Deep seated density anomalies across the Iberia-Africa plate boundary and its topographic response

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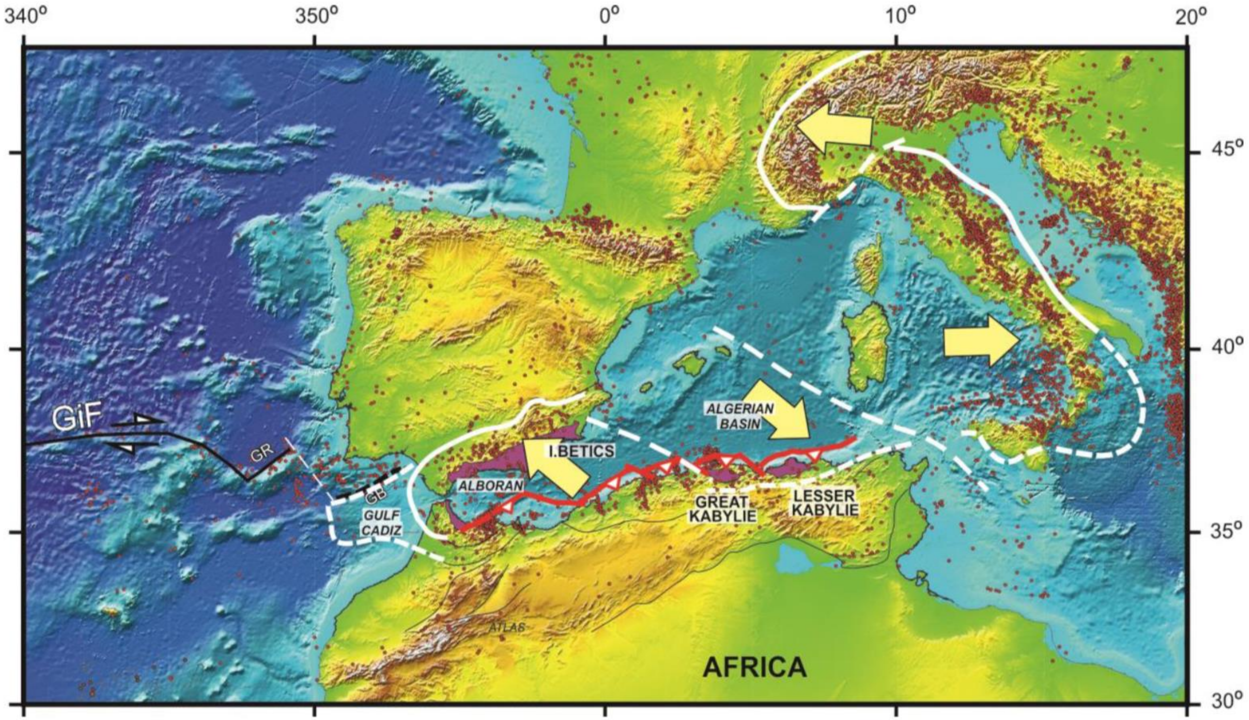
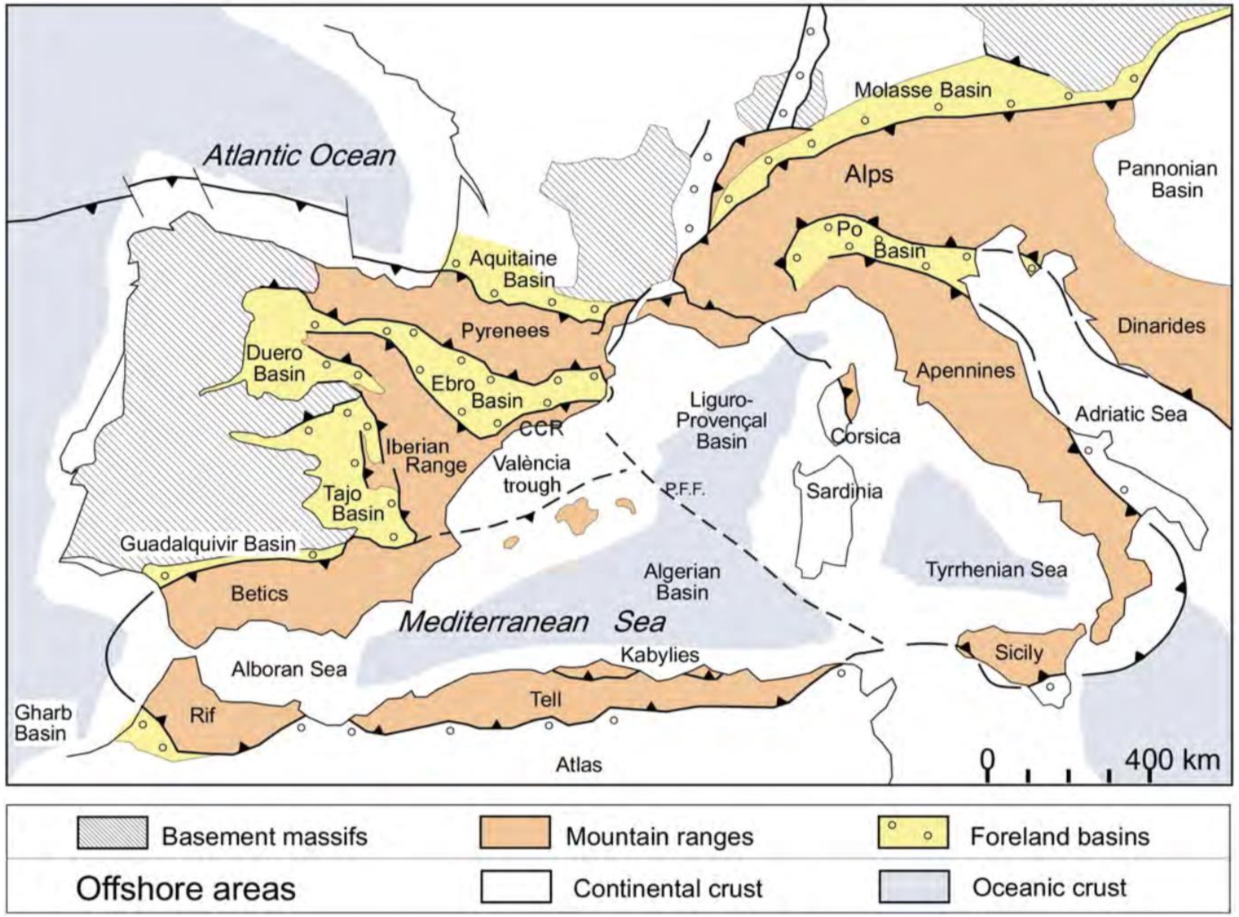
The modes in which the lithosphere deforms during continental collision and the mechanisms involved are not well understood. While continental subduction and mantle delamination are often invoked in tectonophysical studies, these processes are difficult to be confirmed in more complex tectonic regions such as the Gibraltar Arc.

