Topographic Imaging of European Mantle Plumes

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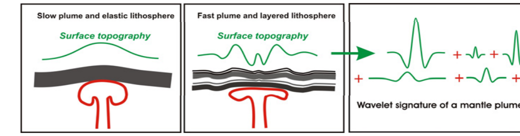


Summary

• Recent numerical experiments based on tectonically realistic formulation for the lithosphere and representative mantle rheology, have shown that plume-induced undulations exhibit temporal successions of uplift and subsidence at various wavelengths (**A**).

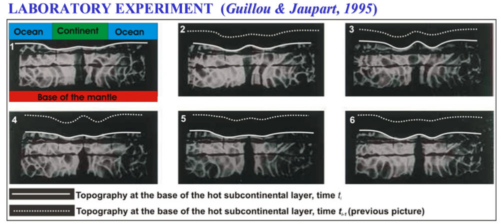
• From spectral (Fourier) analyses of the undulations would appear that two groups of wavelengths (200-400 km and 60-100 km) predominate. Interestingly, a spectral analysis of Europe's topography also reveals two dominant groups (**B**).

•To discriminate between tectonically-induced undulations (uni-directional deformation) and plume-induced undulations (omni-directional deformation) (**C**), we use a spectral analysis with a wavelet formulation (**D**).

• The European lithosphere is well-suited for this approach since it has been suggested that two mantle plumes (the Massif Central and the Eifel area) underlie Western Europe (**E**), where Alpine compression has folded the lithosphere over several hundreds of kms.

• The wavelet analysis of Europe's surface topography confirms that energy distribution of the topographic undulations outside the two main volcanic provinces is homogeneous (**F**), thus contrasting with the large-scale and medium-scale high-energy features that are obtained for the Massif Central and Eifel areas (**G**). Similar signatures are also found beneath the northern Sudetes area (**H**).

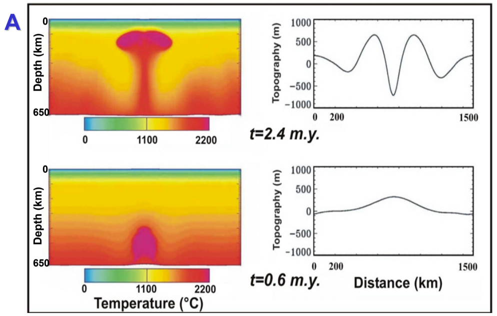
LABORATORY EXPERIMENT (*Guillou & Jaupart, 1995*)



Plume dynamics involve topographic undulations at the base of the top boundary layer. However, the upper surface is here « rigid », as in numerous previous numerical experiments...

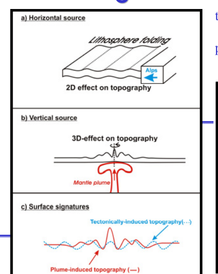
NUMERICAL EXPERIMENT (*Burov & Guillou-Frottier, 2005*)

A

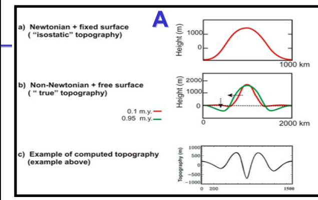


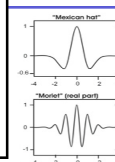
Numerical simulation of plume-lithosphere interaction, with a free upper surface, and a tectonically realistic formulation for the lithosphere.

C



A





D

Continuous wavelet transform of surface topography h(x) can be defined as:

$$C_h(a,b) = \int h(\tau)\, \overline{\psi}_{a,b}(\tau)\, d\tau \text{ = wavelet coefficients}$$

where a>0 is the <u>**scale**</u> (or dilation) parameter, b is the <u>**position**</u> (or translation) parameter, and $\overline{\Psi}$ is the conjugate of Ψ, the <u>**"mother" wavelet**</u>, which defines a series of functions:

$$\psi_{a,b}(\tau) = \frac{1}{\sqrt{a}}\psi\left(\frac{\tau - b}{a}\right)$$

Values of wavelet coefficients, $C_{(a,b)}$, increase as the shape of the analysed signal approaches that of the wavelet.

