Quantifying the dynamic topography through a combination of basin-averaged erosion rates and geomorphic analysis from the Anti Atlas and Western Meseta (Morocco) transient landscape

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The topography of the Atlas-Meseta system (Morocco) is the result of Late Cenozoic rejuvenation related to mantle-driven uplift. This recent, large-scale dynamic uplift is testified by the occurrence of uplifted shallow-water marine deposits in the Middle Atlas Mountains and in the Western Meseta, indicating that surface uplift must have started after the Late Miocene (Messinian) at rates of 0.1 to 0.2 mm yr-1. This recent pulse is still recorded by transient river networks and by the presence of uplifted relict landscape. In particular, in the Anti Atlas and Western Maroccan Meseta, the lack of significant Cenozoic crustal shortening and the occurrence of several hundred of meters of mantle-driven uplift, offers the possibility to investigate magnitude, timing and rates of deep-seated uplift. In this study we have combined geomorphic analysis of stream profiles with in situ-produced cosmogenic concentrations (10Be, 26Al) in river sediments and bedrock surfaces (corresponding to relict landscape upstream of knickpoints), in order to decipher the uplift history.

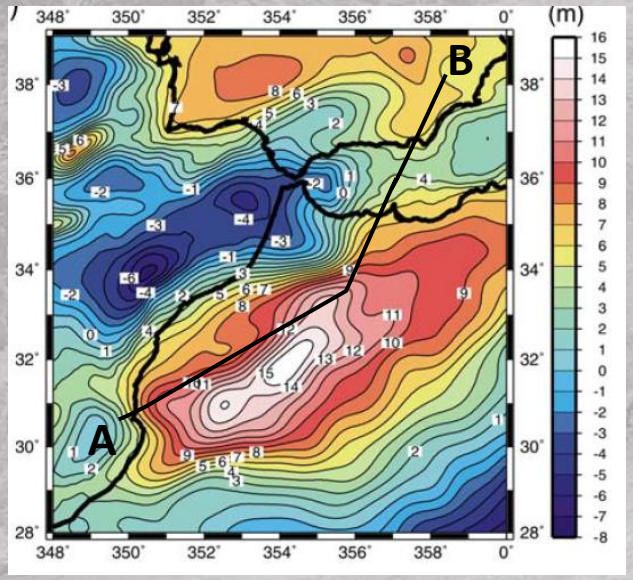
Our catchment-mean erosion rates allow us to quantitatively constrain the transient state of landscape and hence to unravel the contribution of regional surface uplift on mountain building processes in Morocco during the Plio-Quaternary.

Goal → Decipher the uplift history (mainly dynamically-supported) of Anti Atlas and Westerm Meseta region

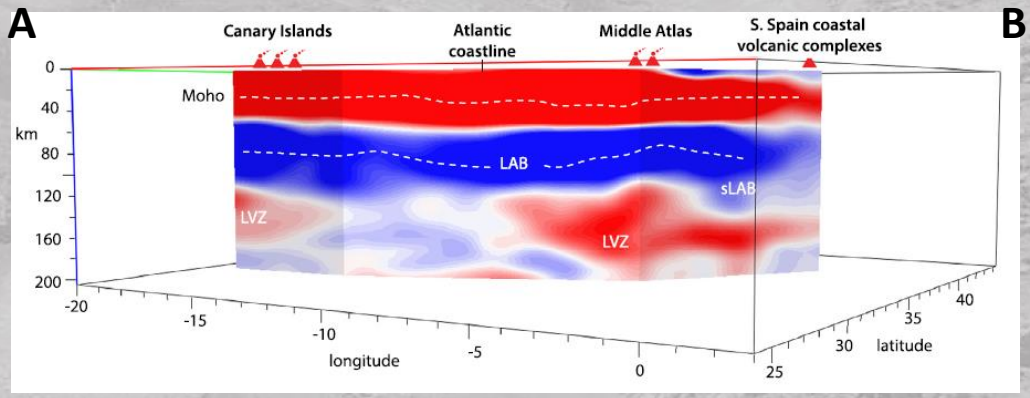
Structural studies → **Crustal shortening** of:

- High Atlas: 13 km (15%) to 26 km (24 %)
- Middle Atlas: 4.7 km (15 %)
- Anti Atlas no evidence/ limited during Cenozoic

Geophysical and vulcanological studies → Topographic is supported by mantle dynamics (**Dynamic Topography**)

