# CHANTIER RGF – PYRÉNÉES

## L’évolution géomorphologique des Pyrénées

03 juin 2019 – Pau

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# When do the Pyrenees rise?

# Relief: Definition

Relief (R): difference in elevation (ΔE) between two points on the Earth surface separated by a horizontal distance ($D_h$)

$$R = \Delta E / D_h$$

➢"Relief" is a relative notion

when $D_h$ is small R = roughness (local relief)


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diameter ($D_{bowl}$): 57,15 mm +/- 0,127 mm (authorized pool bawl)


$R_{bowl}$: 0,127/ 57,15 = 0,002

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# The relief of the Earth

Maximum difference in elevation of the Earth surface relative to its mean diameter ($D_{Earth}$)

$D_{Earth}$ : 12742 km

Maximum difference: 19,764 km

(Mariana Trench: -10916 m; Everest Mount: 8848 m)

$D_{Earth}$ = 12742 km +/- 19, 764 km

$R_{Earth}$:19,764/ 12742 = 0,0016


The Earth is as smooth as a bowl!


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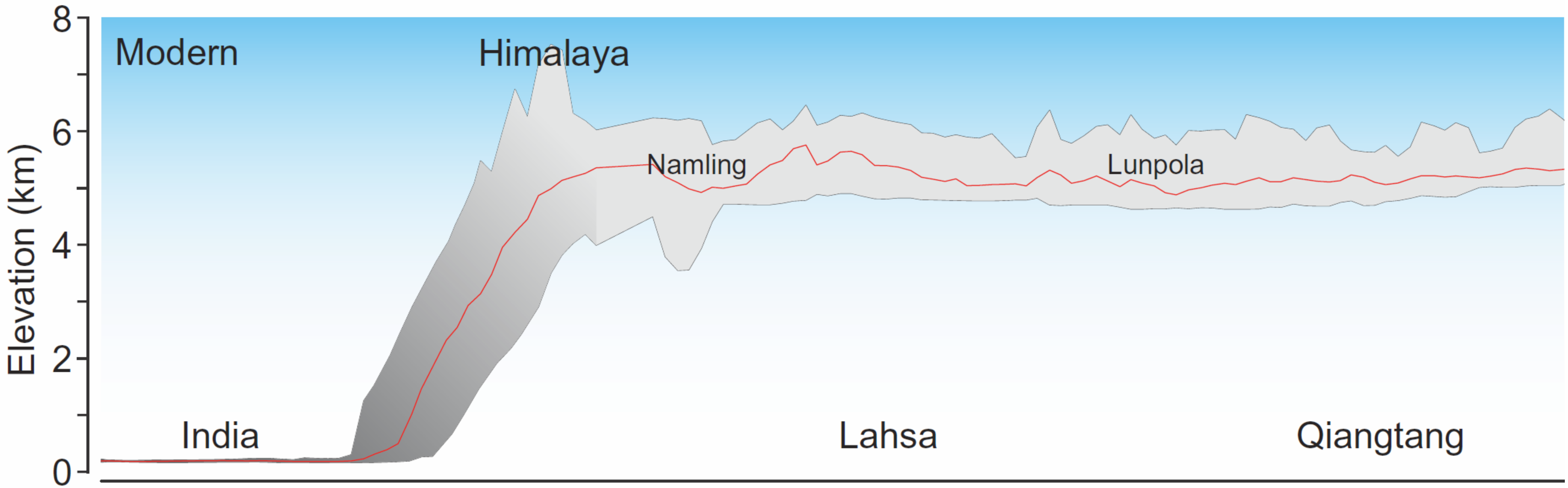


Su et al. 2019

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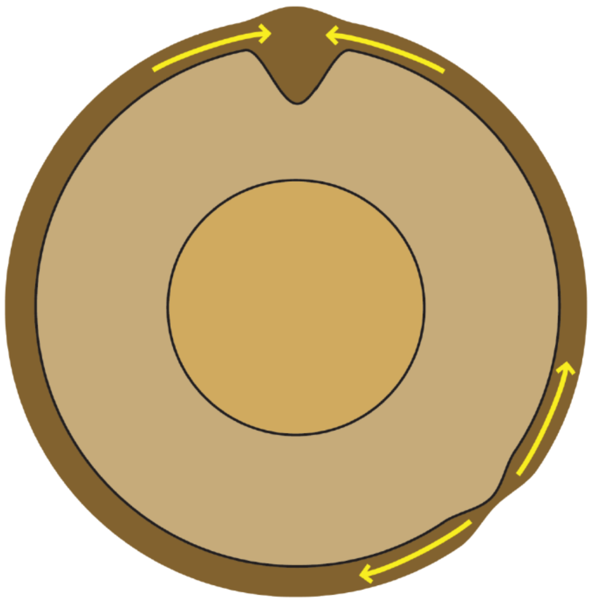
# What cause the Earth's surface to move up and down?



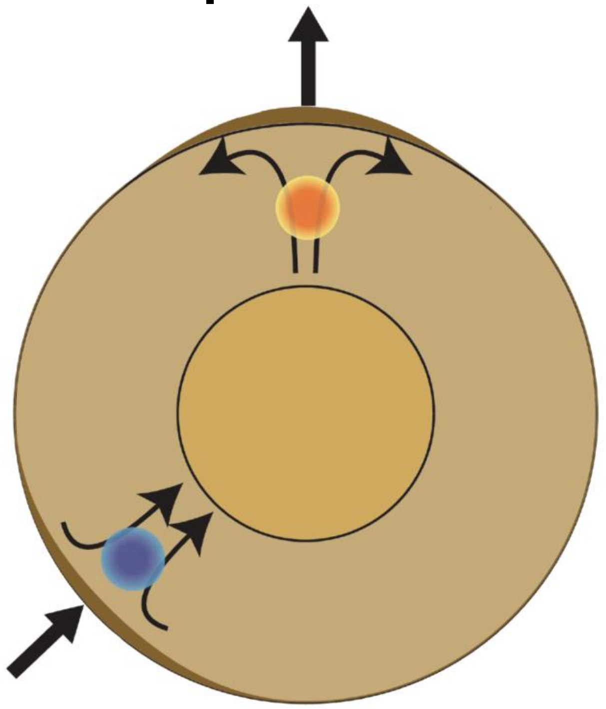
Topography in isostatic equilibrium

Lithosphere deformation

*Wavelength/ Amplitude:*

*Crust: x10km/x1000m (up to 5 km)*

*Lihosphere mantle: x100km/x100m (≥1,5km)*



Dynamic topography

Mantle convection

*Wavelength: x100s to 1000s km*

*Ampitude: x100s up to 1500m*


Running water  carves the landsacape resulting in roughness

# How fluvial erosion carves the landscape

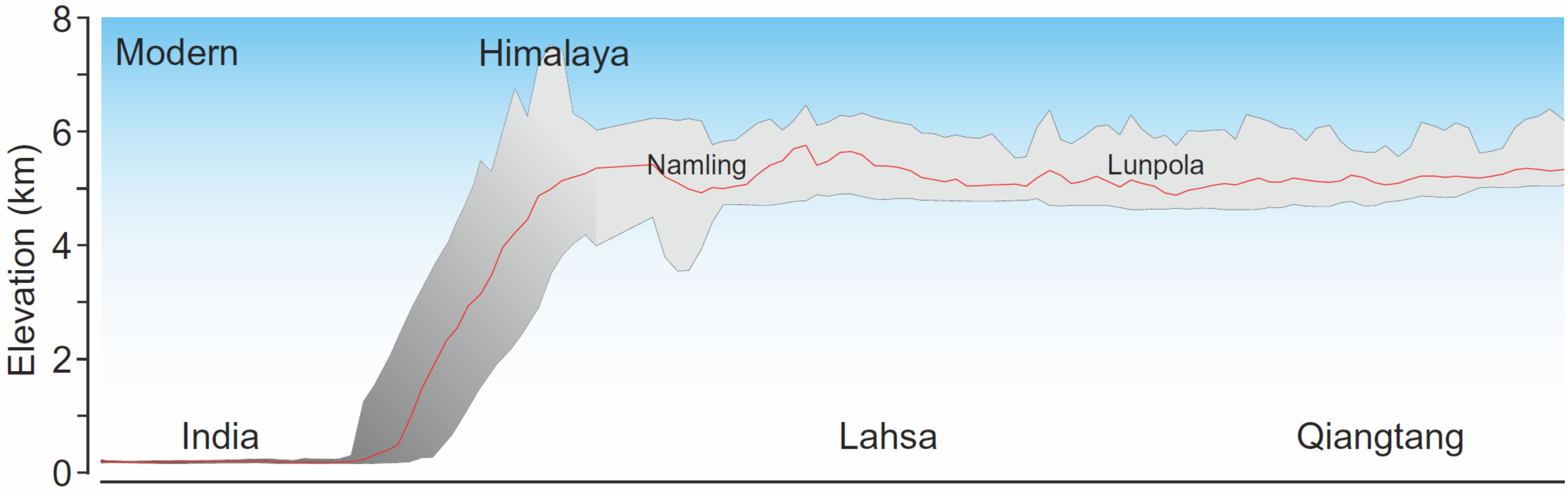
*Fluvial incision = relief production*
*Hillslope erosion =r elief smoothing*

***Relief production***
Increase of the headwaters elevation
(= mean elevation increase)
Drop of rivers base level

*Mean elevation increase requires*
*crustal thickening and/or*
*mantle lithosphere  thinning*