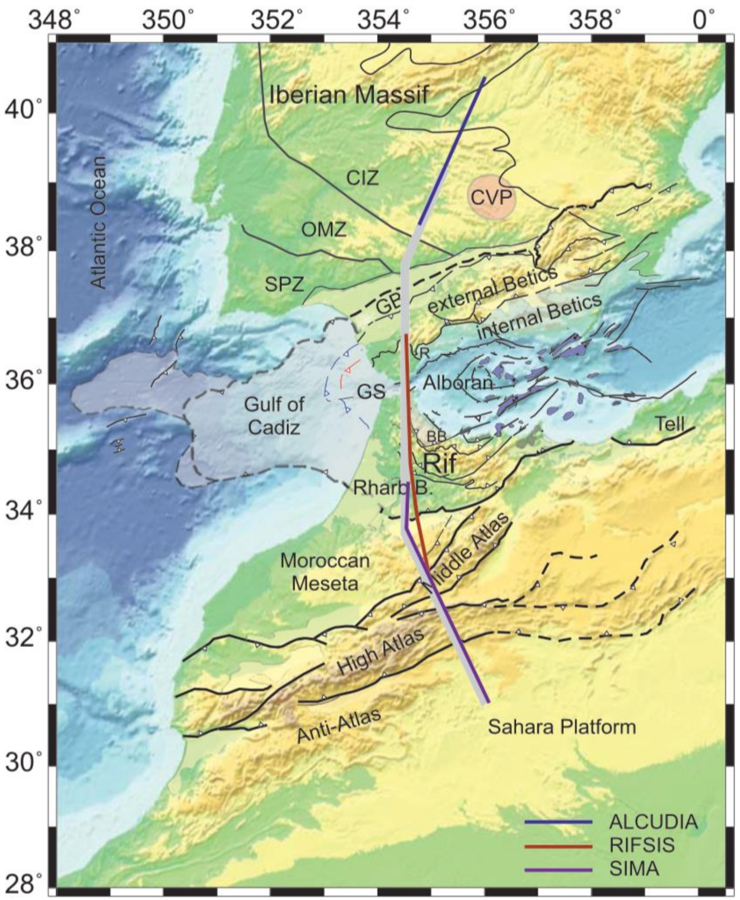




Vergés and Fernàndez (2012); Casciello et al. (2014)

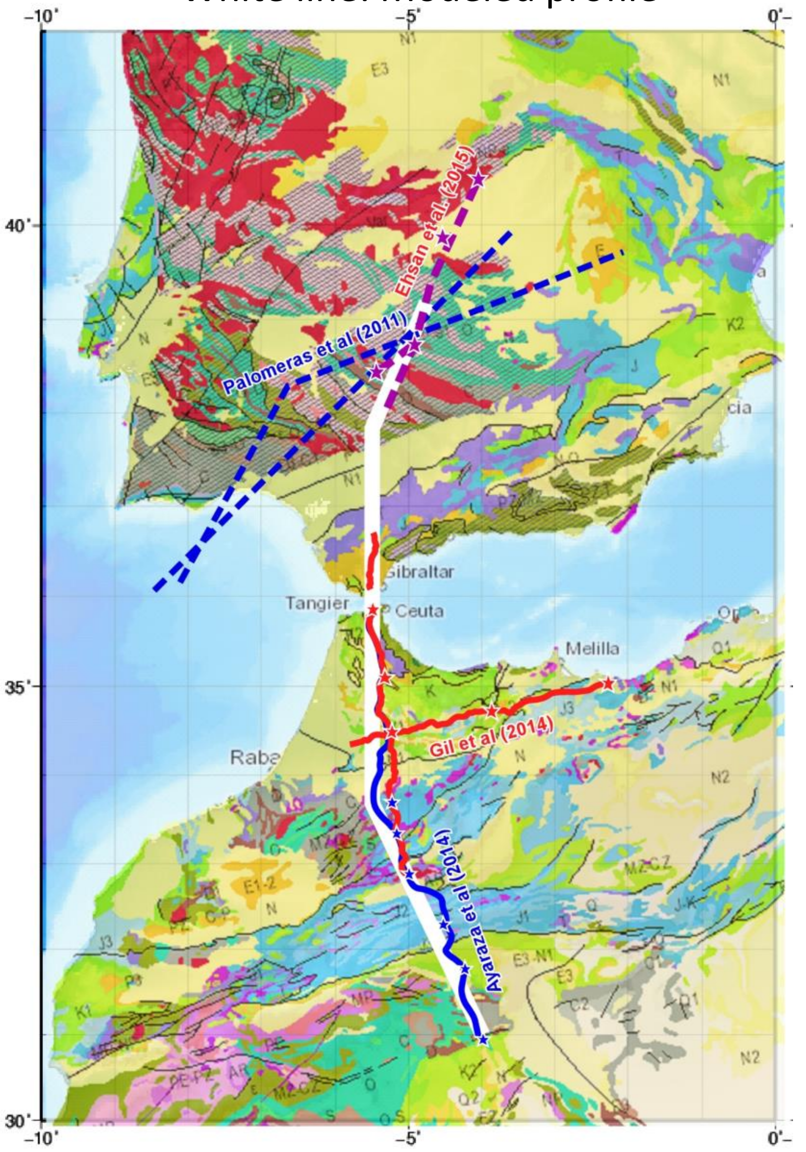
We study the present-day density and compositional structure of the lithosphere along a transect running from S Iberia to N Africa crossing the western Gibraltar Arc.

This region is located in the westernmost continental segment of the African-Eurasian plates, characterized by a diffuse transpressive plate boundary.



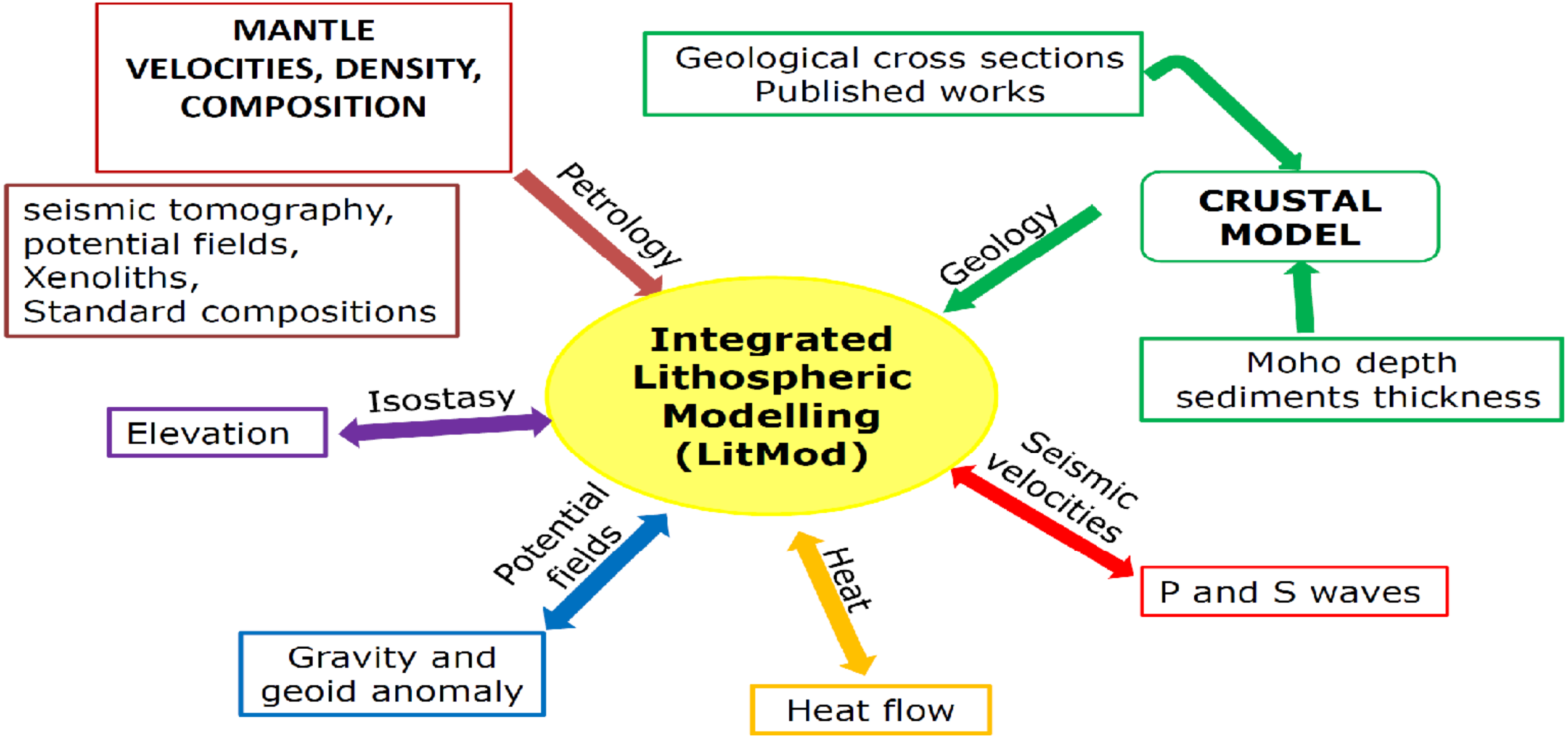
Jiménez-Munt et al., JGR (2019)