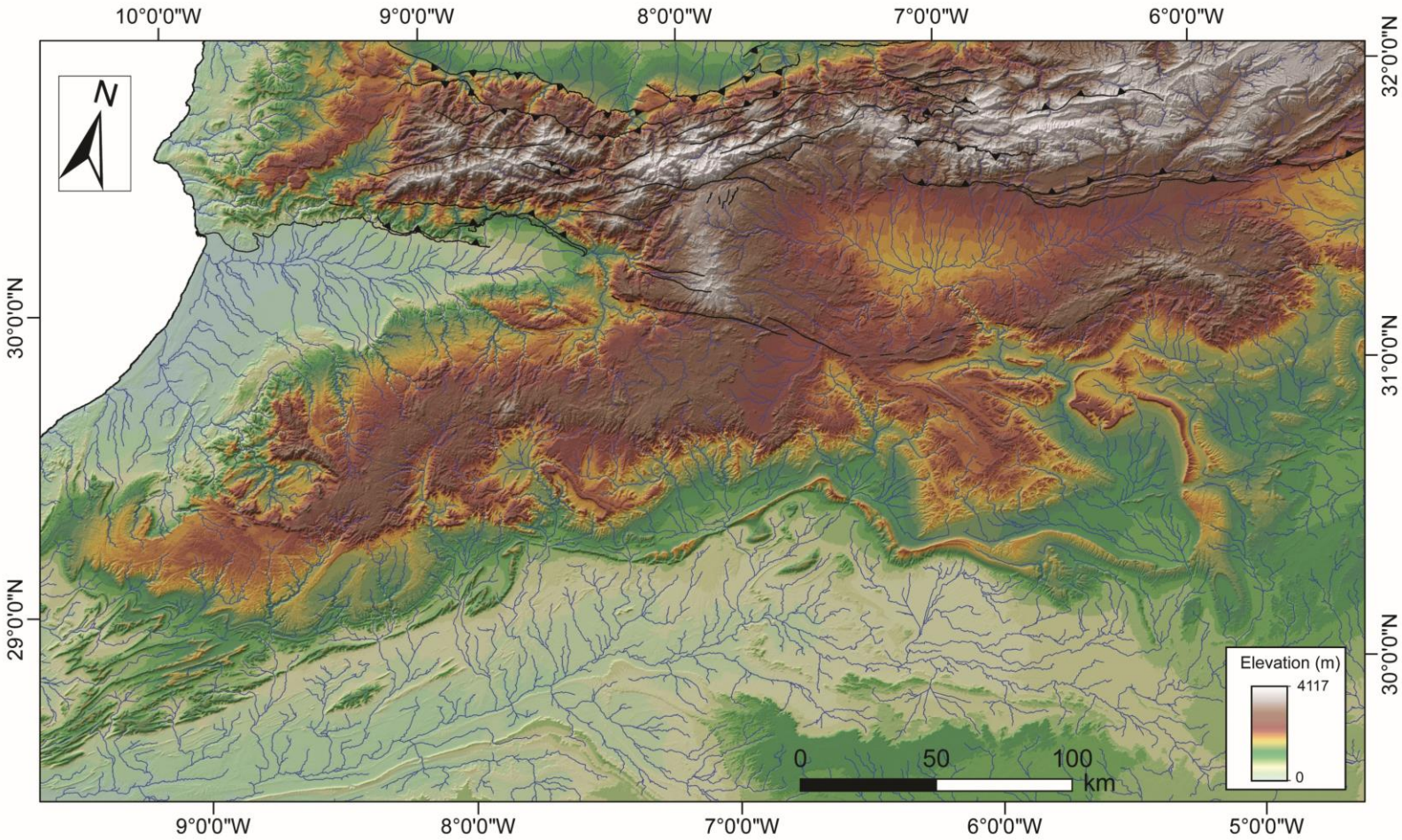


Geoid anomaly map (Lemoine et al., 1998)