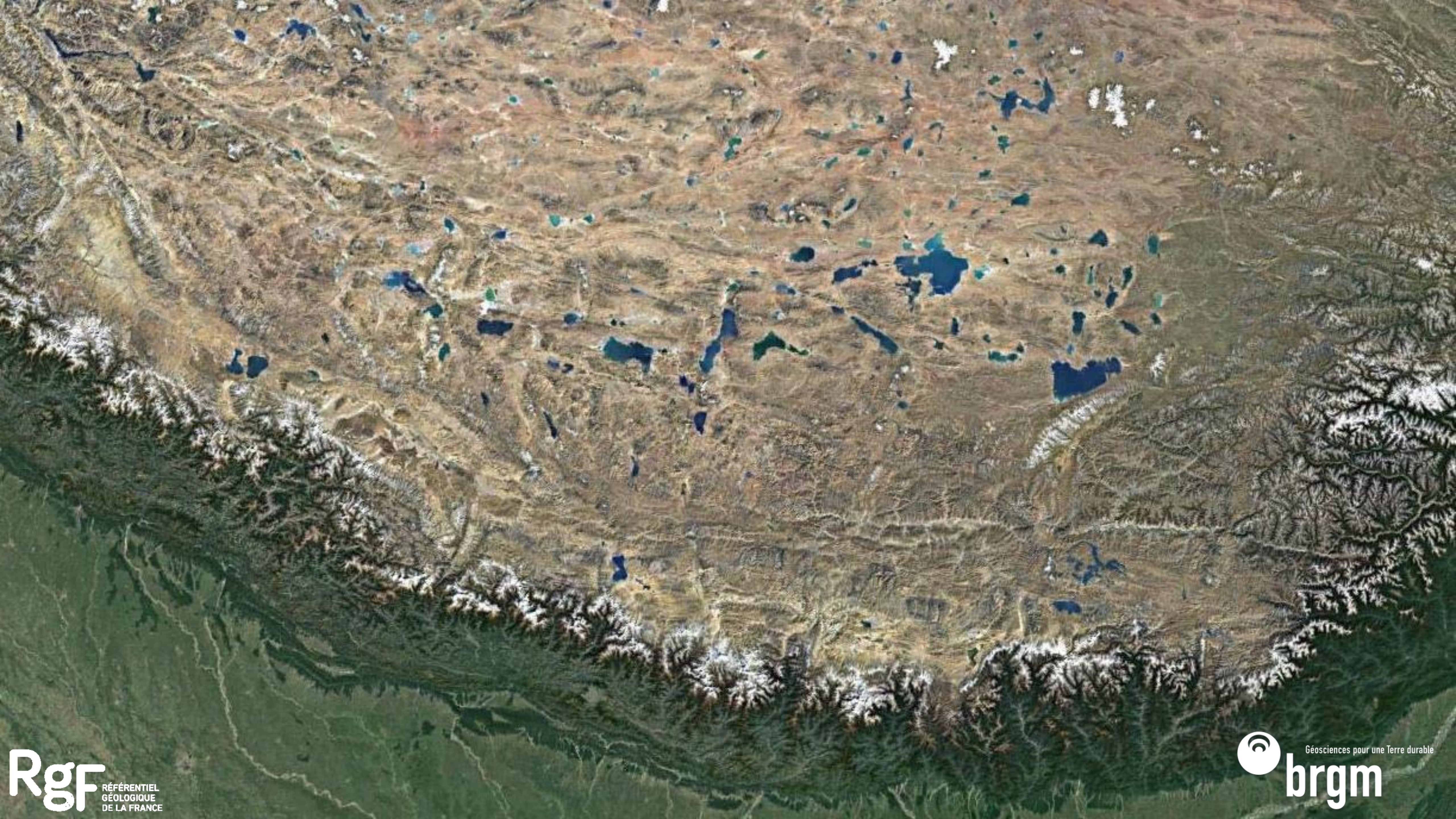
***Relief smoothing***
Decrease headwaters elevation
(=mean elevation decrease)
Increase of rivers base level

*Mean elevation decrease requires*
*crustal thinning and/or*
*mantle lithosphere thickening*



Modern
Himalaya
Namling
Lunpola
India
Lahsa
Qiangtang
Elevation (km)
0
2
4
6
8


Su et al. 2019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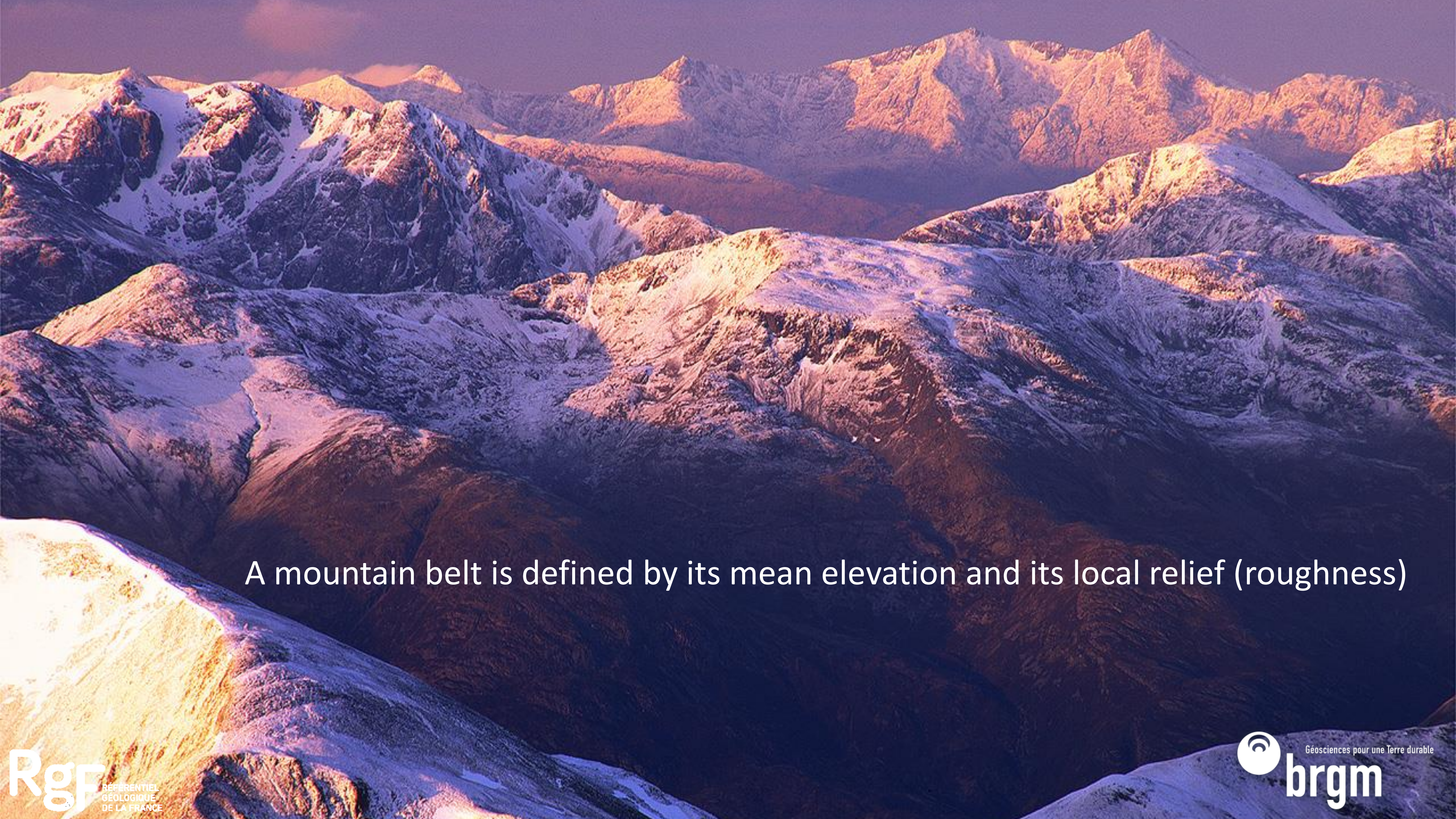
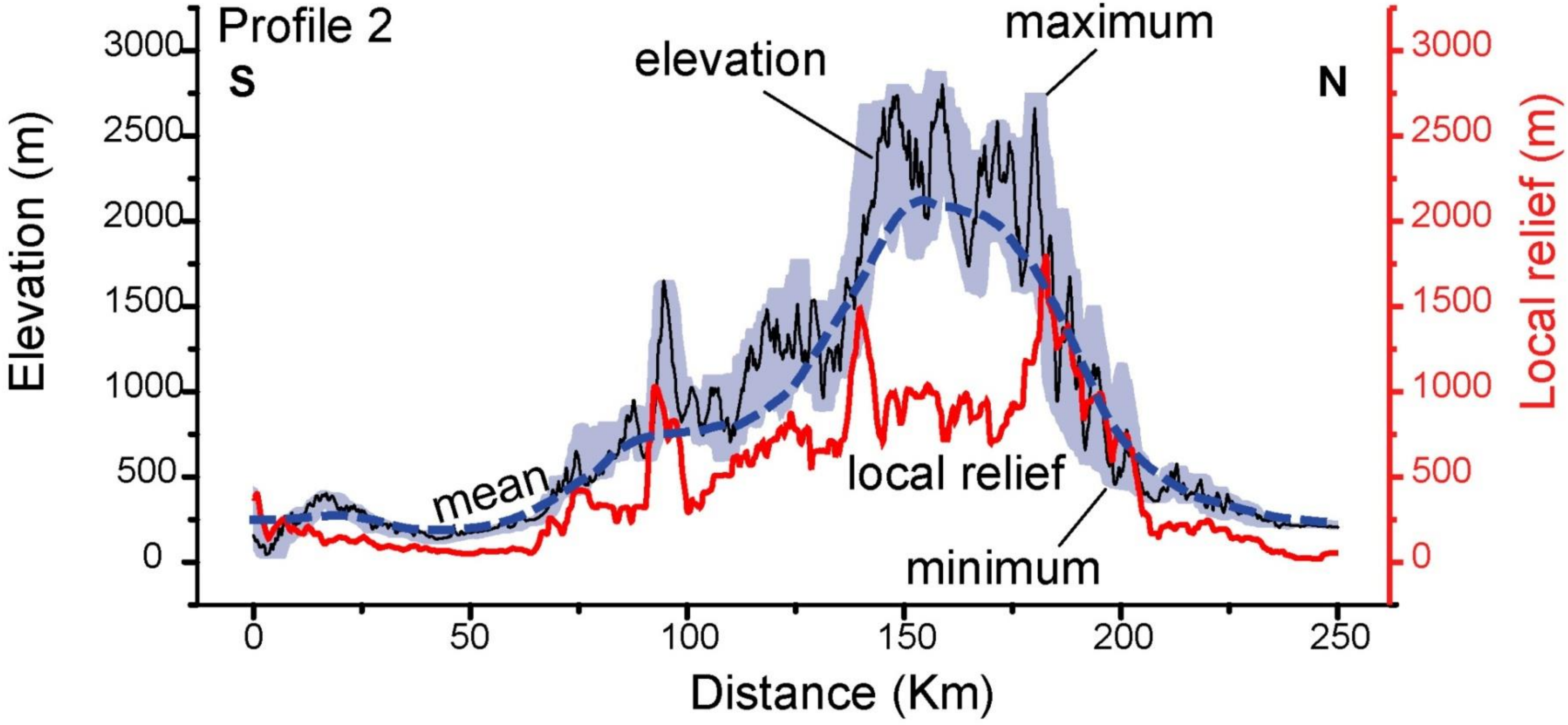

A mountain belt is defined by its mean elevation and its local relief (roughness)