White line: Modeled profile

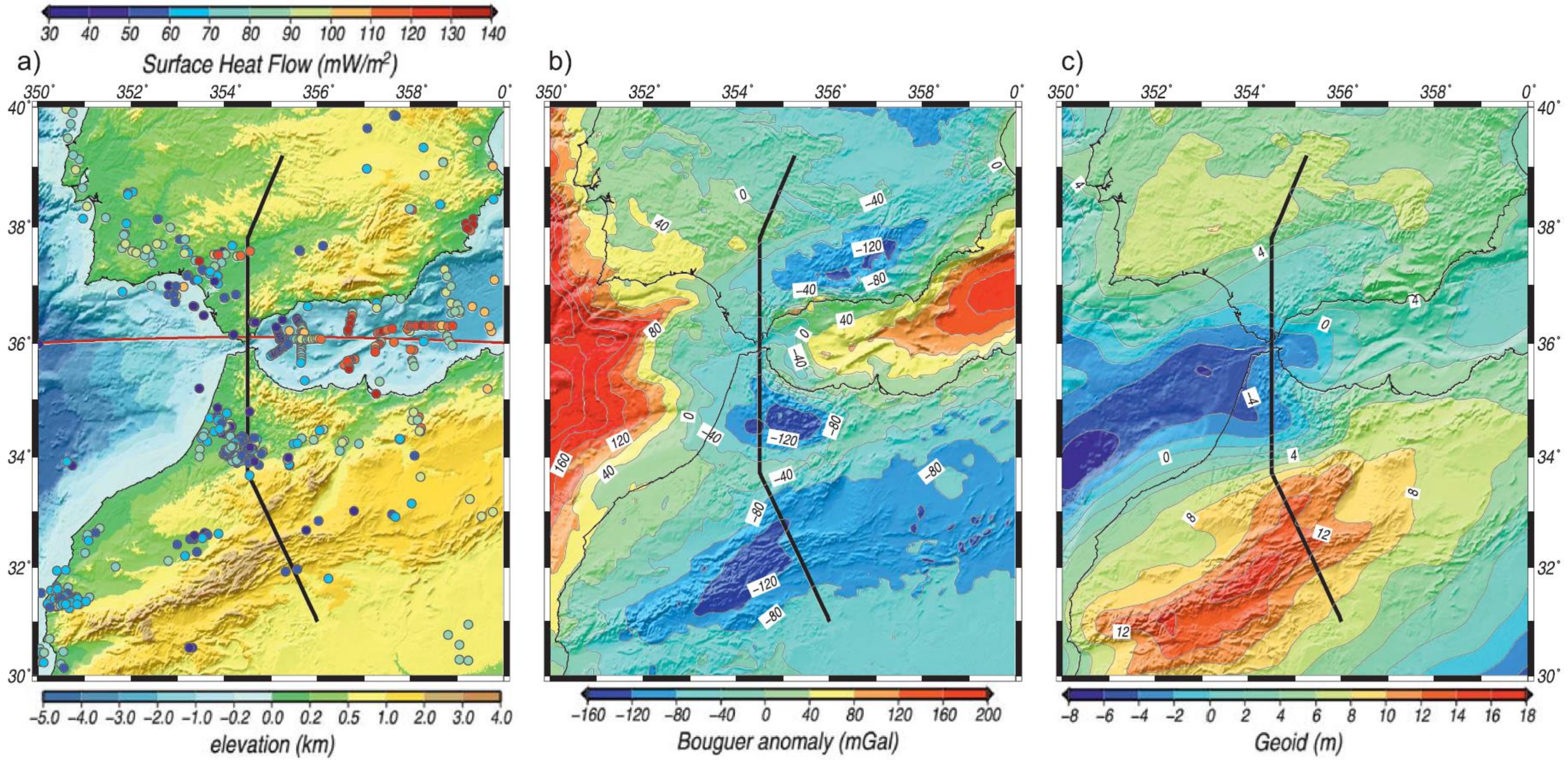


New **LitMod2D_2.0 –** Integrated Lithospheric Modeling. Kumar et al., G3, 2020

An integrated and self-consistent geophysical-petrological methodology is used to model the lithosphere structure variations and the thermophysical properties of the upper mantle. By simultaneously solving the heat transfer, thermodynamic, rheological, geopotential, and isostasy equations, the program calculates the temperature, pressure, surface heat flow, density, seismic wave velocity, geoid and gravity anomalies, and elevation for a given lithospheric structure.