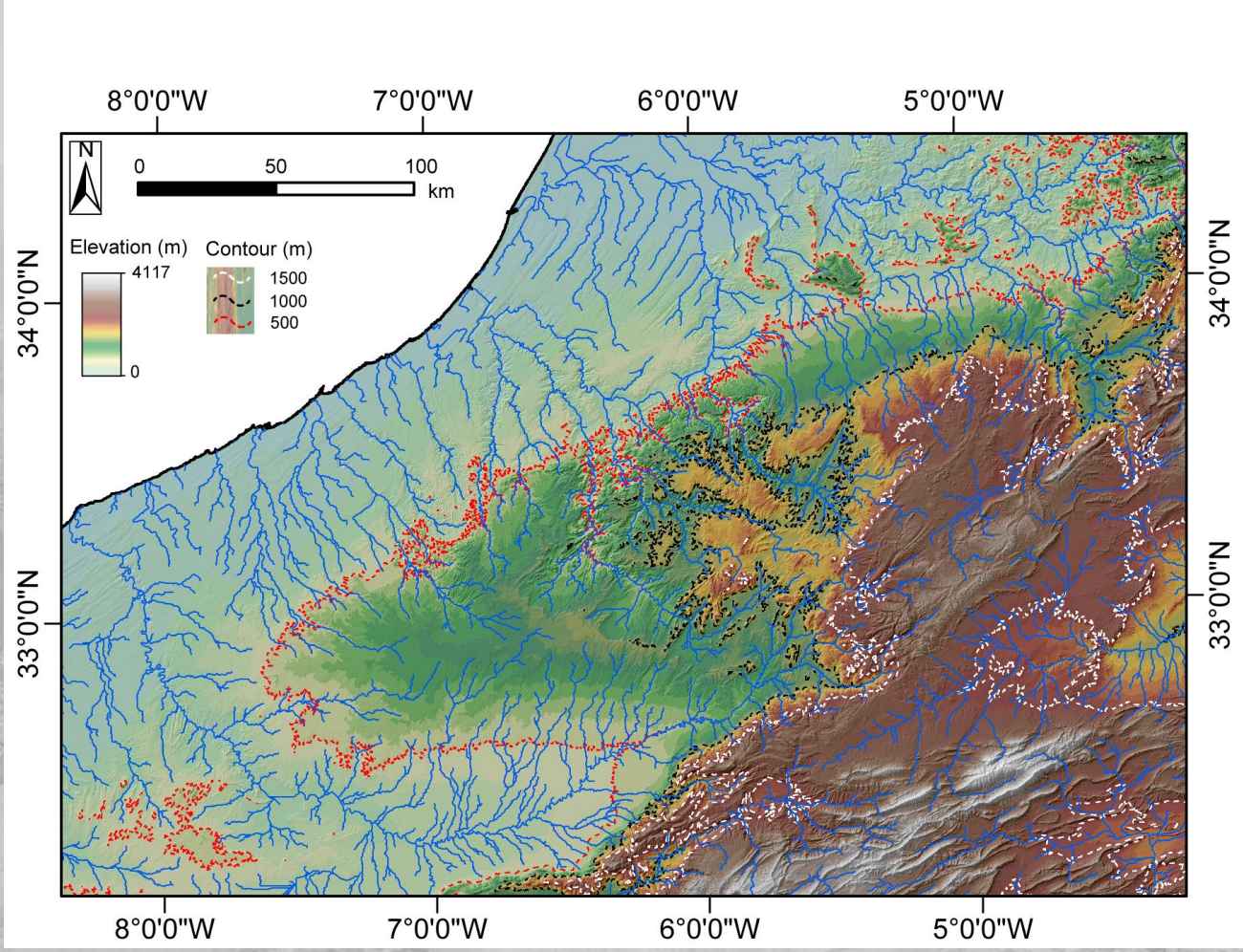
Miller et al., 2015

Anti Atlas



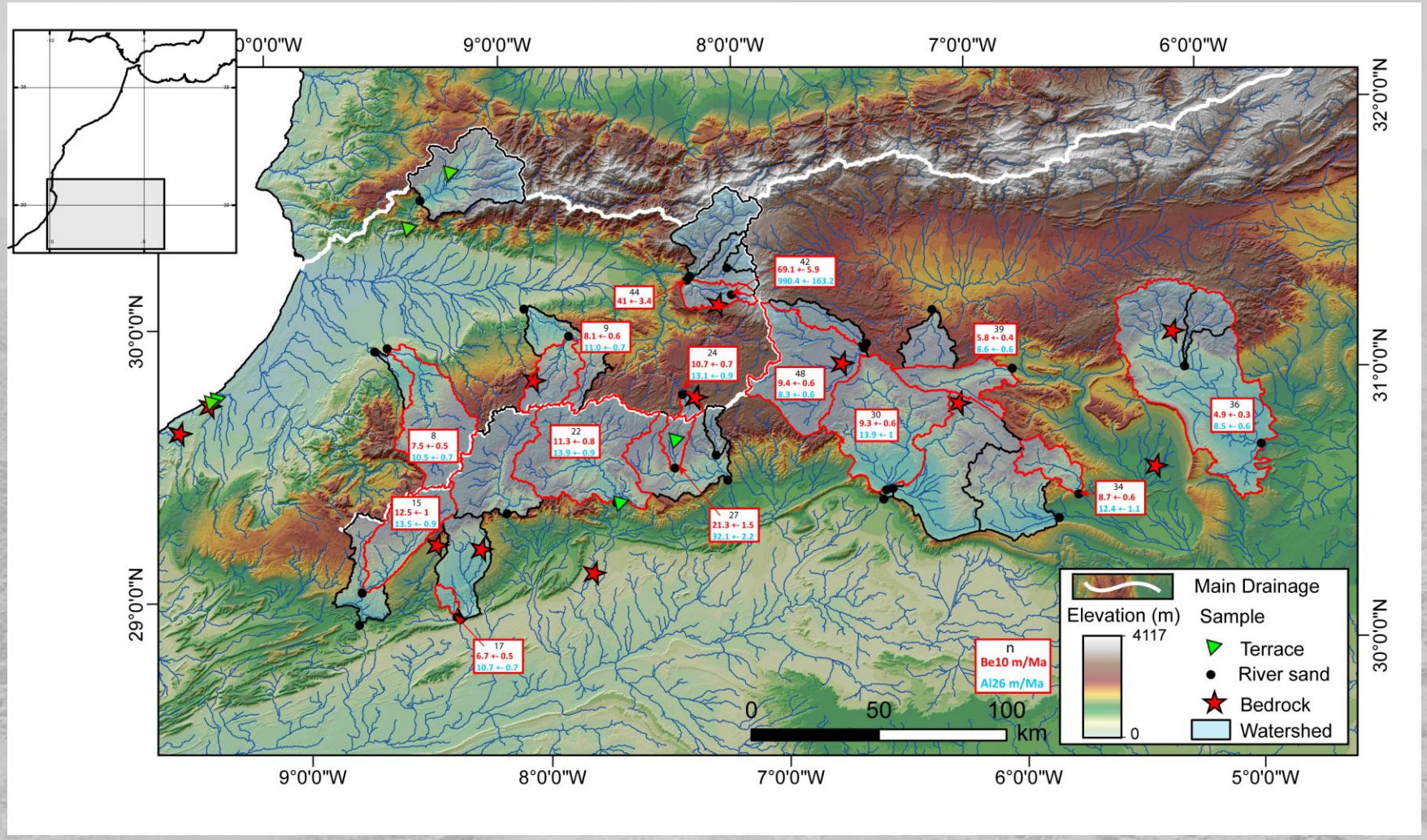
The Anti Atlas represents a mountain belt composed of Precambrian and Paleozoic rocks deformed during the Variscan orogeny. The belt consists of large Precambrian basement inliers(“boutonnières”) exposed all along the axial zone over a wave length of ca. 50 km. Our morphometric analysis outlines the occurrence of non-lithological knickpoints that suggest a transient state of adjustment of the landscape.