# When do the Pyrenees rise?




Babault et al. 2005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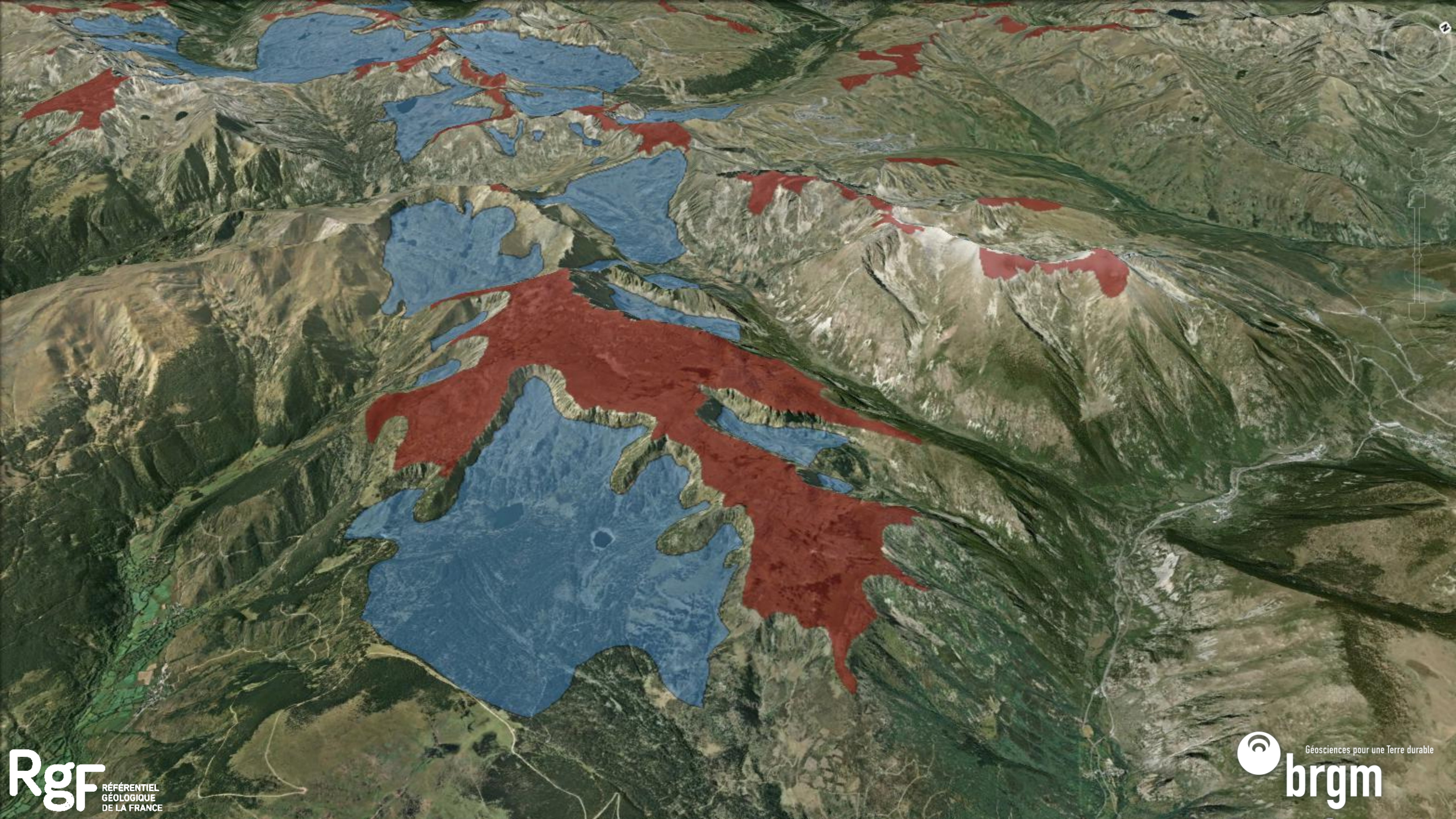
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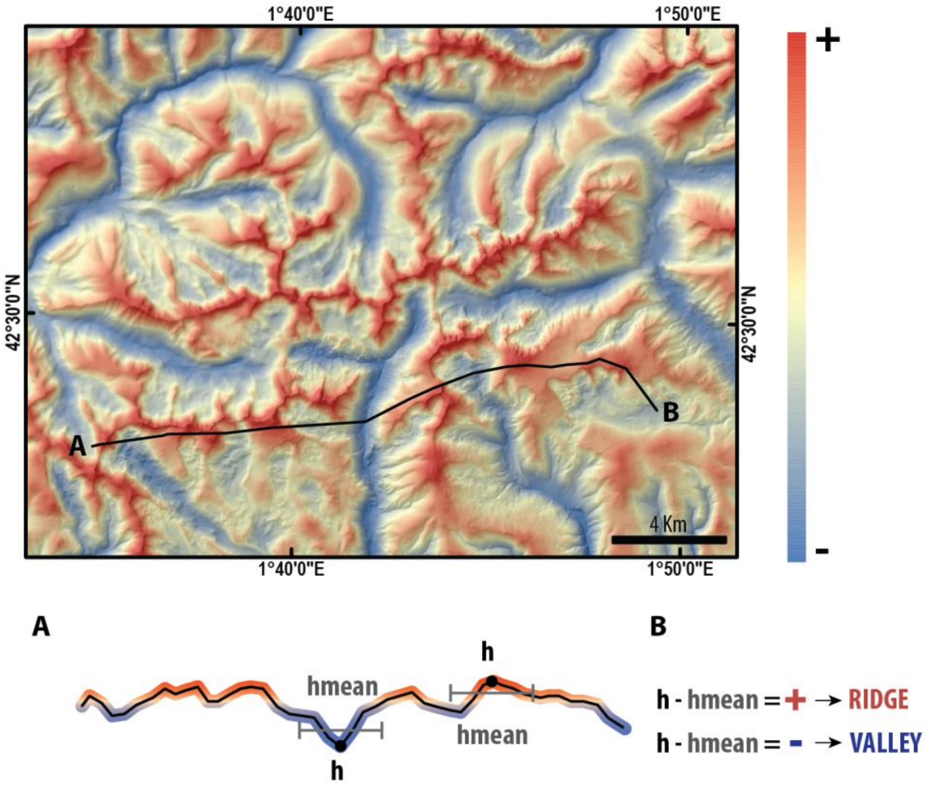
# Mapping of the high-elevation, low-relief surfaces of the Pyrenees




Topographic Position Index (TPI) *(e.g. Weiss, 2001)*

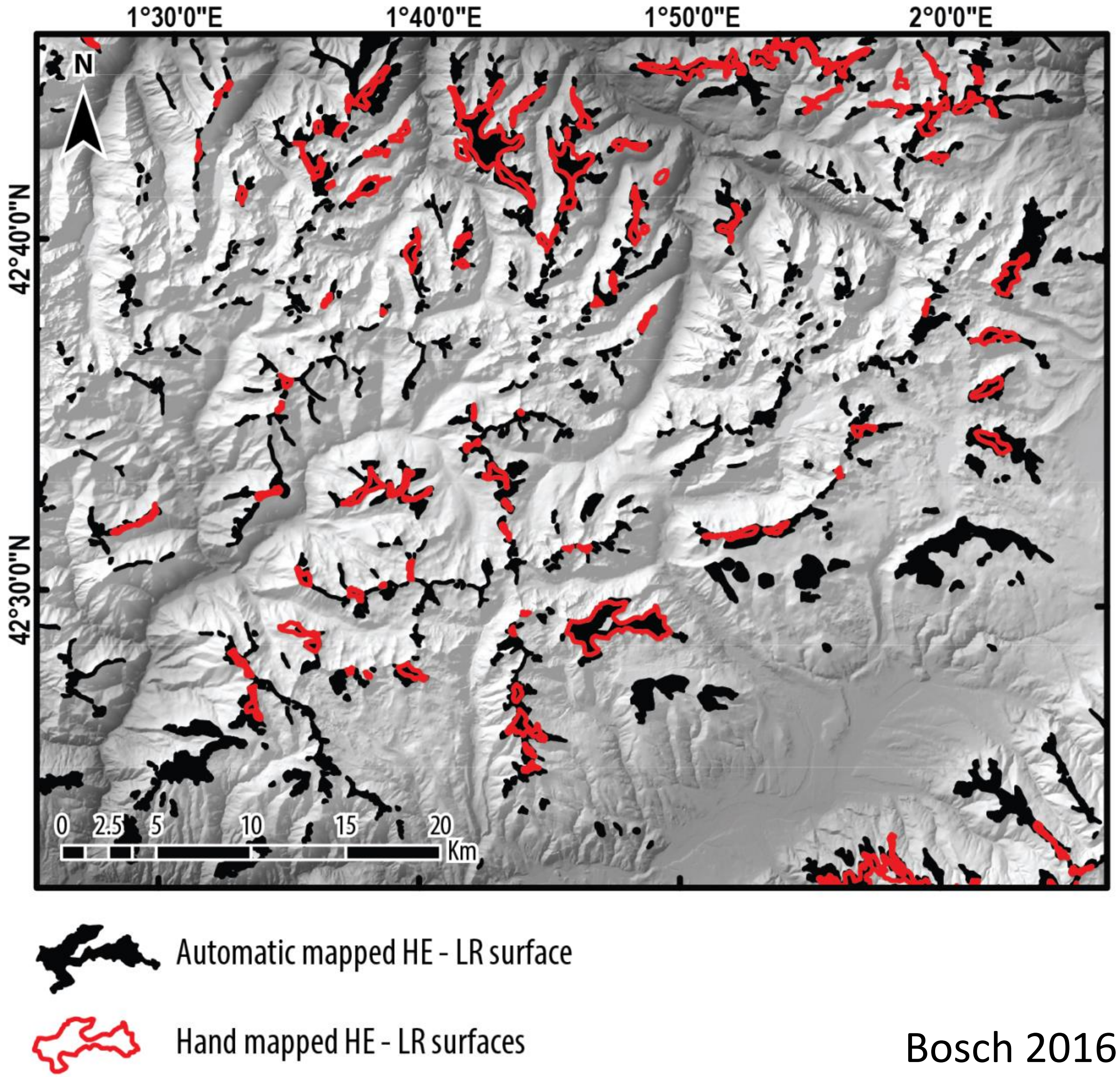
TPI = h-hm (R)