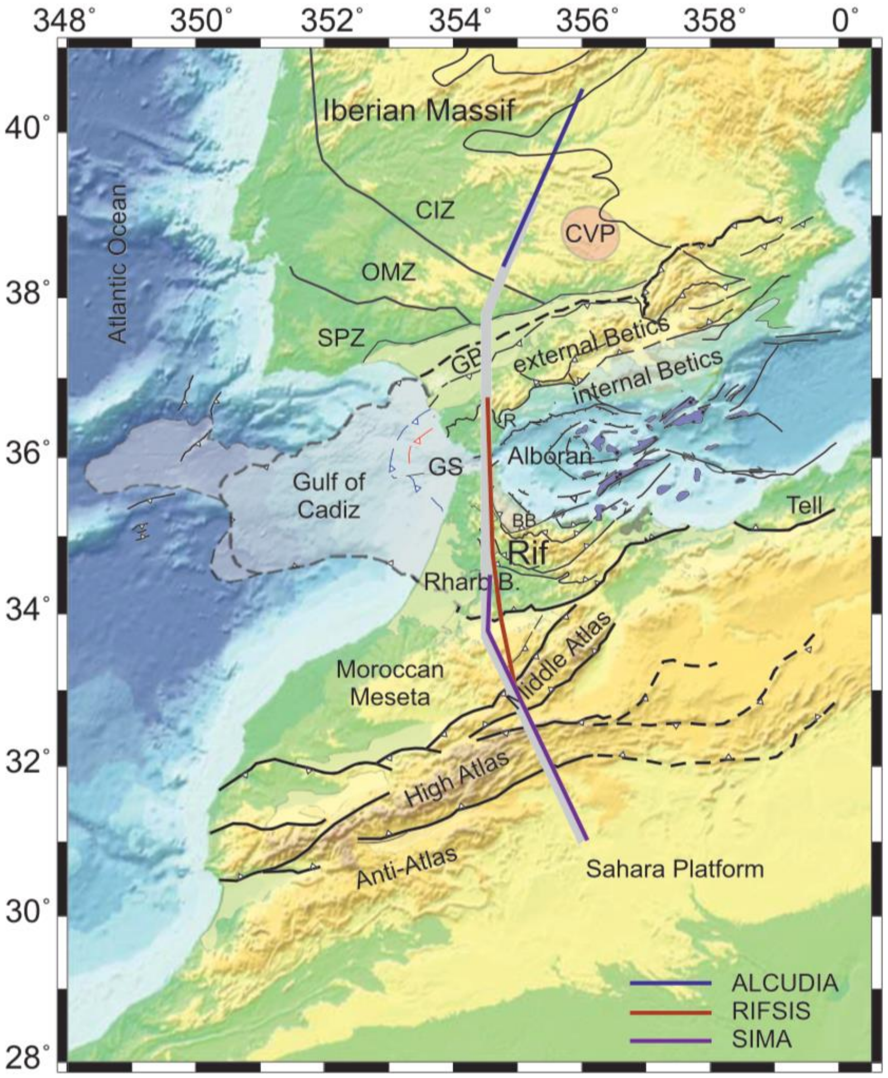


Surface Geophysical Data

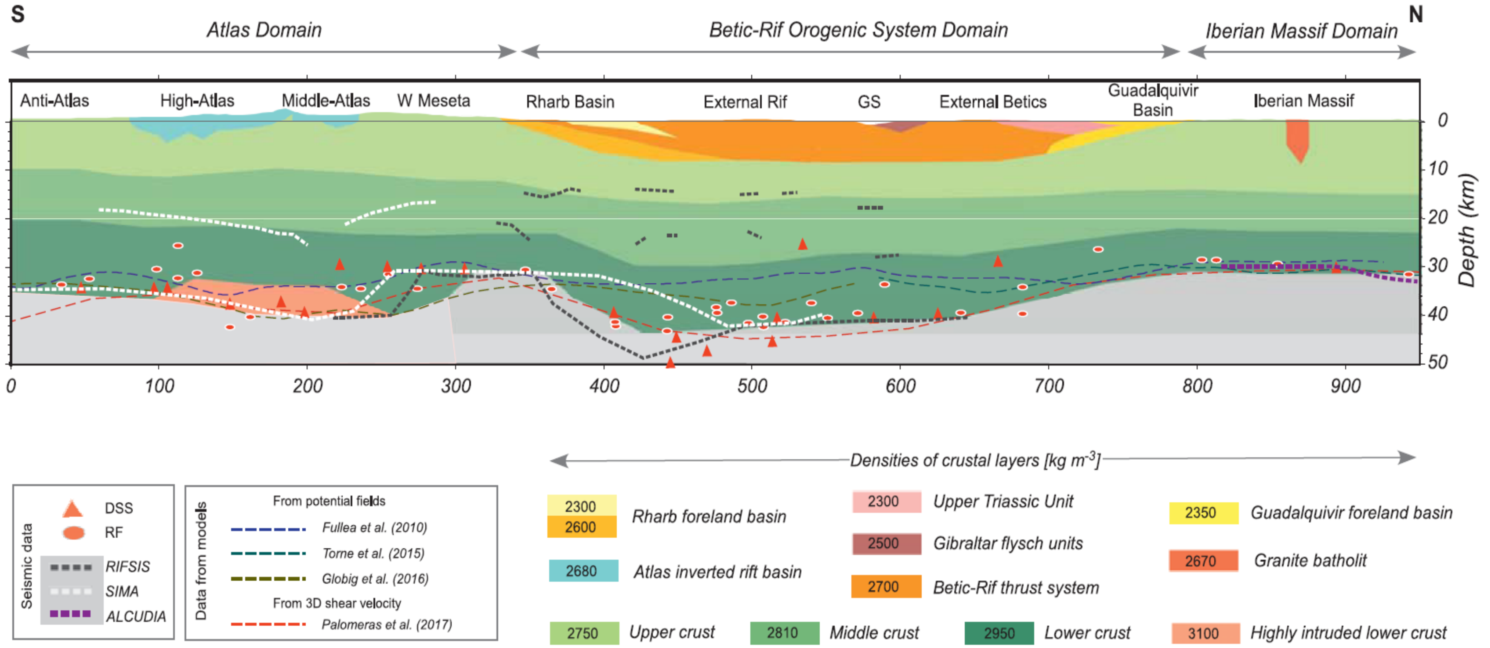


(a) Elevation and surface heat flow (dots), (b) Bouguer anomaly, and (c) geoid filtered at degree 10. Gray line is the location of the transect from this study.

The crustal structure is mainly constrained by seismic experiments and geological data, whereas the composition of the lithospheric mantle is constrained by xenolith data.
We have used the recently acquired wide-angle reflection and refraction seismic profiles along the geotransect to constrain the geometry and seismic velocities within the crust and the uppermost mantle.



Gray line is the location of the transect from this study.



Crustal structure resulting from our modeling, colors are associated to the assumed densities. Different symbols and dashed lines show the Moho depth and internal crustal boundaries from previous studies. RIFSIS (Gil et al., 2014), SIMA (Ayarza et al., 2014), ALCUDIA (Ehsan et al., 2015), and DSS and RF (deep seismic sounding and receiver functions compiled by Diaz et al., 2016).