Western Meseta



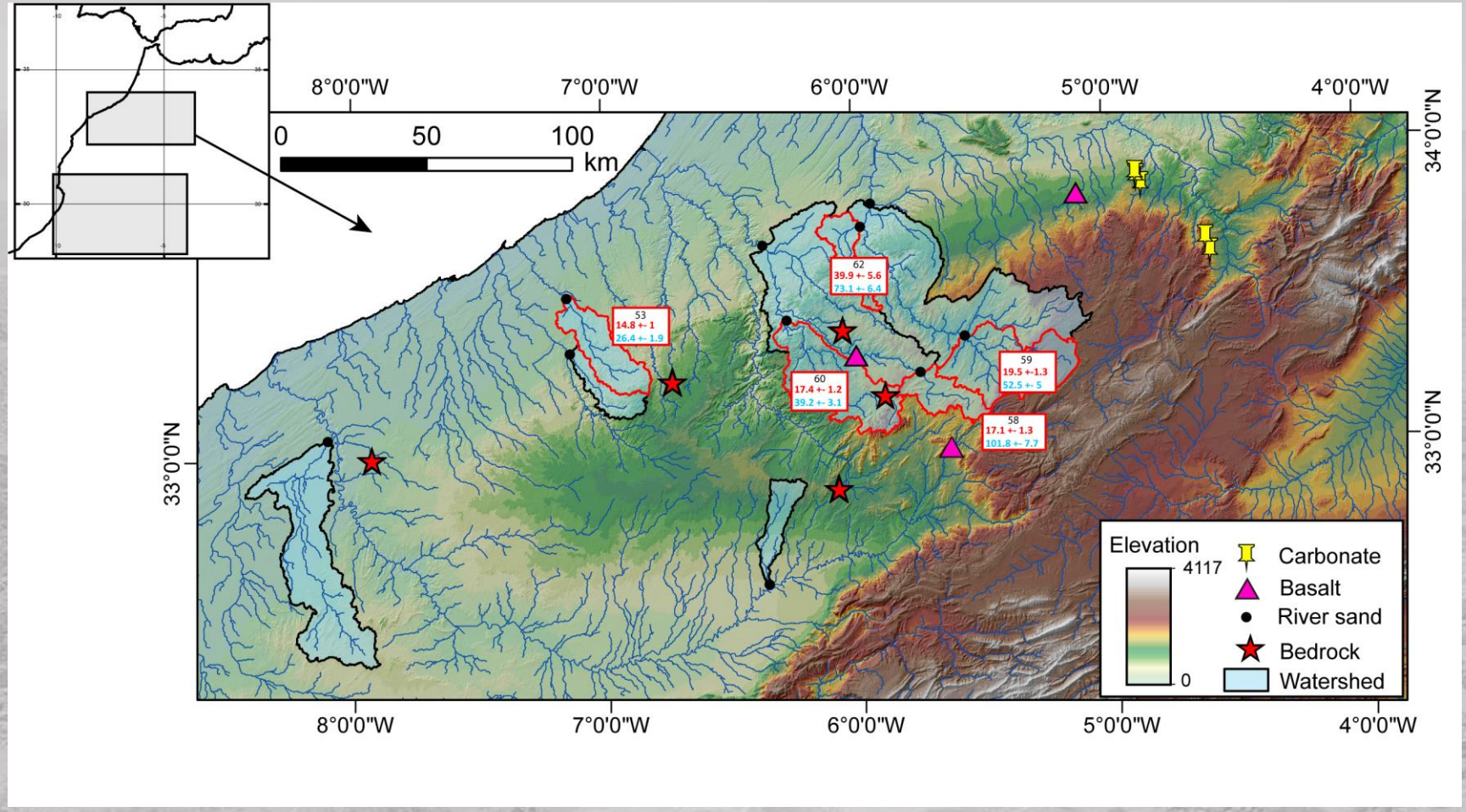
The Western Meseta consists of a tabular region composed mainly of Paleozoic rocks. The southern flank is an open synform composed by Cretaceous and Paleogene deposits that lie unconformably over Paleozoic rocks. Here, the recent large-scale dynamic uplift is testified by the occurrence of uplifted shallow-water marine deposits indicating that surface uplift must have started after the Late Miocene (Messinian) atrates of 0.1 to 0.2 mm yr-1.