Normalization by the variation of the elevation

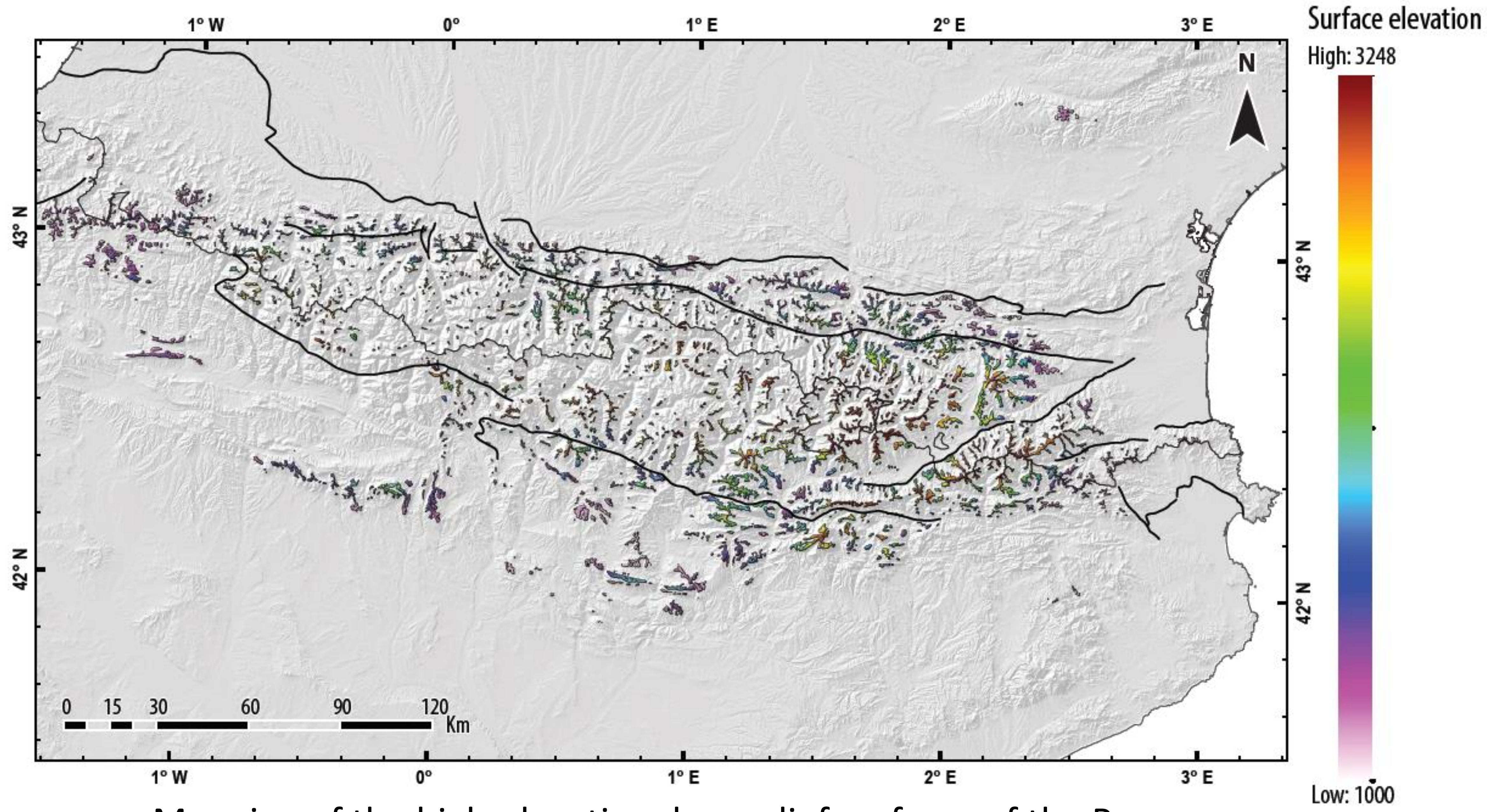
*dev* = TPI (R) / Std(R)

Std: standard deviation of the elevation

*(Galland et Wilson, 2000; De Reu et al.2013)*




Bosch 2016




Mapping of the high-elevation, low-relief surfaces of the Pyrenees

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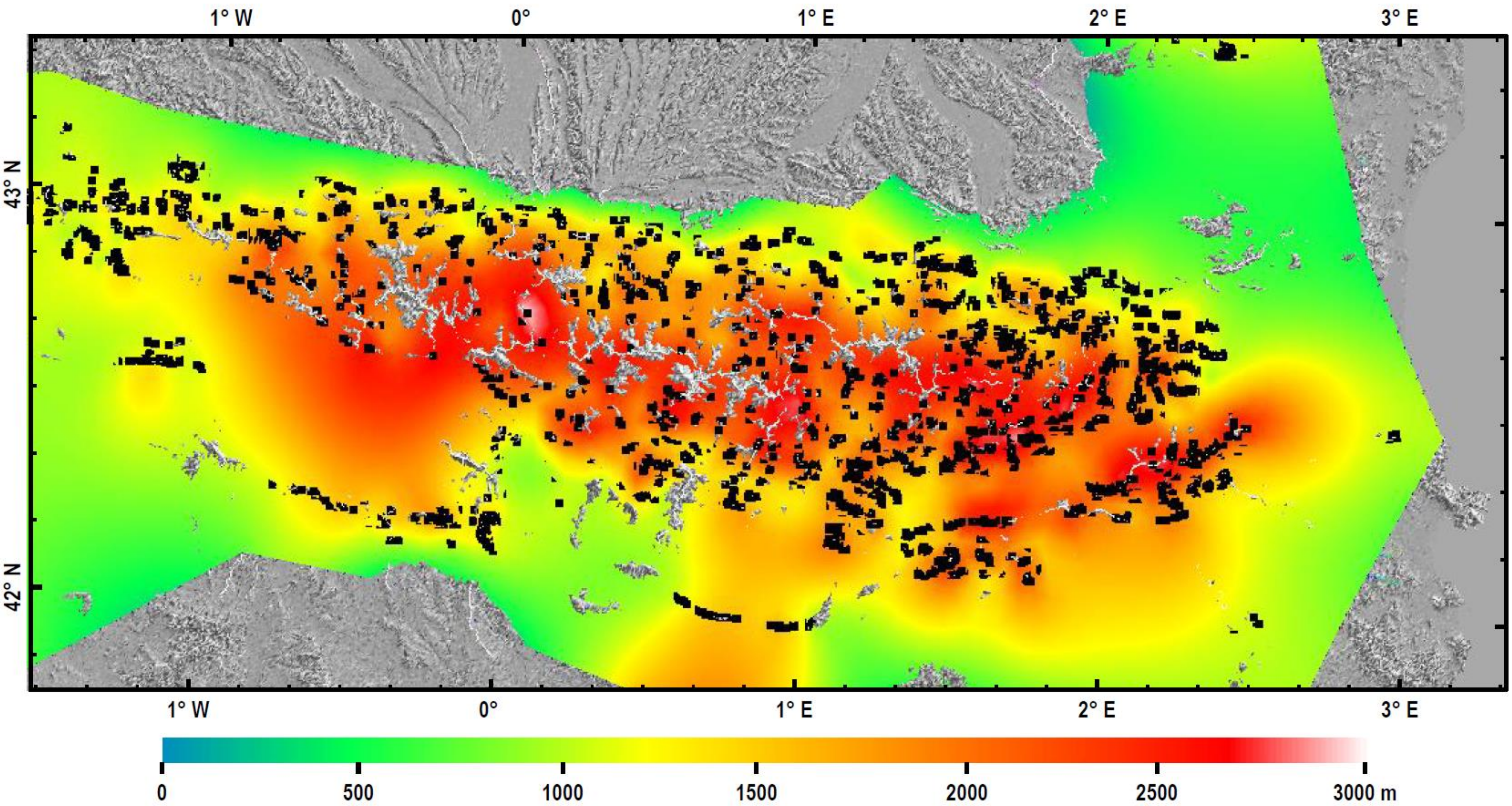
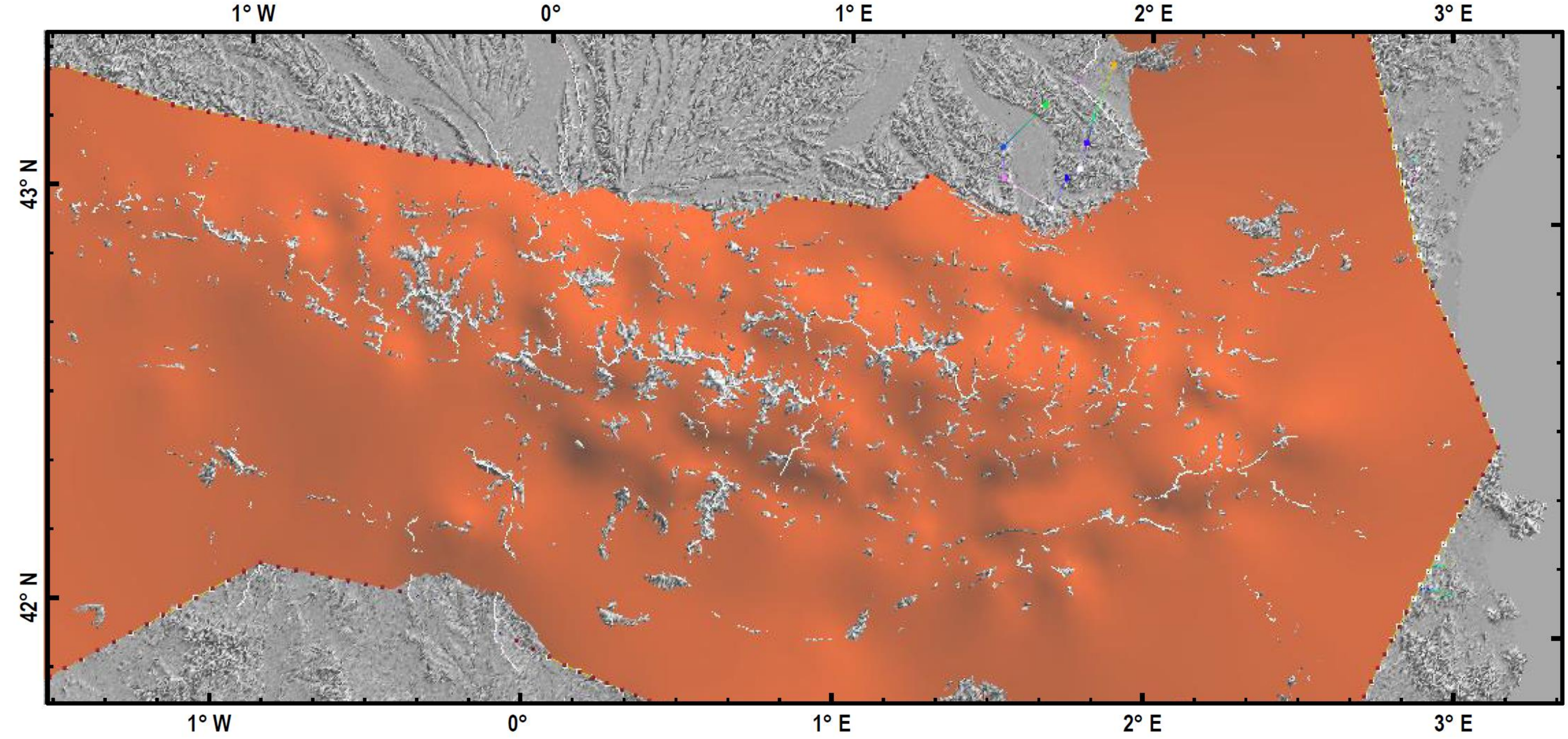
Bosch et al. 2016