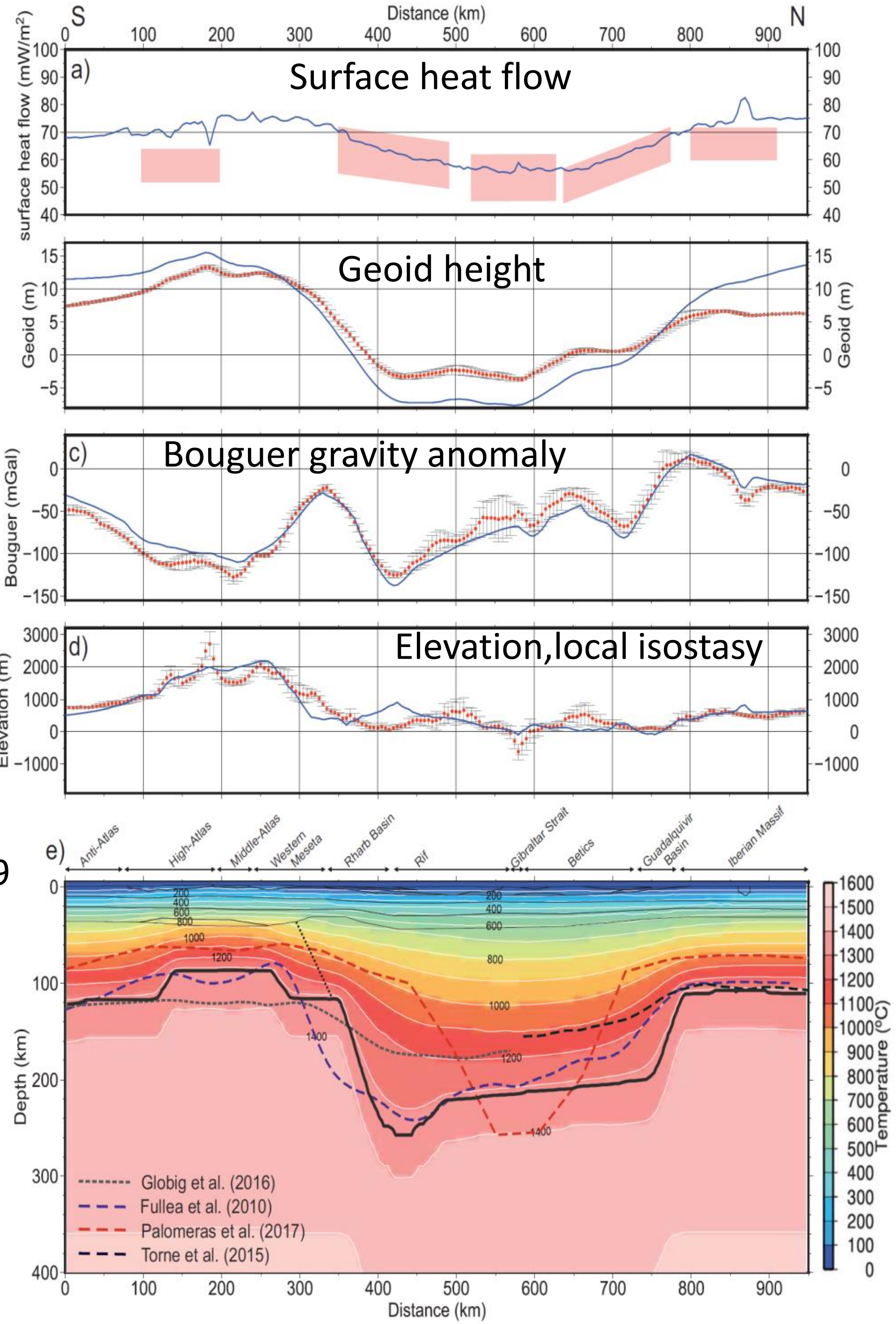
Jiménez-Munt et al., JGR, 2019

Model results

The results show large lateral variations in the topography of the lithosphere-asthenosphere boundary (LAB). We distinguish different chemical lithospheric mantle domains that reproduce the main trends of the geophysical observables and the modelled P- and S-wave seismic velocities.
The calculated heat flow and elevation match the major observed trends along the profile, but geoid and Bouguer anomaly show large misfits of long wavelength indicating a mass deficit in the central part of the geotransect.

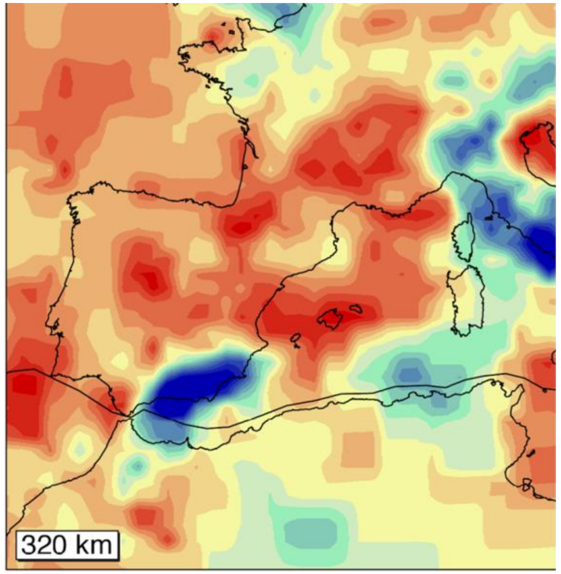
A major caveat is that the modeled geotransect runs across strongly three-dimensional structures at shallow and deep levels.

Jiménez-Munt et al., JGR, 2019

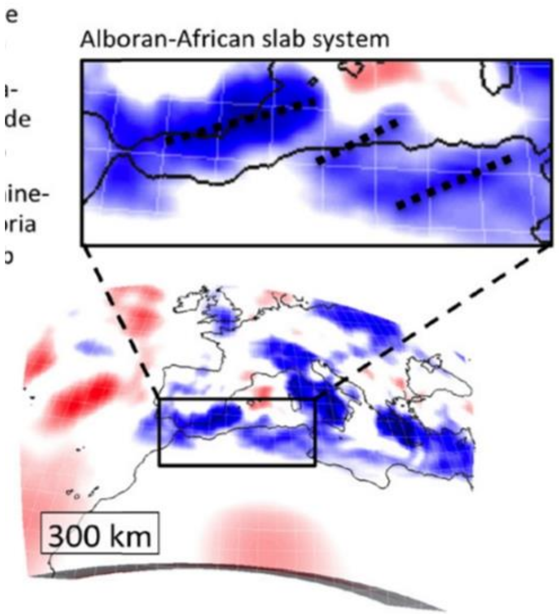


(e) Temperature distribution (color pattern), lithosphere-asthenosphere boundary (thick black line), and transition between the two lithospheric mantle compositions (thin black dashed line) resulting from our model. Color dashed lines are the lithosphere-asthenosphere boundary resulting from previous studies.

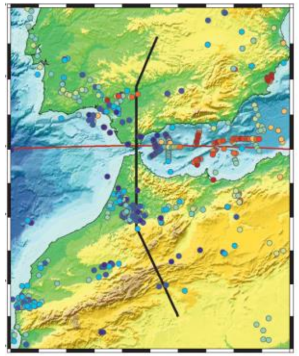
Tomography models reveal that the lithospheric slab beneath the Betic-Rif orogen dips radially toward the Alboran Basin, and therefore, the central segment of our geotransect crosses only the upper part of the slab, whereas the deeper part is east off profile, as illustrated in Figure 3 and been reported by previous studies (e.g., Gutscher et al., 2002; Thurner et al., 2014).



Villaseñor et al., 2003

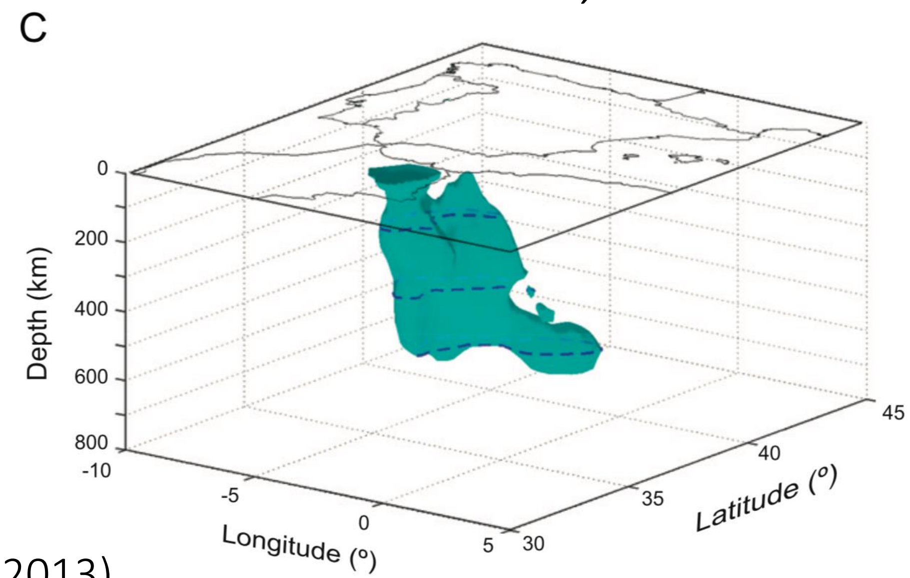


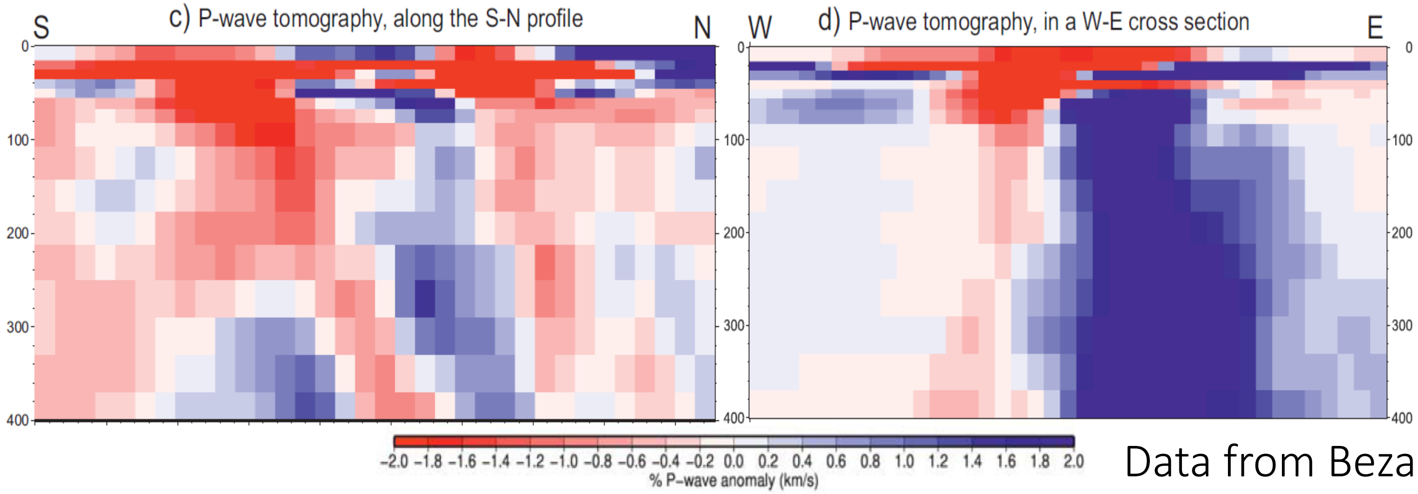
Fichtner and Villaseñor, 2015



Despite this, the off-profile portion of the cold and dense slab will be reflected in the measured potential fields.

