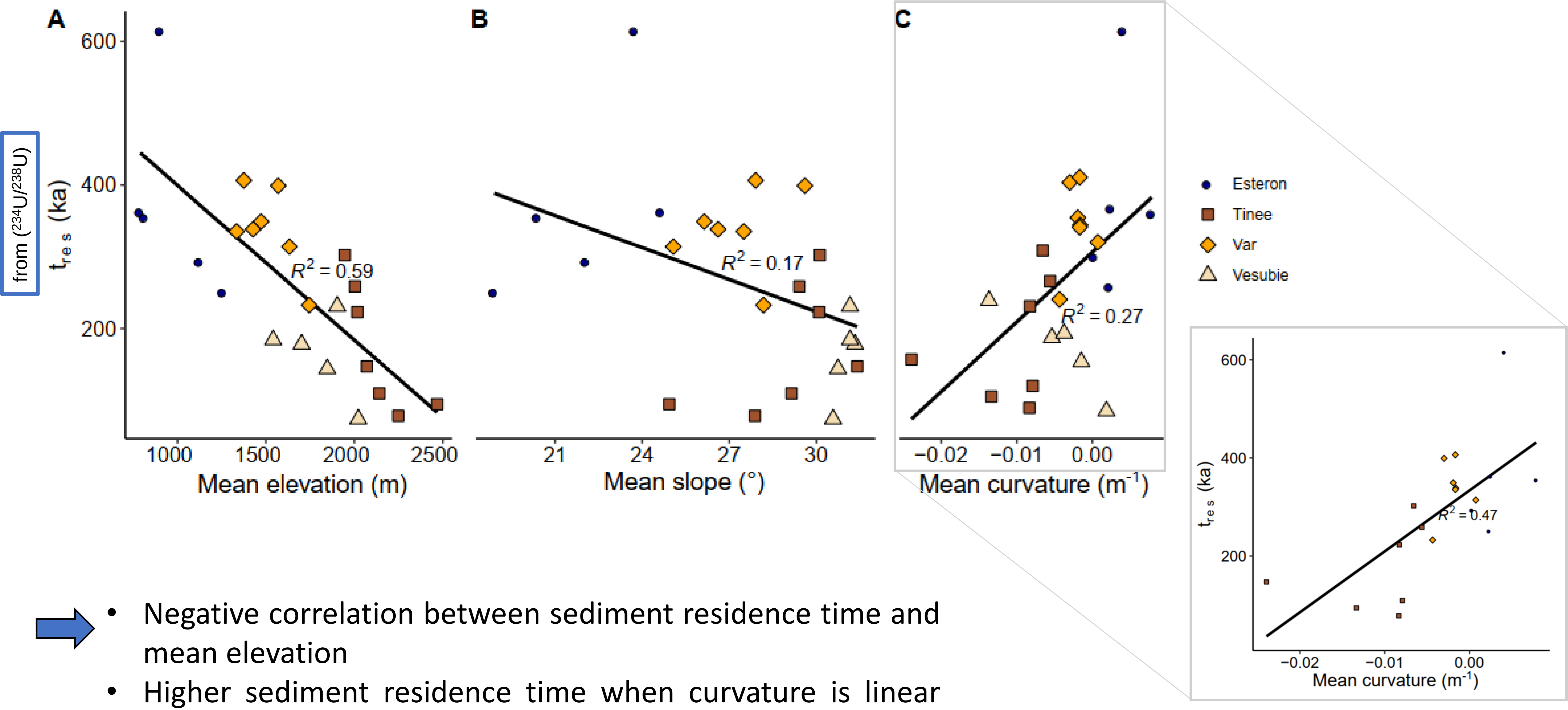
Residence time





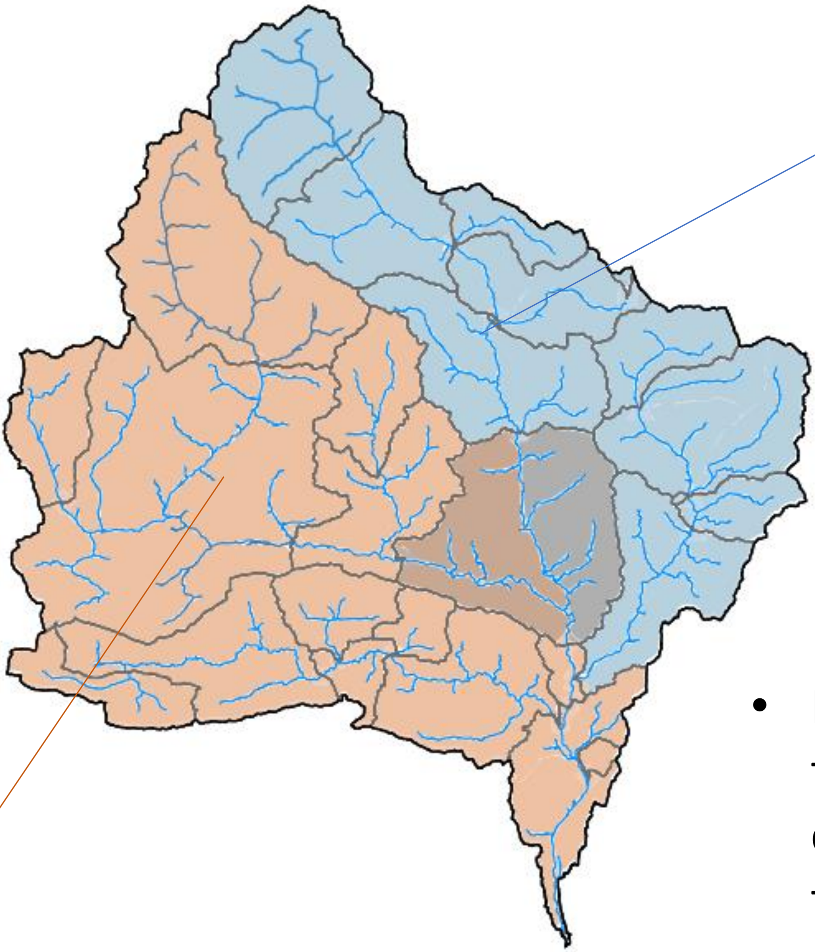
- Estimates of residence time based on denudation rate and soil thickness are underestimated (influence of particle size?)
- The mean estimated residence time of Var sediments could be possibly affected by the presence of an alluvial cover, which have not been considered in the soil thickness estimation.

Geomorphological variations



- Negative correlation between sediment residence time and mean elevation
- Higher sediment residence time when curvature is linear (i.e. around 0)

Conclusion



Weathering-limited area
High relief
High slope
Non linear-curvature

($^{234}U/^{238}U$) ≥1
Low sediment residence time

Transport-limited area
Low relief
Low slope
Linear-curvature

($^{234}U/^{238}U$) < 1
High sediment residence time

- In low elevation area, the soil is generally thicker leading to an increase of the storage capacity. Thus, the sediment will stay longer in the source to sink system leading to a higher fractionation between ^{234}U and ^{238}U

- In mountainous region, the denudation rate is high leading to thick soil thickness. Thus, the sediment will be exported quickly out of the source to sink system leading to ($^{234}U/^{238}U$) close to 1.

Perspective

- Studying ($^{234}U/^{238}U$) in core sediments samples to measure past sediment residence time variations.
- Linked the past sediment residence time variations with a source tracer (e.g. Nd isotopes) to identify if the U variations are caused by a sediment source change or if it is due to a past geomorphological variations. It could provide information on paleo-weathering as the soil thickness is the balance between soil production and soil denudation.

Sediment residence time could be used to reconstruct paleo-geomorphological variations and linked it with the past climatic variations

Thank you

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