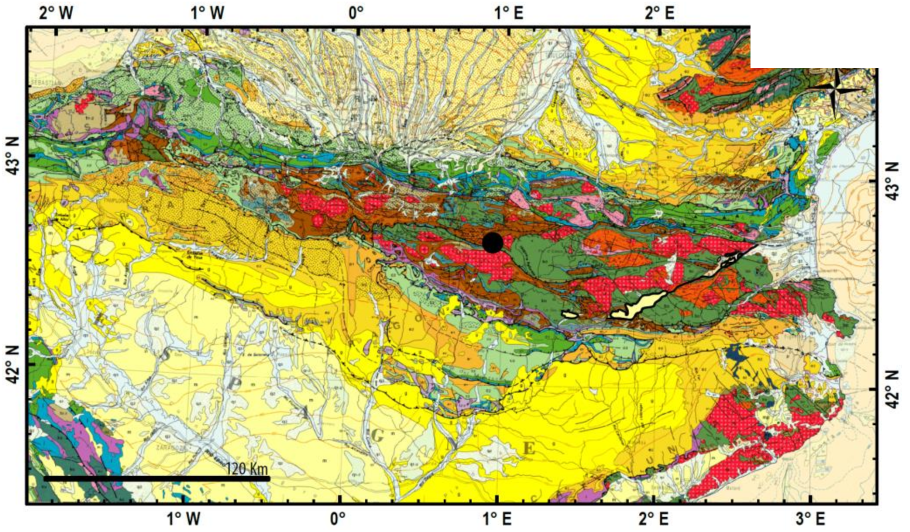

Interpolation of the HE-LR surfaces

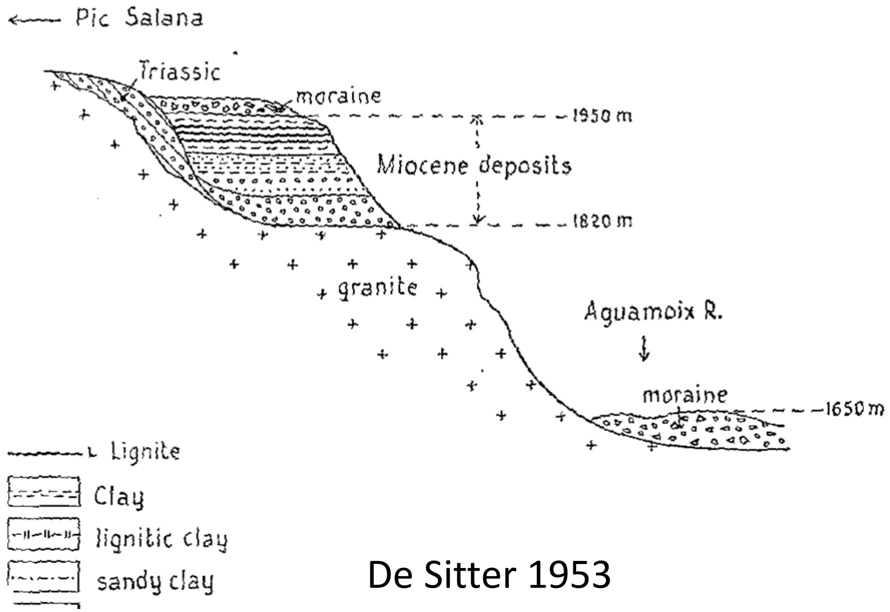
Bosch et al. 2016

# Interpolation of the LR-HE erosional surfaces

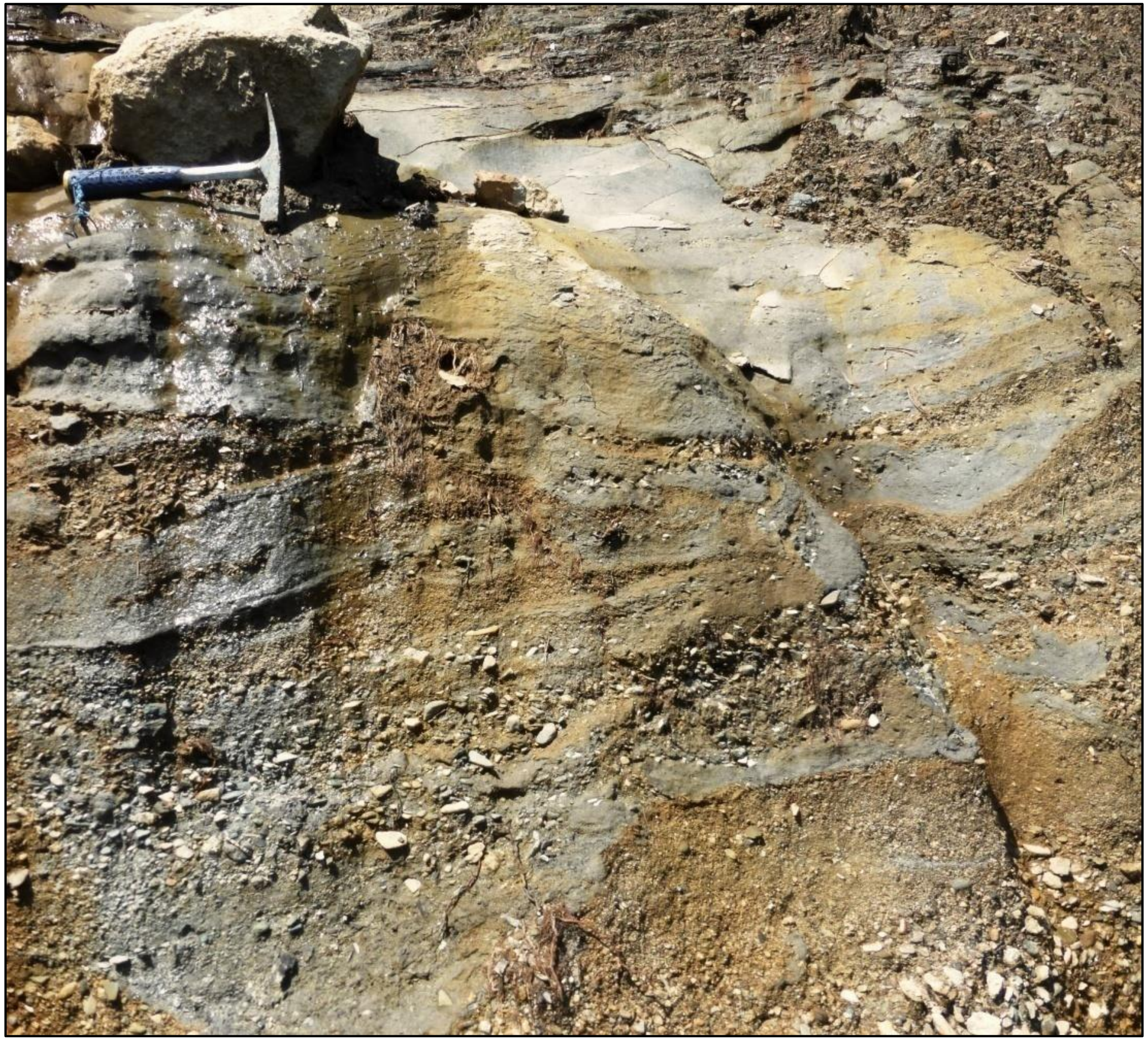



Bosch et al. 2016



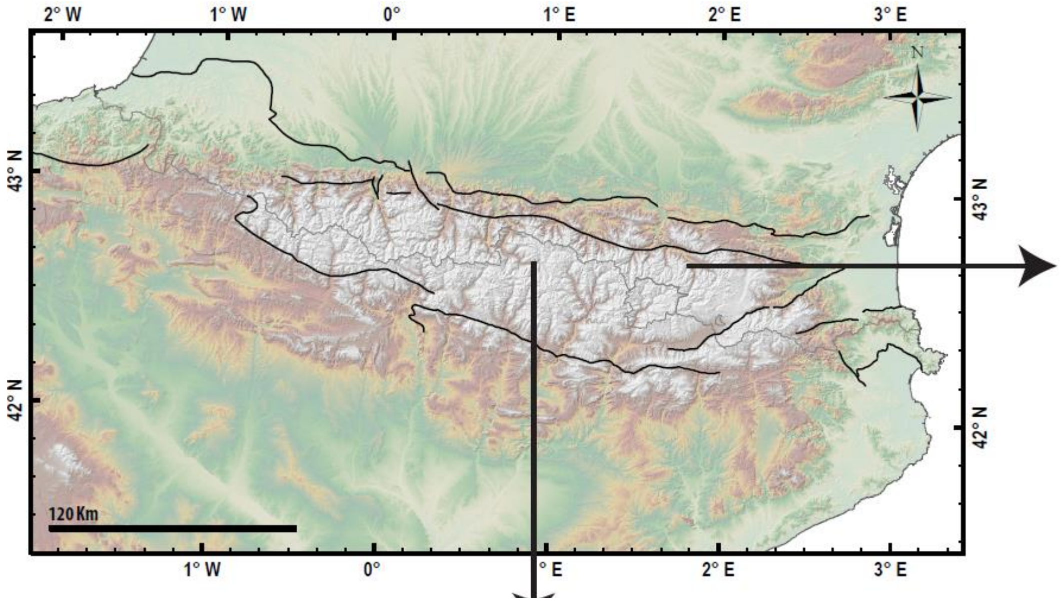

De Sitter 1953

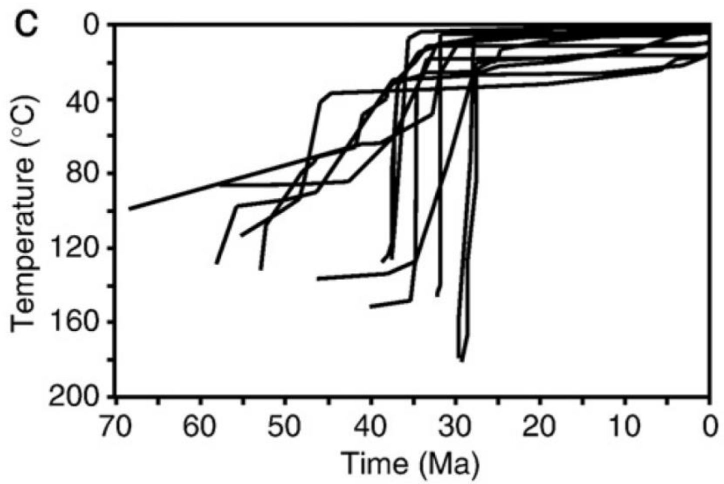


*Bosch 2016*

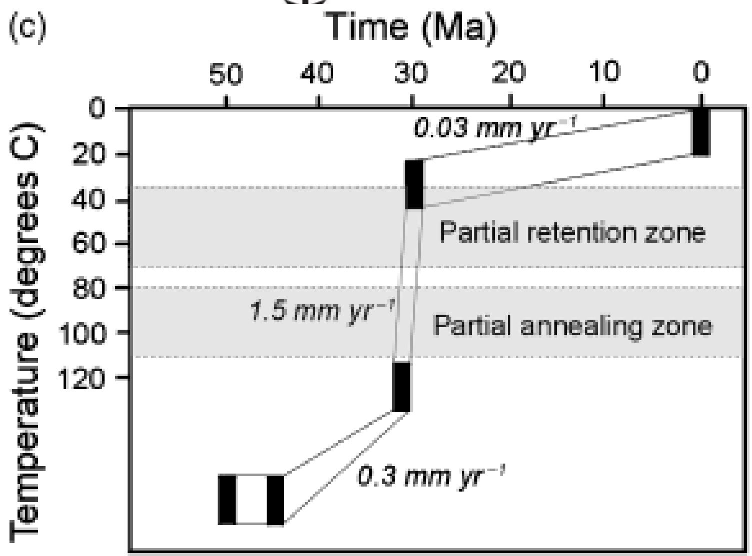
Upper age-limit: 11 Ma

# Lower-age limit: 30 Ma (Thermochronogy AFT and AHE)

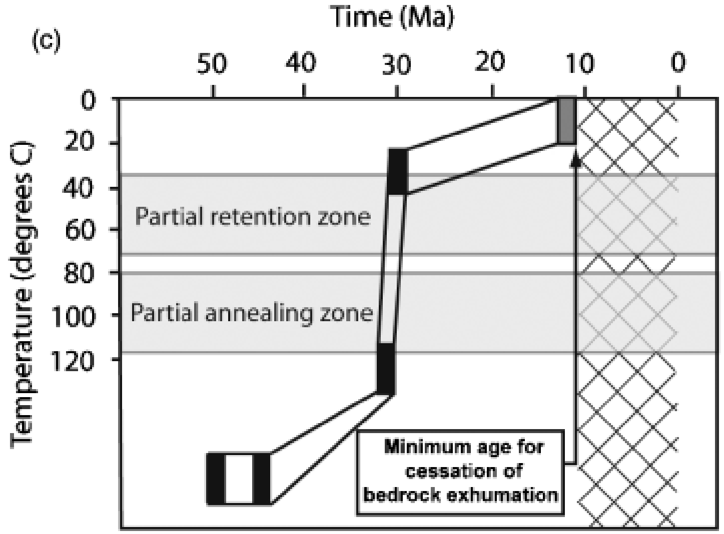



*Gunnell et al. 2009*




*Gibson et al. 2007*




*Babault et al. 2009 modified from Gibson et al. 2007*

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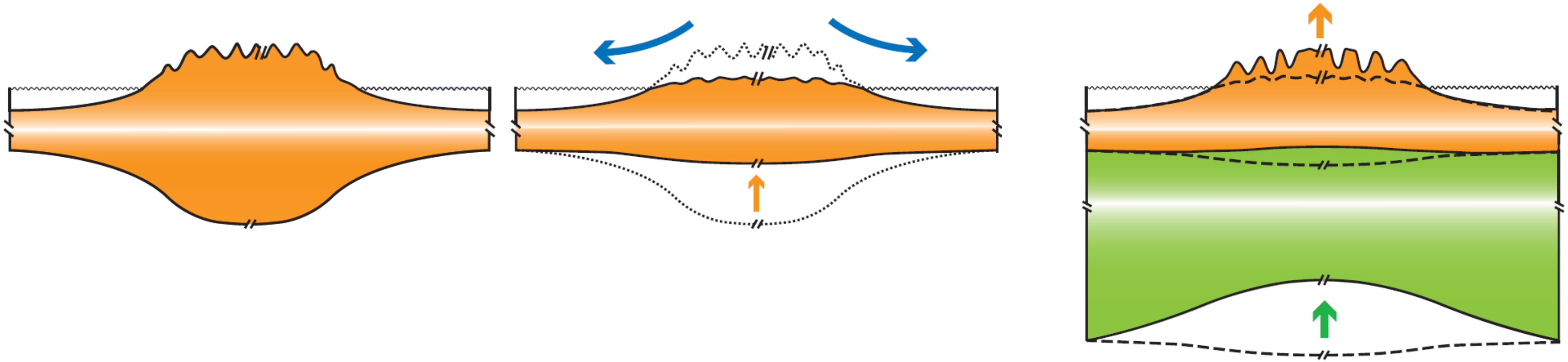