Bezada et al., 2013

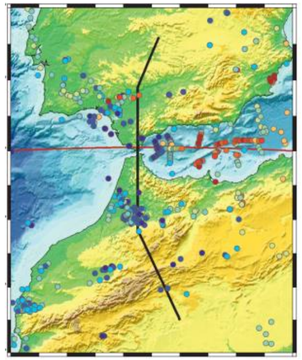




Data from Bezada et al. (2013)

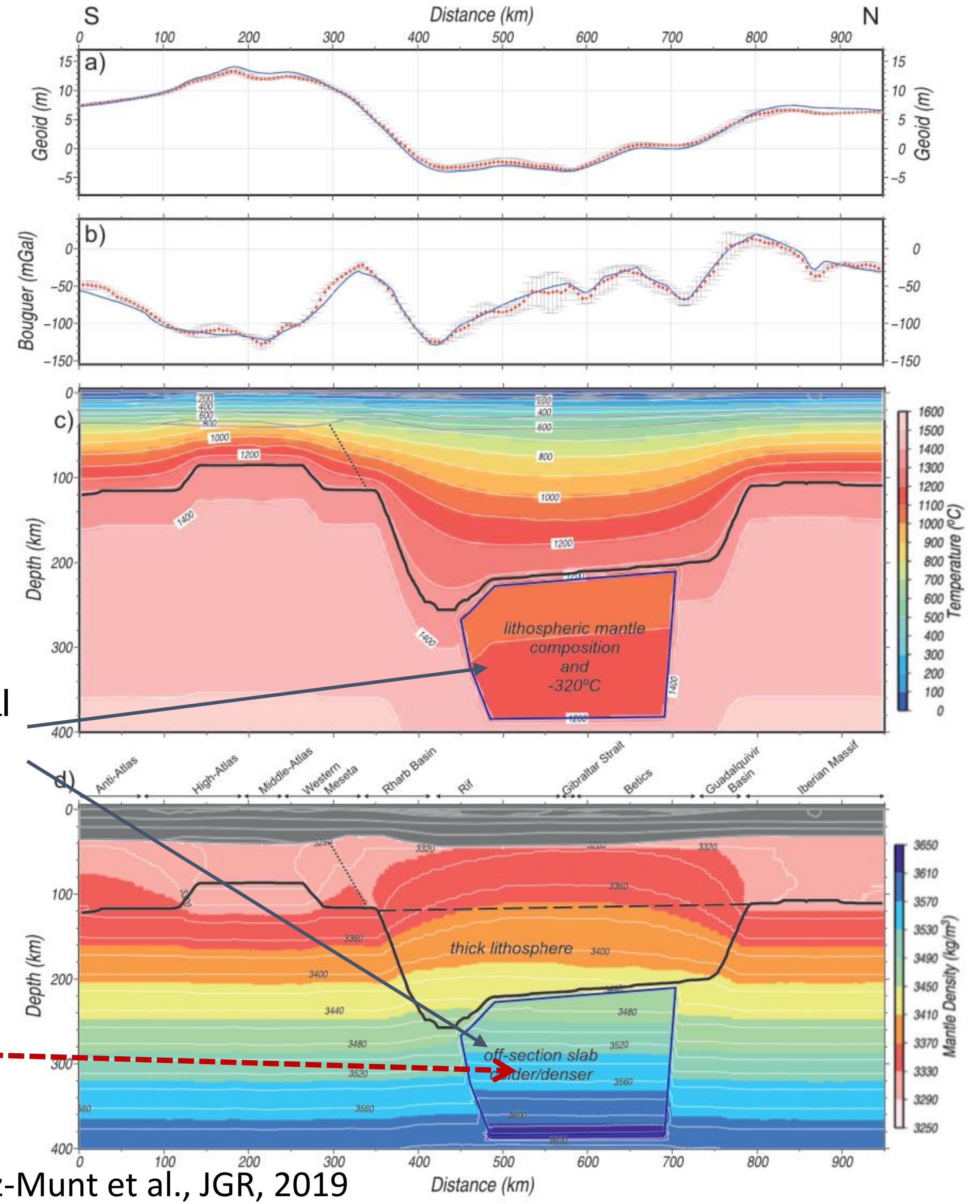
Model results

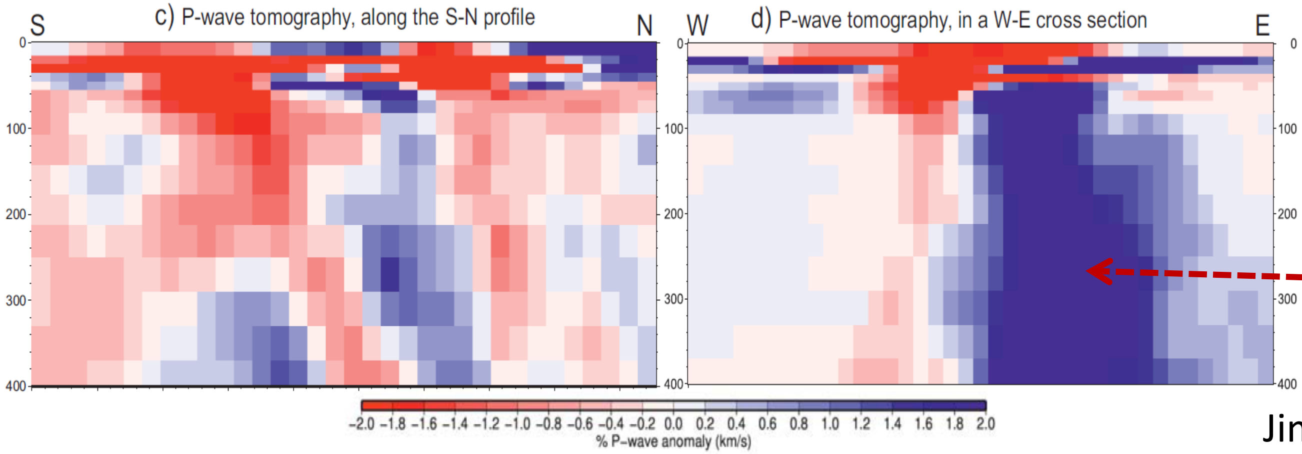
We calculate the contribution of a slab on the geoid height and Bouguer anomaly by considering a sublithospheric body beneath the External Betics and Rif with a temperature anomaly of −320°C and chemical composition corresponding to the berian-Rif lithospheric mantle. This sublithospheric body is needed to adjust the measured potential fields.



We link this body to the Iberian slab localized just to the east of the profile and having some effect on the geoid and Bouguer anomalies.