Anti Atlas erosion rates



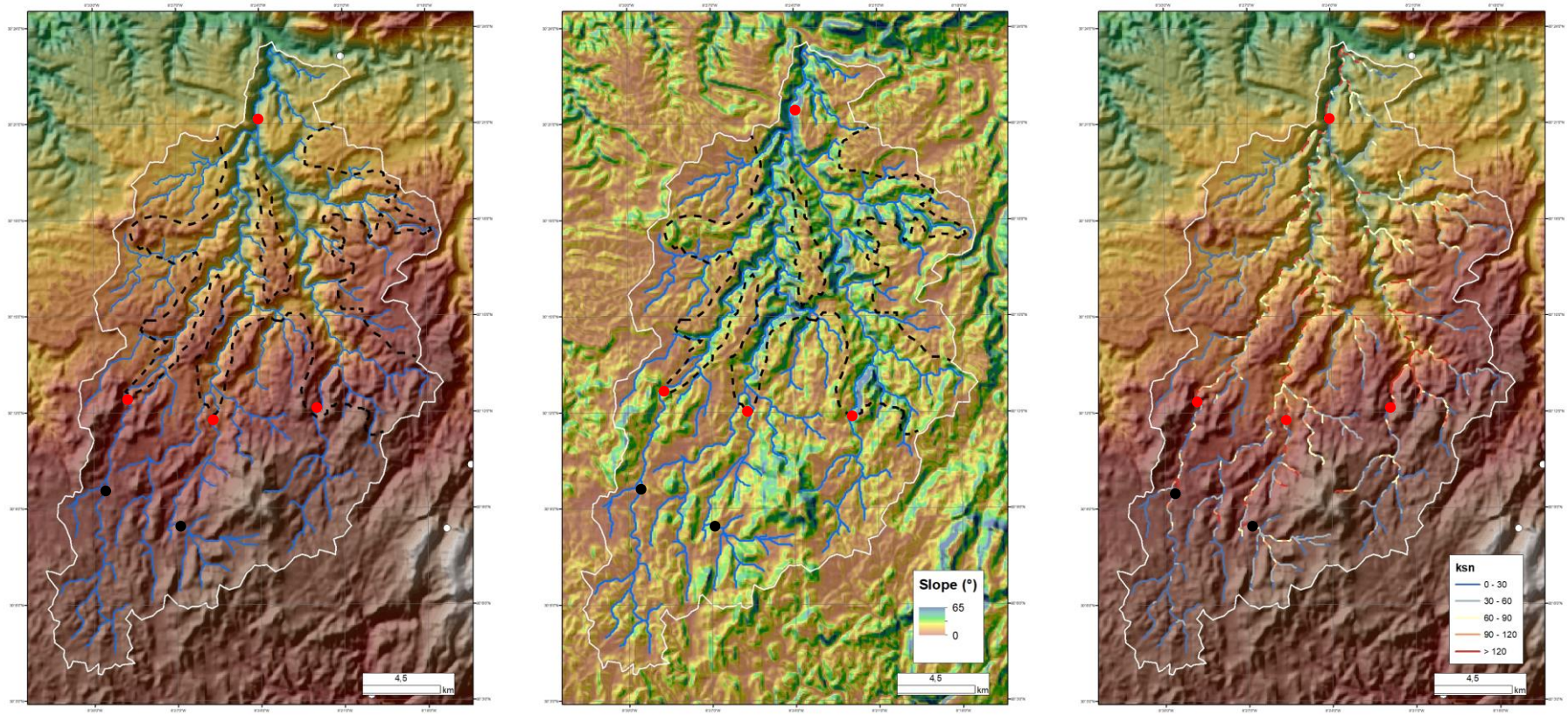
Our catchment-averaged erosion rates from 10Be and 26Al concentrations are uniformly distribuite along strike. The sharp increase in erosion rates is localized in the Siroua area, where there is a complex uplift history associated with Neogene Volcanism and the growth of the Siroua volcano, onto the Precambrian basement.

Western Meseta erosion rates



The catchment-averaged erosion rates estimated from 10Be and 26Al concentrations are uniform in the patches of the drainage basins above the knickpoints. The western catchment is characterized by lower values of denudation in agreement with a decrease in topographic relief.
The highest value is located in the basin 62, which is a equilibrium state.

