Geomorphometric mapping of spatio-temporal changes in Plio-Quaternary uplift in the NW European Alpine foreland

A. Demoulin [1] & H. Bourdon [3]

[1] FSR-FNRS Belgium and Université de Liege, Dept. of Physical Geography and Quaternary, Liege, Belgium
[2] Royal Museum for Central Africa (RMCA), Brussels, Belgium

Corresponding author: ademoulin@ulg.ac.be

Introduction

Most Variscan massifs of Western Europe have been uplifted in Plio-Quaternary times but, although the overall picture suggests continental-scale cause(s) for these spatially separate events, it is still controversial whether they were driven by lithospheric buckling in front of the Alpine collision zone (Cloetingh et al., 2005; Bourgeois et al., 2007), by a number of mantle diapirs rooted in the upper mantle (Burov & Guillou-Frottier, 2005), or in close association with the development of the European Cenozoic Rif System (Ziegler & Dèzes, 2007), or still by a combination of these causes (Burov & Cloetingh, 2009). Here, we explore the contribution of geomorphometry to the debate through appraisal of the distribution in time and space of Plio-Quaternary uplift throughout the NW European foreland of the Alpine arc.

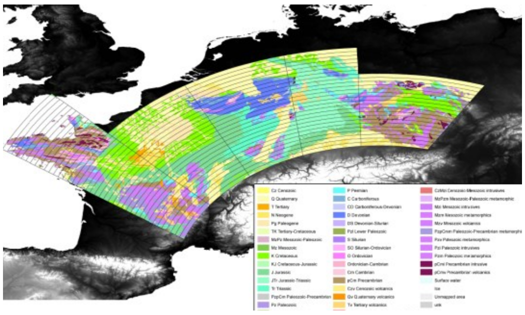


Fig. 2. Study area, distributed in five bands of predominantly Variscan or Mesozoic geology.

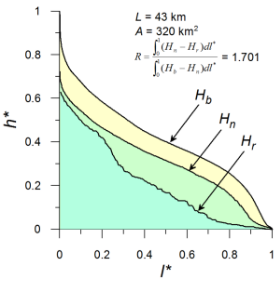
Methods

We use the composite metric *R* in order to quantitatively evaluate the stage of the fluvial landscape response to uplift. Based on three hypsometric integrals that describe the nested levels of basin (H_b), drainage network (H_n) and trunk stream (H_r), R is calculated as (Demoulin, 2011) (Fig. 1a)

$$R = \frac{\int_0^1 (H_n - H_r)\,dl^*}{\int_0^1 (H_b - H_n)\,dl^*}$$

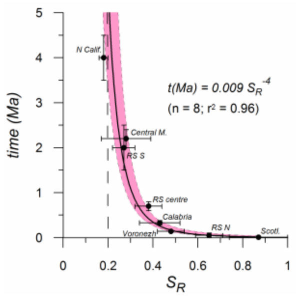
The three integrals are respectively indicative of the long-, middle-, and short-term components of the landscape response, so that *R* contains time information. However, as another major control on *R* is catchment size *A*, the time estimate is finally obtained from the derived index S_R, taken as the slope of the *R* = ln *A* linear regression at the regional scale and shown to decrease with the time elapsed since the last uplift signal (Demoulin 2012) (Fig. 1b).

We use the SRTM 3" elevation data resampled at 90 m resolution and compute *R* for 7478 catchments > 15 km² distributed in five N(W)-S(E) trending bands covering the NW European platform and drawn so as to roughly separate Variscan massifs (Central Massif, Brittany, Rhenish shield, Bohemia) from Mesozoic basins (Paris and Franconian basins) (Fig. 2). Inside each band, S_R N-S variations are estimated by calculating the index within a moving 60-km-wide window displaced by 20-km steps. In order to improve the lateral resolution of the S_R map, we also calculate S_R for smaller rectangular areas.