Sublithospheric thermal and chemical anomaly



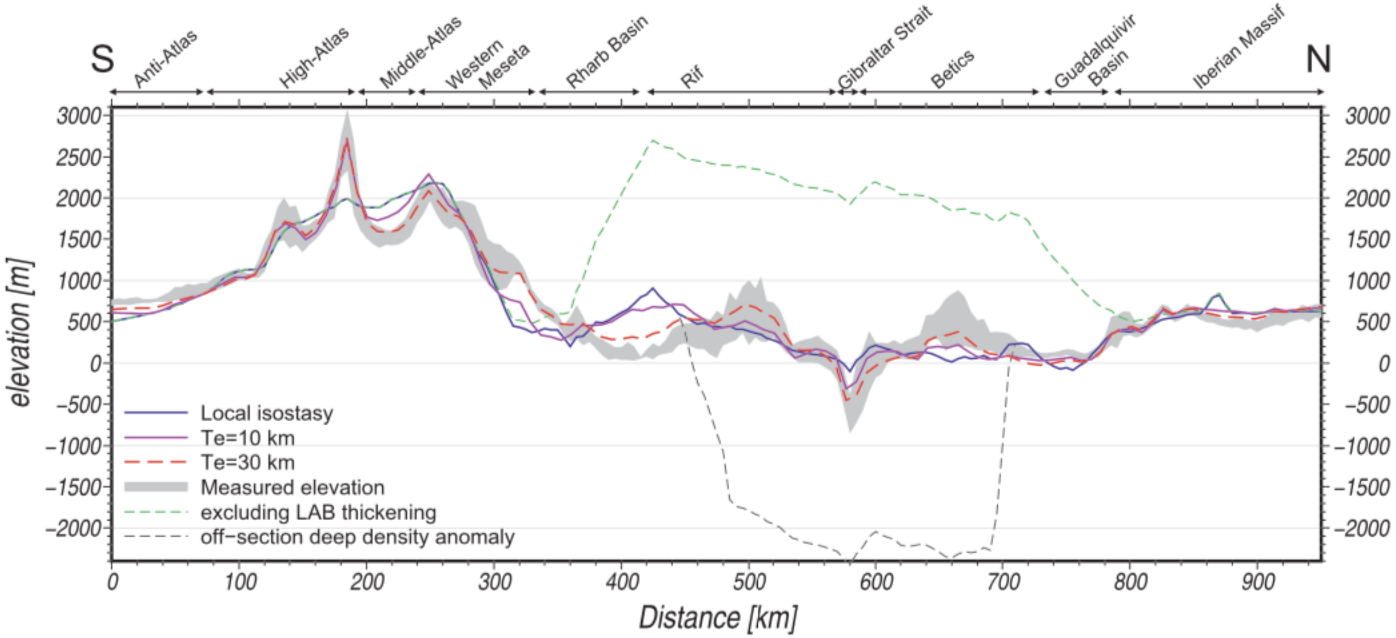


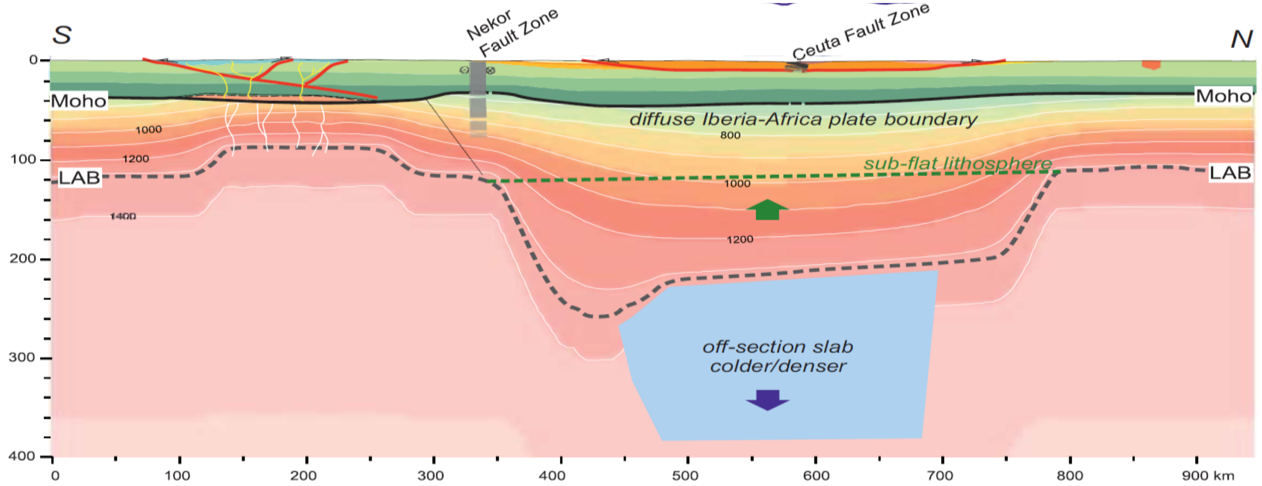
Jiménez-Munt et al., JGR, 2019

Model results

The predicted elevation would be between 1,500 and 2,000 m higher in the Betic-Rif orogenic system domain without the lithospheric thickening (green dashed lines). This represents an estimation of the amount of slab pull that has sunk the strait of Gibraltar since the Messinian salinity crisis, purportedly triggering the reflooding of the Mediterranean basin after a kilometric sea level drawdown around 5.5 Ma.

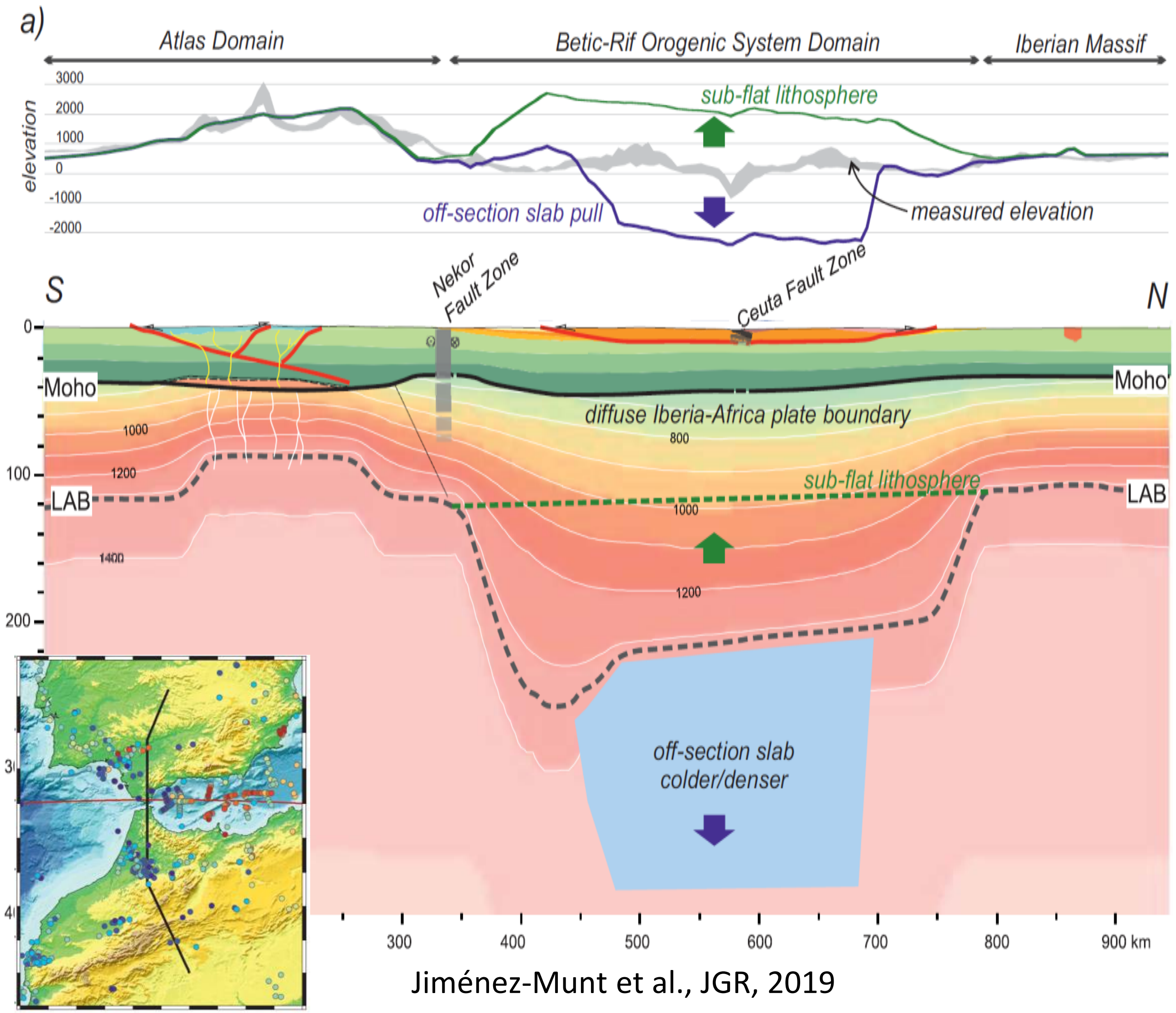
If the negative buoyancy of this slab were entirely transmitted onto the profile, it would produce a negative topography of ~2,000 m (black dashed line). However, the slab is attached to the Iberia-Rif lithosphere some tens of kilometers to the east of the Gibraltar Strait, where bathymetry increases up to 1,400 m toward the Western Alboran Basin and the basement lies at depths exceeding 9 km