# The peneplanation process
# by decreasing the elevation of headwaters:

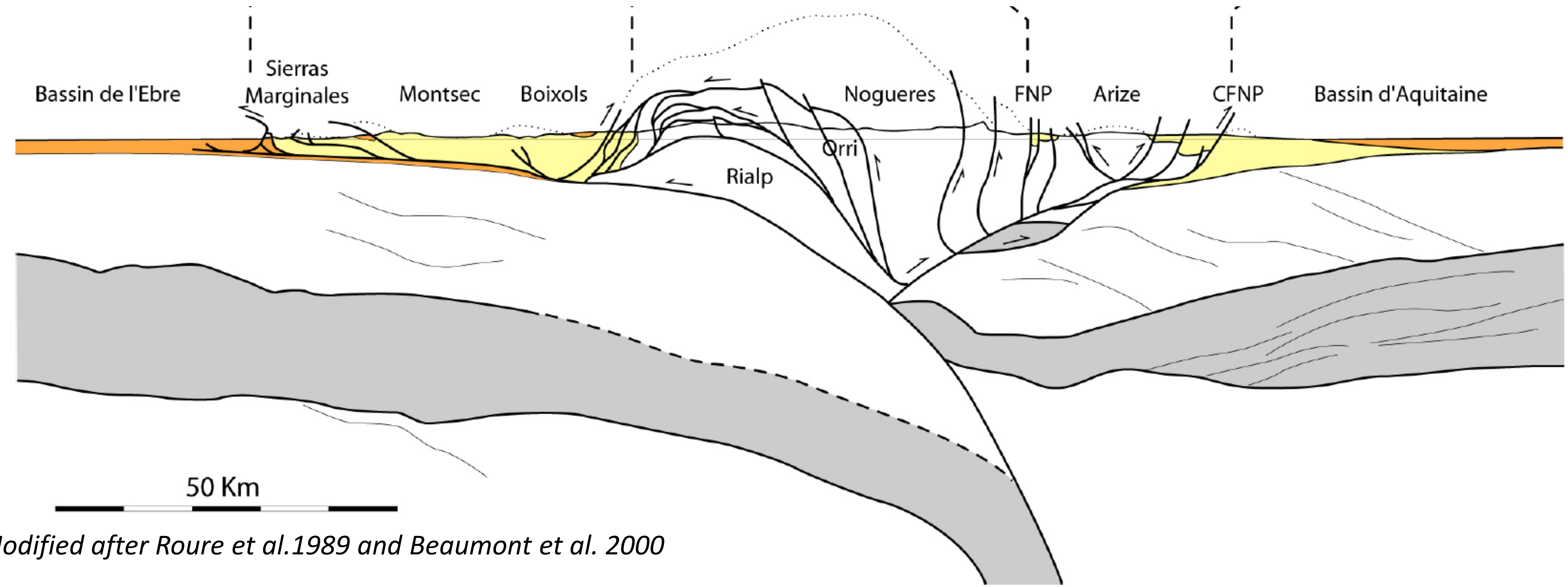
*A classical interpretation for dissected high elevated peneplain*



Erosion → Crustal thinning → Elevation lowering → Lithospheric mantle thinning to reach high elevation



*Babault et Van Den Driessche, 2005 and Bosch et al., 2015*




*Modified after Roure et al.1989 and Beaumont et al. 2000*

*The only presence of a crustal root below the Pyrenees demonstrates that the HE-LR surfaces of the Pyrenees cannot be interpreted as uplifted relics of a peneplain*

A high Pyrenean chain did exist since the Miocene!

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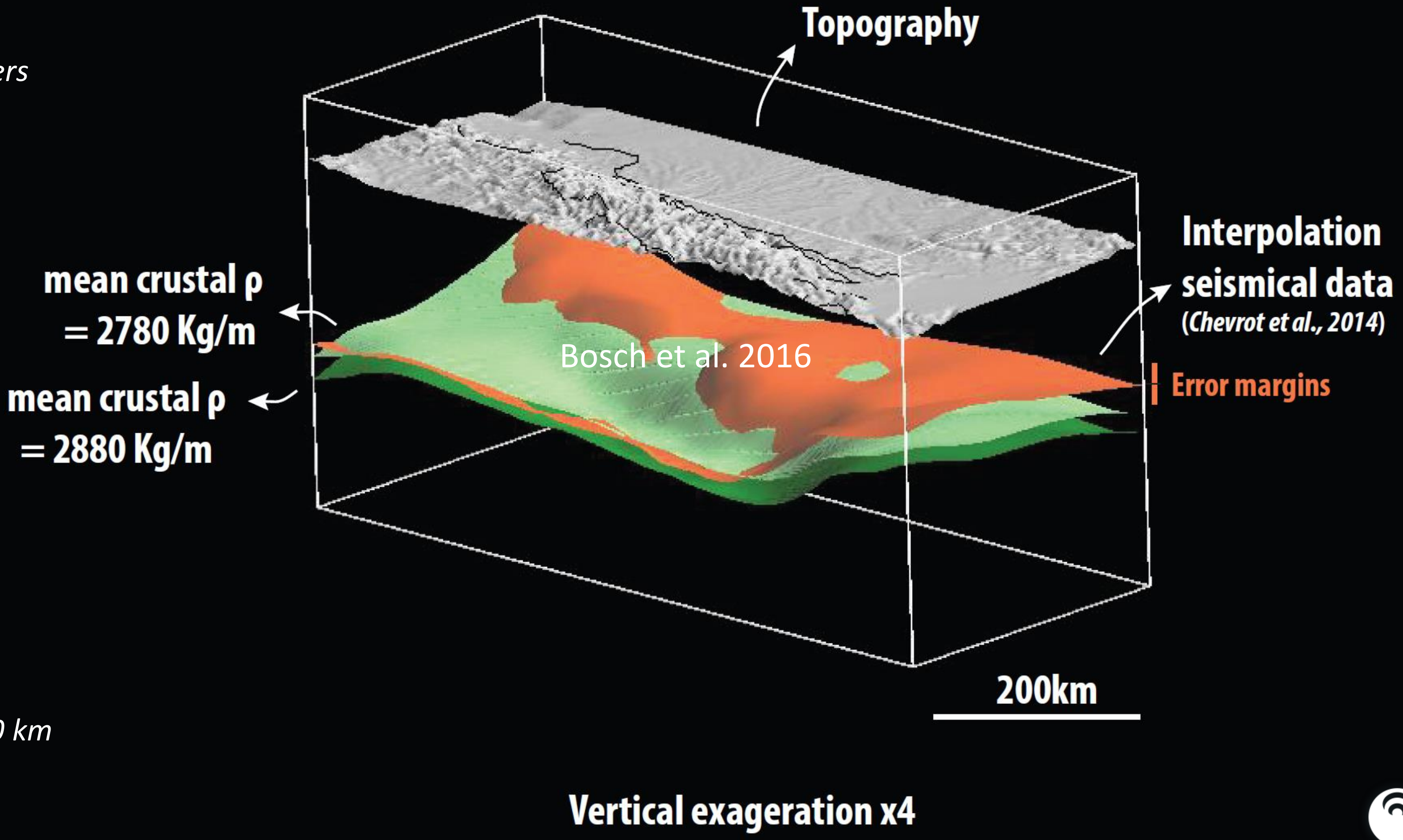
# 1D modelling of crust and lithosphere thickenesses (*Fullea et al., 2007*)