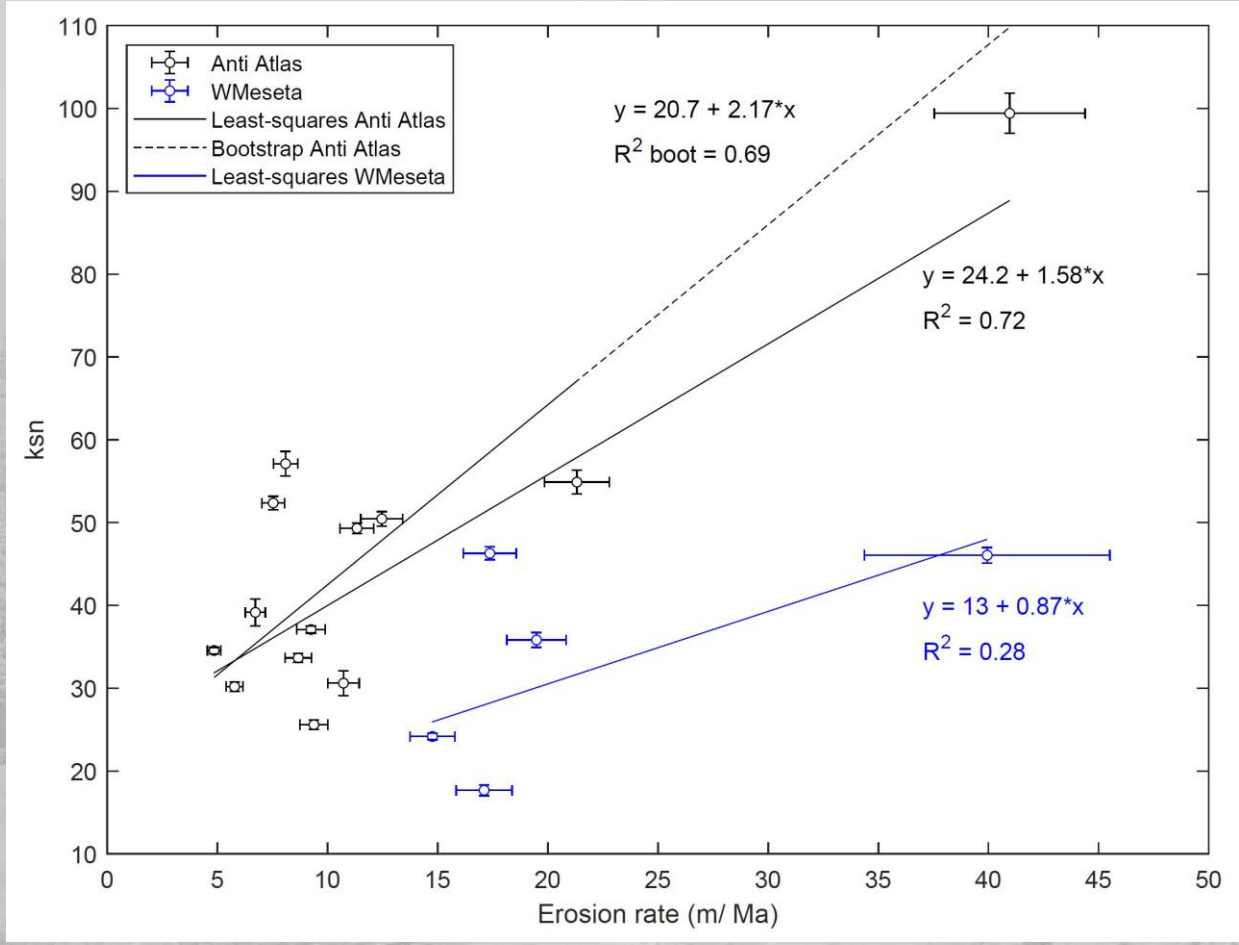
Case study: Anti Atlas basin



Red dots are transient- knickpoints that are migrating headword, while black dots are lithological and minor knickpoints. The black dashed line represents an ongoing wave of transient channel adjustment that is propagating headward. The landscape upstream of the knickpoints is characterized by low slopes and a low topographic relief and represents an uplifted relict landscape. Slope and ksn values increase downstream of the knickpoints (red dots), where river longitudinal profiles are in equilibrium.

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Erosion rates vs average catchment ksn



The relationship between channel steepness (ksn) and erosion rates depends on uplift rates, climate and bedrock erodibility (Kirby & Whipple, 2012). Several studies show a rather linear and our study agrees with that, although the Anti Atlas and Meseta show a different trends.

Erodibility coefficient (K)

$$k_{sn} = \left(\frac{E}{K}\right)^{\frac{1}{n}}$$

Applying the power law function and considering a reference concavity index (Qref) = 0.45 and n = 1, it is possible to compare rivers with variable drainage areas and different tectonic and climatic settings (Kirby & Whipple, 2012, ref. therein).
The equation allow calculating the erodibility of the bedrocks in the catchment (K).

	A	B	C
1	**K erodibility**	K mean	Area
2	0,25		
3	0,14		
4	0,35		
5	0,26		
6	0,14		
7	0,25		
8	0,14	**0,25**	Anti Atlas
9	0,37		
10	0,39		
11	0,17		
12	0,19		
13	0,23		
14	0,41		
15	0,97		
16	0,54		
17	0,61	**0,67**	Wmeseta
18	0,38		
19	0,87		



?