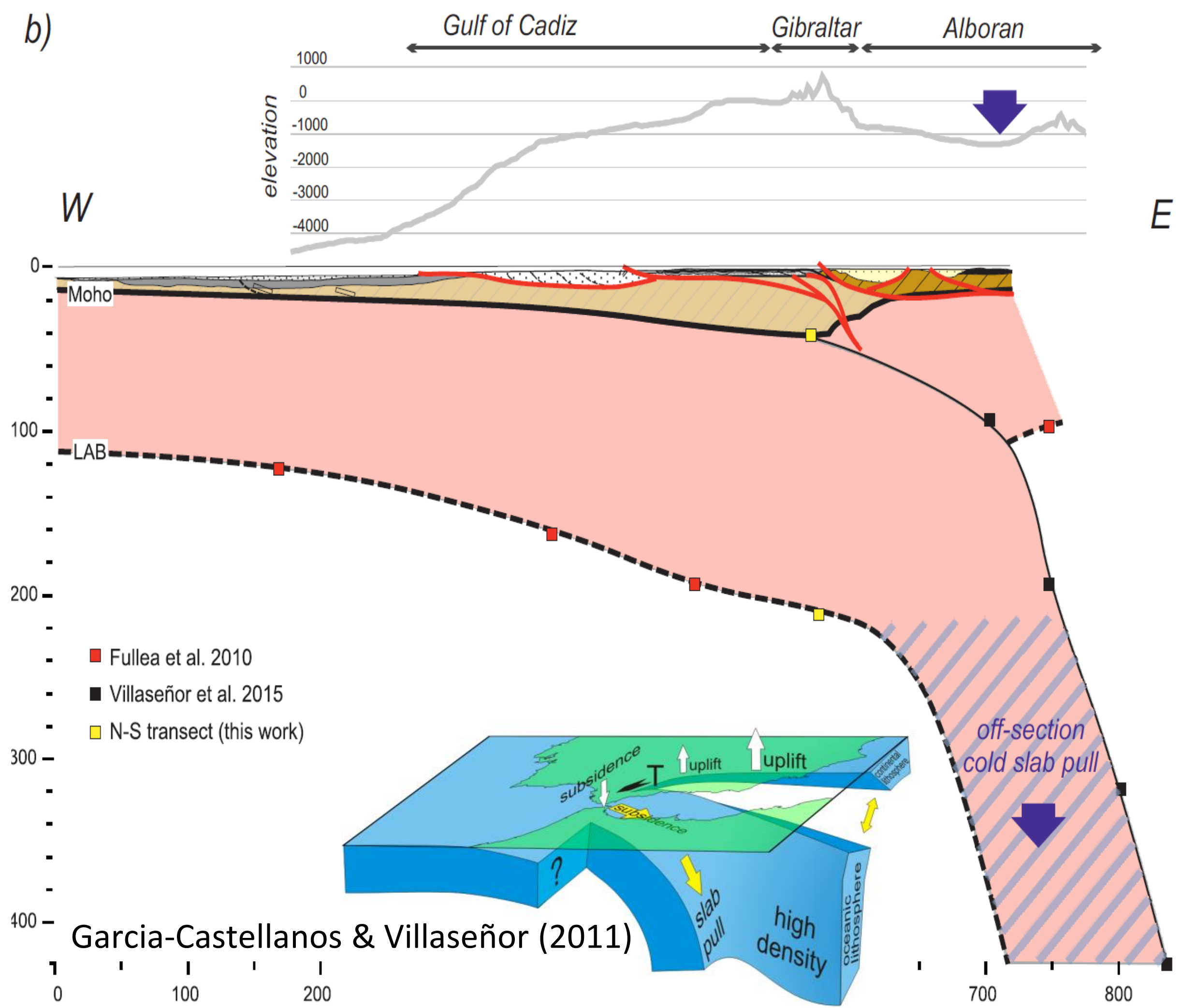




Jiménez-Munt et al., JGR, 2019

Lithospheric profiles crossing Gibraltar, (a) S-N profile, resulting crustal structure and temperature distribution from this work. The top panel shows the measured elevation (gray), the uplifted elevation considering a flat LAB beneath the Betic orogenic System (green), and the pulled down elevation considering the off-section slab (blue). (b) E-W cross section, perpendicular to our profile. The slab beneath the Alboran Sea corresponds to the “off-section slab” affecting the geoid and gravity calculations along our profile, and it is pulling down the Alboran basin.





Concluding remarks

Jiménez-Munt et al., JGR (2019)

The crust, constrained by seismic results, is thicker beneath the orogenic systems of Betics and Rif and under the Atlas Mountains. The Betics and Rif orogens are depicted as thin skinned along the geotransect whereas the Atlas Mountains are interpreted as thick skinned by the product of basin inversion during the Cenozoic.

The LAB, however, shows significant lateral variations in thickness (110–260 km) and composition, showing a good match with their respective crustal domains characterized by different tectonic evolutions. An abrupt LAB depth is noticeable toward the Betics and Rif tectonic domains with values at 220 and 260 km, respectively. We link this lithospheric thickening to the lithospheric slab visible in seismic tomography and estimate that it may have pulled down the topography of the Strait of Gibraltar by about 1,500–2,000 m. The latest part of this subsidence could be responsible for the reconnection of the Atlantic Ocean and the Mediterranean Sea, leading to the reflooding of the Mediterranean after the Messinian salinity crisis.

The Ligurian-Tethys subducting-delaminated slab beneath the Betic-Rif orogenic system is incorporated into the model as an off-profile thermocompositional sublithospheric body with a temperature anomaly of −320 °C and chemical composition as the Iberian-Rif domain.

The obtained lithospheric structure across the Iberia-Africa boundary is compatible with a subduction related orogenic system related to the consumption of the Tethys lithosphere that produced a significant northwest and west directed rollback. During rollback the cover units of both Iberian margin (Betics) and NW African margin (Rif) were imbricated ahead of the tectonically emplaced Internal metamorphic units.