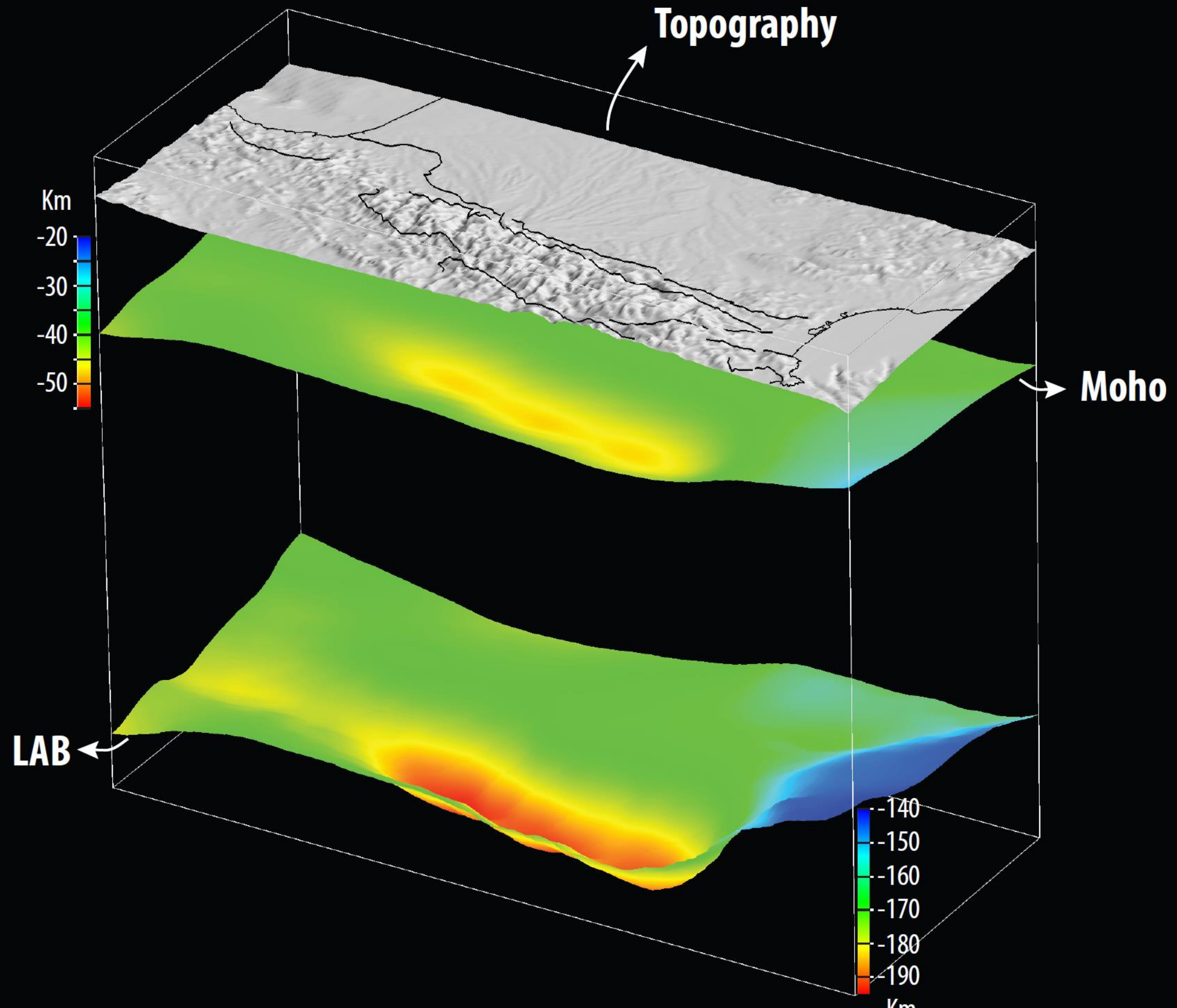
*Inputs*
*Topography*
*Geoide*
*Densities*
*Thermal parameters*




*Assumptions*
*Local isostasy*
*thermal equilibrium*
*compensation at 400 km*

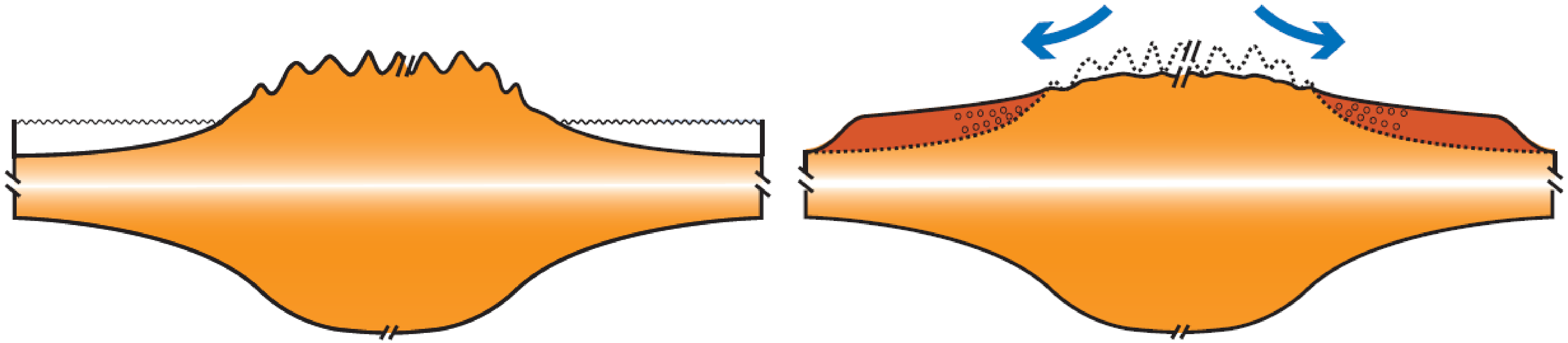
*Bosch et al. 2016*

# 1D modelling of crust and lithosphere thickenesses (*Fullea et al., 2007*)




*Bosch et al. 2016*

# The only process: peneplanation at high elevation by increasing the base level



Erosion → Base level increase (Piemont sedimentation) → Crustal root preserved → High elevation preserved

*Babault et Van Den Driessche, 2005; Babault etal., 2005; Babault et al., 2007*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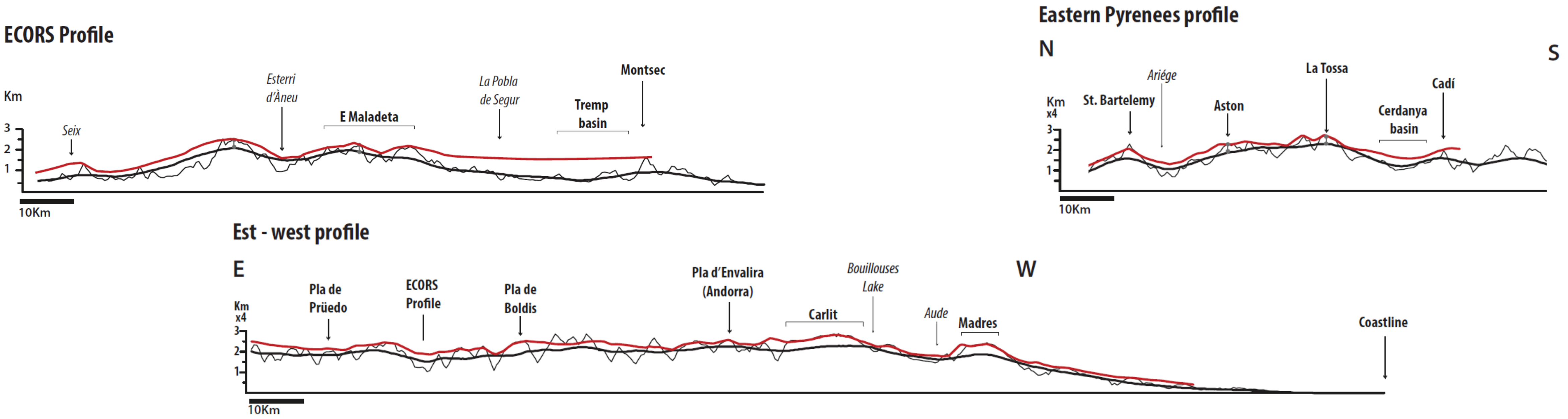
# Local base level and efficient base level (the river transport length)

# Disssection of the high elevated Miocene peneplain: the isostatic rebound

# Amount of Plio-Quaternay erosion




*Bosch et al. 2016*

- The restored Miocene peneplain corresponds to the mean elevation of the Pyrenees at that time
- The difference between the elevation of this surface and the actual mean elevation of the Pyrenees corresponds to the amount of Plio-Quaternary erosion
- This difference is about *400 m ( mean erosion rate ~ 0,1 mm/an)*