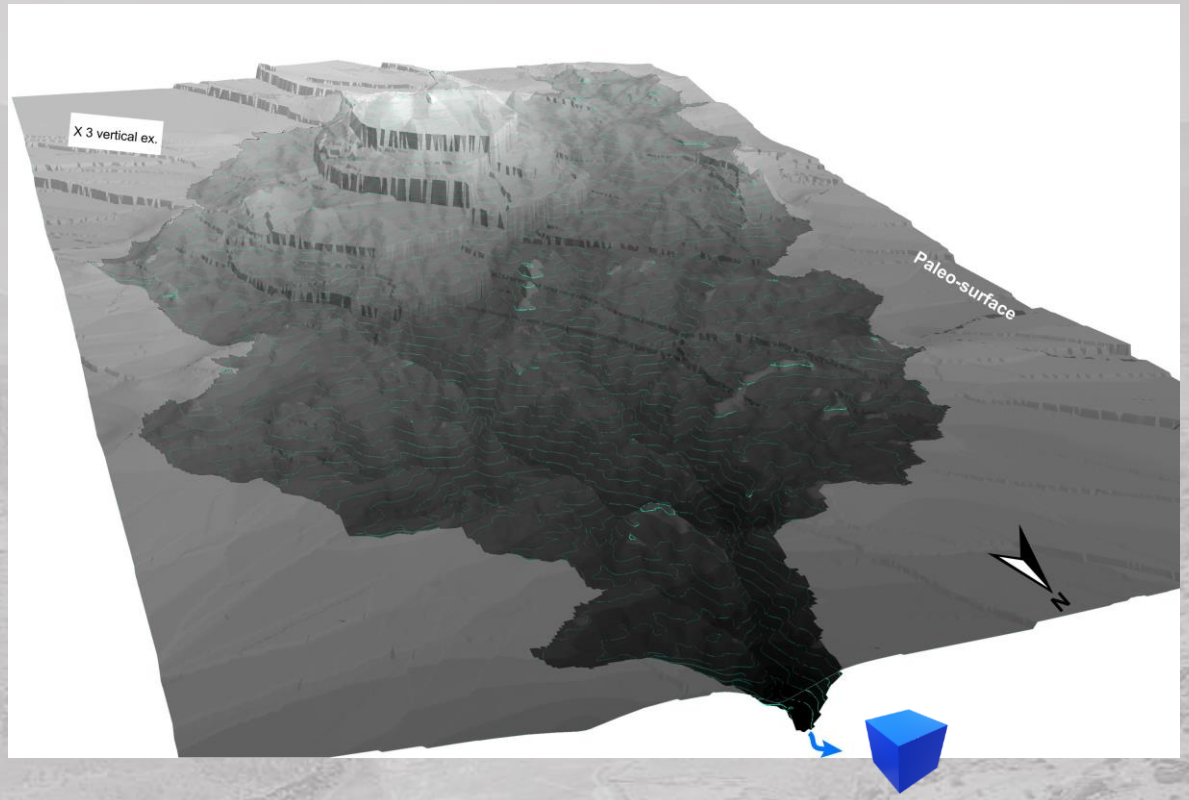
Ksn values depend on rock strength and climatic conditions (Whittaker, 2012), where the rock strength is expressed by the erodibility coefficient. This coefficient integrates climatic conditions and lithological characteristics, which appear to differ significantly between the Anti Atlas and the western Meseta.

Watershed excavation time

$$\Delta z = \Delta t\,(U_f - U_i)$$

The watershed excavation time (Δt) allows estimating the onset of surface uplift (cosmogenic-derived erosion rates) by dividing the eroded volume (Δz) over the erosion rate (Whipple, 2010; Schildgen et al., 2012; Siame et al., 2015).

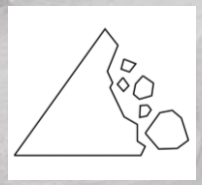
This estimation represents a minimum age, because we assume a negligible U_i (initial uplift) value.





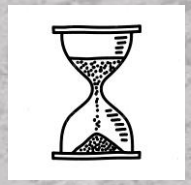
Volume estimation (Δz)

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Erosion rates ($E = U_f$)

=



Excavation time (Δt)

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Preliminary conclusions

- The catchment-averaged erosion rates allow to quantify the different uplift history between Anti Atlas and Siroua region. Siroua has experienced an higher uplift related to the overlap of several component (dynamic, tectonic and thermal influence Missenard et al., 2008).

- Excavation time for the case study basin in Anti Atlas, in the previous slide, is 15 +- 1 Ma ago.

- Applaying the same methodology to two other Anti Atlas basins, we got: - 16.4 +- 1 Ma ago
- - 11.2 +- 0.9 Ma ago.

- These are preliminary results, but the estimated time is in accordance with the timescale of Siroua volcanism activity (from 11.6 to 2.1 Ma, Berrahma and Delaloye, 1989). The estimated excavation time can represent the time range of beginning of dynamic support of Anti Atlas topography.

- We discuss also the importance of erodibility derived from basin wide erosion rates. The fluvial erodibility (K) is the result of interaction between rocks strength and climate of the study areas.
  Moreover, the Anti Atlas erodibility ranging between 0.1 and 0.4 m/ Ma. Similar values have been also estimated in Appalachians (Gallen 2018) for the same Paleozoic-Precambrian rocks, where the geological and tectonic setting resemple the case of Anti Atlas.

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