← *Fig. 1a. Definition of the R metric.*

Fig. 1b. Empirical relation between S_R and time since the last uplift event. →



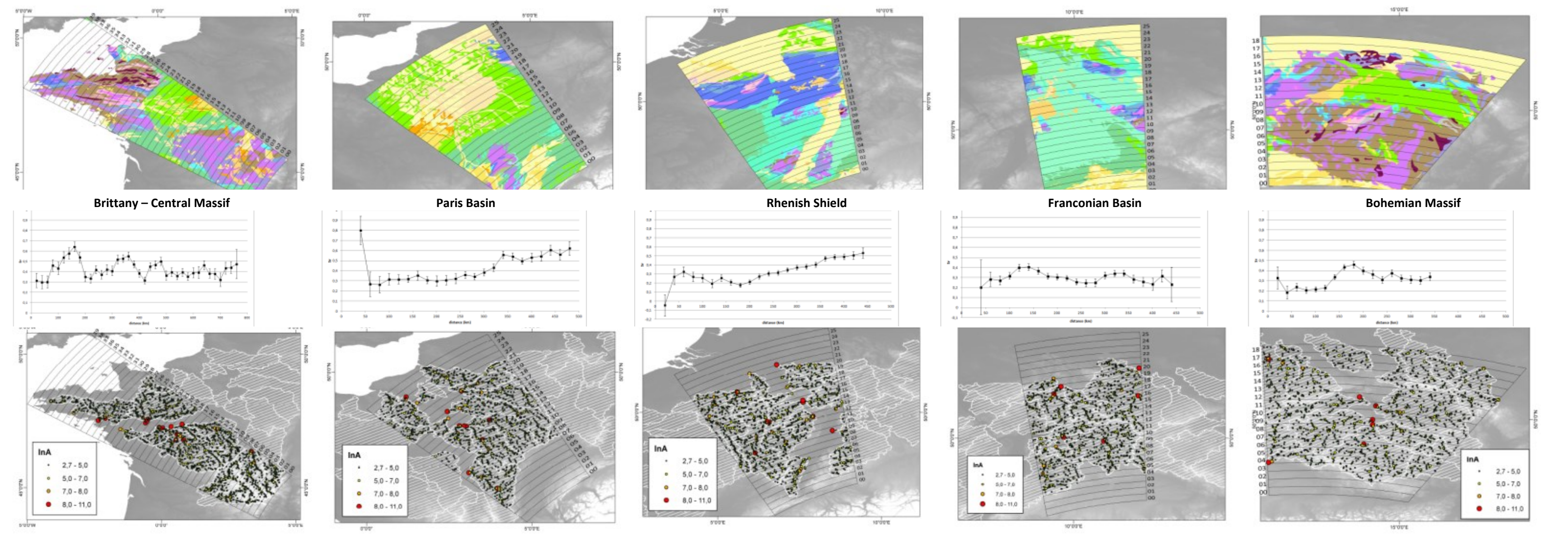


Fig. 3. S_R curves per band of either mainly Variscan substrate or Mesozoic cover, from west to east across the NW European platform in front of the Alpine arc (bottom row: outlets of the measured catchments).

Results

Figure 3 shows the N-S evolution of S_R (centre row) for the five bands of predominantly Variscan or Mesozoic geology (top row) in parallel with the number and size of catchments involved in the calculations (bottom row). Catchments are assigned to the band in which their outlet is located, a preliminary choice that we feel might not be the most appropriate. Nevertheless, it already consistently highlights one main observation: bands B and C, essentially encompassing the Paris basin and the Rhenish shield in front of the west-central Alps, display a fairly regular northward increase in S_R suggesting that a wave of uplift migrated away from the collision zone during the Plio-Quaternary in this area. While the complex tectonic settings crossed by bands A (from Central Massif to Brittany) and E (across Bohemia, in a region of possible influence of the Carpathian arc) are probably responsible for more confuse S_R curves, the second important and rather surprising point is the almost flat curve of band D that points to stability mostly since the Early Pleistocene in this transitional area between the more recently uplifted central Bohemia and Rhenish shield.

The increased resolution of the S_R map of Fig. 4 evidences a significant degree of lateral variations in S_R that remains largely unexplained and might betray the effect of a variable (tilt component of deformation?, uplift rate?) so far unidentified in studies concerned with smaller areas of investigation, or a pattern of local variations in uplift timing more complicated than expected. In any case, it makes also desirable to map S_R on another spatial basis such as, e.g., by large catchments rather than a moving window of fixed shape independent of the underlying fluvial framework.

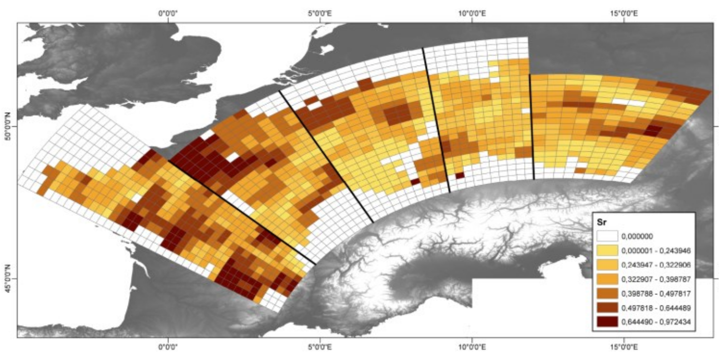


Fig. 4. High-resolution S_R map (S_R computed on 3x3 rectangles; single rectangle width: 60 km).

Conclusion

Though preliminary, our results point to the Plio-Quaternary northward migration of a continental-scale uplift wave across the Paris basin and the Palatinate Mountains-Rhenish shield area that tends to lend support to a cause directly related to the northern push of the Alpine chain. If confirmed, this will leave open questions regarding why this uplift dies out eastward across the Franconian basin and how such migrating vertical crustal deformation may be mechanically related to folding of a rheologically complex lithosphere.

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