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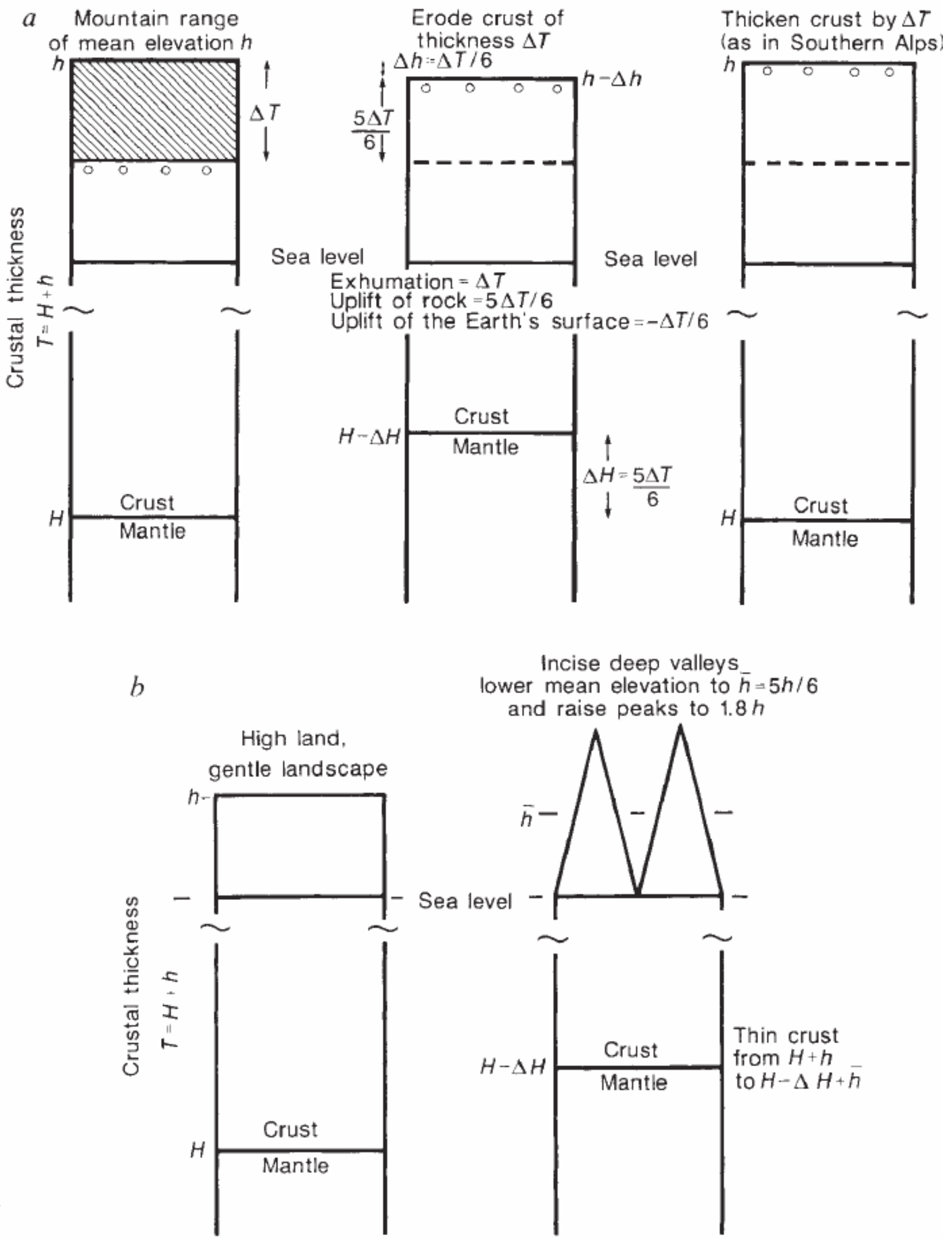
FIG. 2 Simplified crustal sections showing the effects of erosion and crustal thickening on mean elevation, depth of the Moho (the crust/mantle boundary) and uplift of rock. *a*, Imagine a mountain range (left) of mean elevation $h$, depth to the Moho $H$ and crustal thickness $T = H + h$, and allow a thickness of crust $\Delta T$ to be eroded. By isostasy, the mean elevation should decrease by $\Delta h \approx \Delta T/6$, and the underlying rock, including the Moho, should rise by $5\Delta T/6$ (centre). Hence, an exhumation of $\Delta T$ yields uplift of rock of $5\Delta T/6$, but a lowering of mean elevation of $\Delta T/6$. Only if, simultaneously, tectonically caused crustal thickening at depth replaces the thickness of crust, $\Delta T$, lost by erosion, will the mean elevation and the depth to the Moho remain constant (right). This is what seems to be happening in the Southern Alps of New Zealand[50] (see text). *b*, Similarly, if a gentle highland of mean elevation $h$ (left) were deeply incised by rivers that eroded valleys nearly to sea level (right), the mean elevation should drop slightly to about $5h/6$, the remaining rock and Moho would rise by an amount equal to $h$, and the highest peaks would be much higher than before. In this way, a climatically induced increase in erosion rate can cause exhumation of rocks, and hence the appearance of uplift, with no increase (in fact, with a decrease) in mean elevation.




*Molnar & England, 1990*

*As a consequence, since the Pio-Quaternary the mean elevation of the Pyrenees has decreased of about 70 m (1/6 of 400 m).*

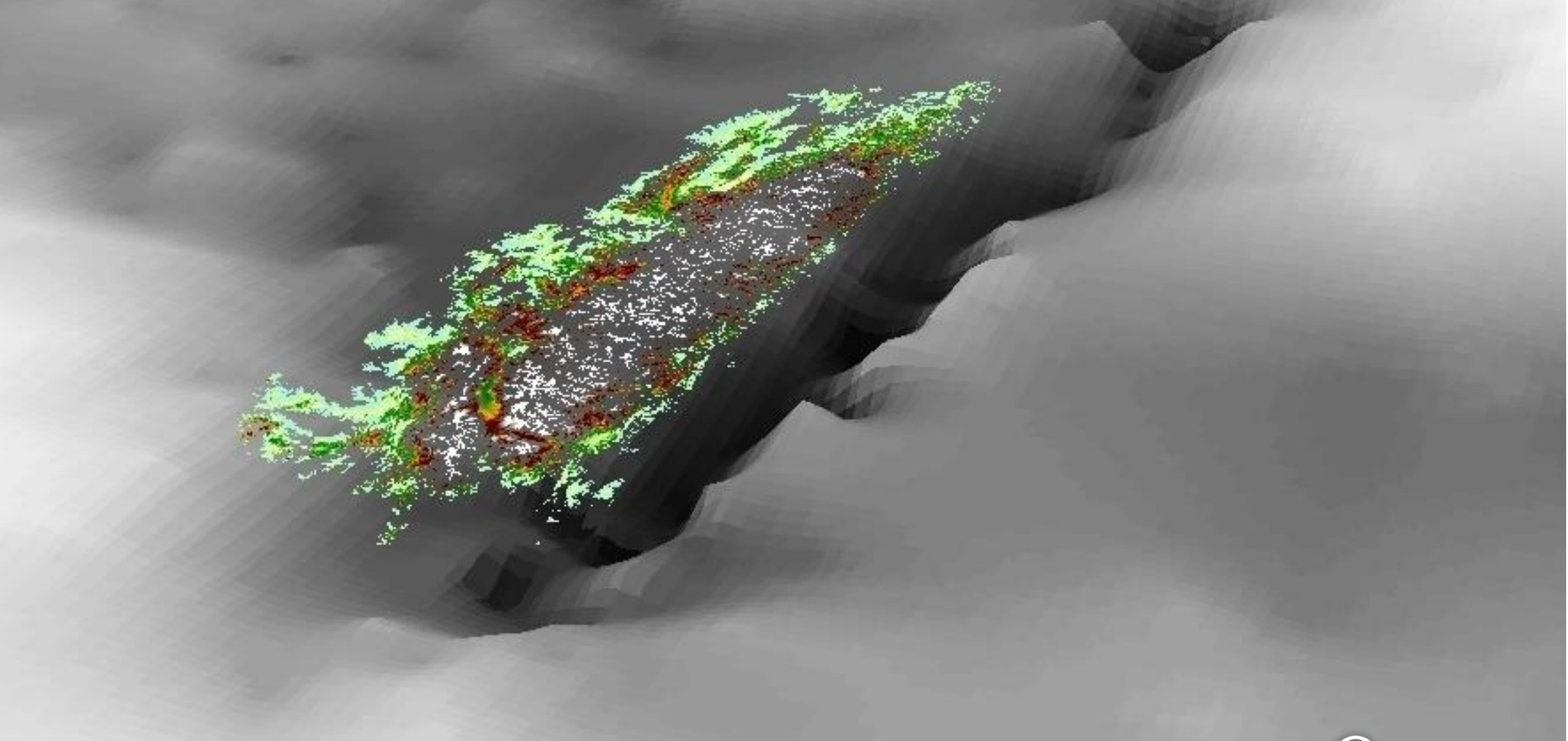
*In the same time, because the HE-LR surfaces can be considered as surfaces of non-erosion, they have consequently risen about 330 m,*

*resulting in drastic local relief (roughness) amplification!*

*Isostasy can't be ignored (Molnar, 2012)*

*The Pyrenees in some 100 My?*

*Merci de votre attention!*



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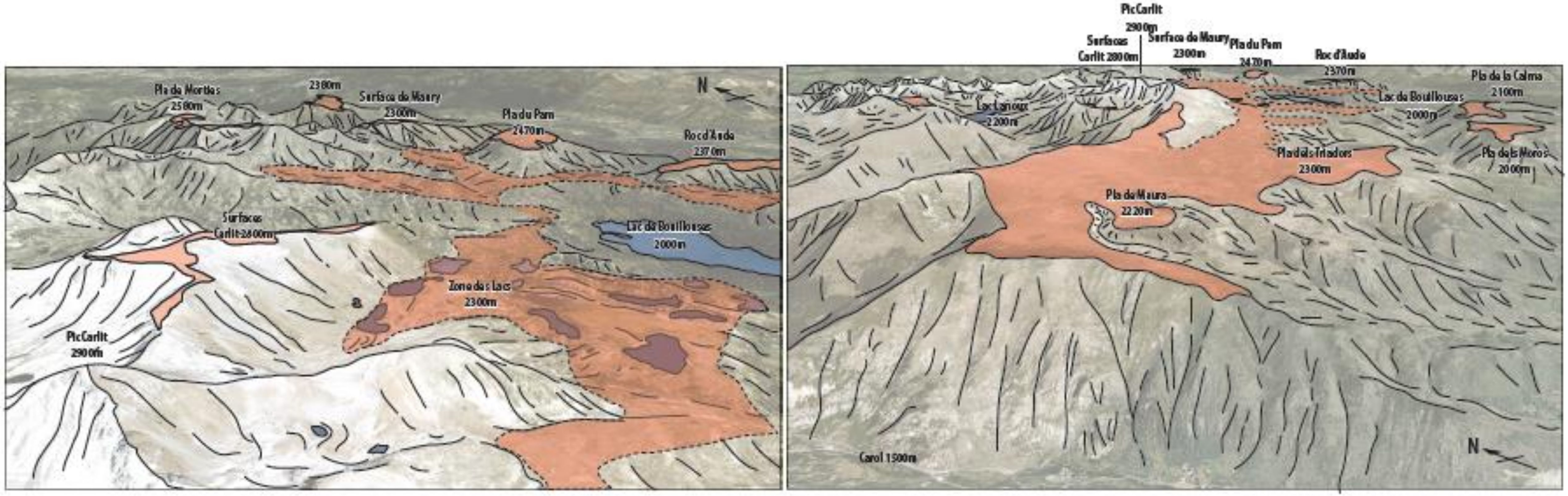

Pla de Mortiès
2580m
2380m
Surface de Maury
2300m
Pla du Pam
2470m
Roc d'Aude
2370m
N
Surfaces
Carlit 2800m
Lac de Bouillouses
2000m
Zone des Lacs
2300m
Pic Carlit
2900m
Pic Carlit
2900m
Surfaces
Carlit 2800m
Surface de Maury
2300m
Pla du Pam
2470m
Roc d'Aude
2370m
Pla de la Calme
2100m
Lac Lanoux
2200m
Lac de Bouillouses
2000m
Pla dels Tiradors
2300m
Pla de les Moros
2000m
Pla de Maura
2220m
Carol 1500m
N