The most frequently used wavelets in geophysics are :

$$\psi_{MH}(x) = \frac{1}{\sqrt{2\pi}}(1-x^2)\, e^{-x^2/2}$$

"Mexican hat" wavelet

$$\psi_{MO}(x) = \pi^{-1/4} e^{i\omega_0 x} e^{\left(-\frac{x^2}{2}\right)}$$

"Morlet" wavelet

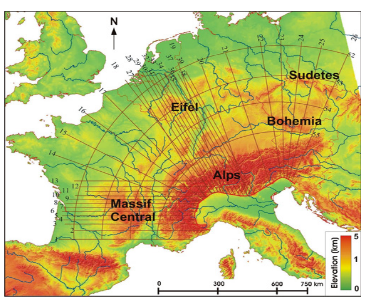
Coefficients $C_{(a,b)}$, can be illustrated by "scalograms", where the horizontal axis stands for the position parameter (*b*) and the vertical axis for the dilatation parameter (*a*). The scalogram refers to an energy distribution defined as the square modulus of the wavelet coefficients.

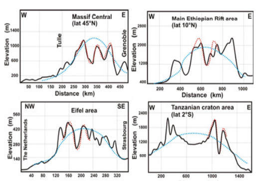
The shape of the « mexican hat » wavelet curve is closer to surface topography obtained in numerical results, and this wavelet appears more appropriate to decipher plume conduits: in addition to large-scale high energy coefficients, medium-scale high energy coefficients appear (white ellipses).

Wavelet analyses with the Morlet wavelet yield too many high-energy coefficients (see the case of Ra=5 10⁶), preventing any clear interpretation.

TOPOGRAPHIC PROFILES IN WESTERN EUROPE

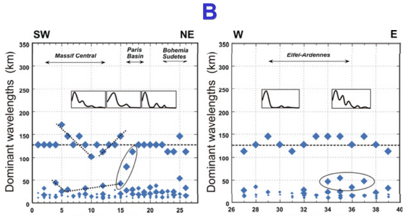
Analyses of dominant wavelengths (Fourier transforms)





Large and small wavelengths in topographic profiles crossing areas of suspected underlying mantle plumes in Europe (top, left), in comparison with similar profiles in east Africa (top, right).

B

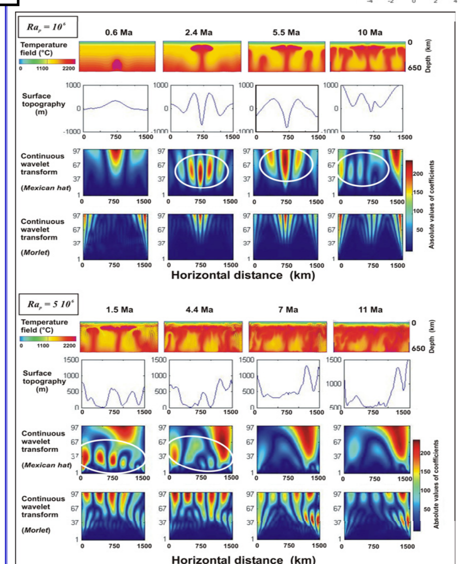


Spectral (Fourier) analyses of surface topography along 39 profiles (see map).

Size of symbols indicate relative importance of each dominant wavelength. Typical spectra are indicated in inserted rectangles.

Dotted lines and ellipses illustrate apparent regional trends, which <u>cannot, however, be attributed to local effects, due to the used spectral (Fourier) technique</u>.

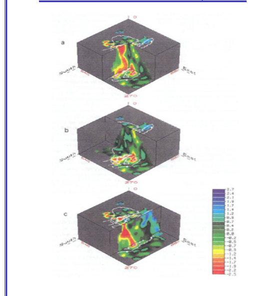
Note however the two distinct ranges of dominant wavelengths.



Numerical models of plume-lithosphere interactions (top, thermal field), for two « plume Rayleigh numbers ». Computed topographic undulations, and their wavelet transforms, using the « Mexican hat » and the « Morlet » wavelets.

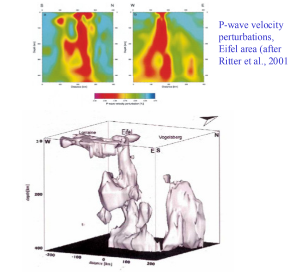
E

MASSIF CENTRAL AREA, France



3D block-diagrams of velocity structures beneath the French Massif Central (after Granet et al., 1995)

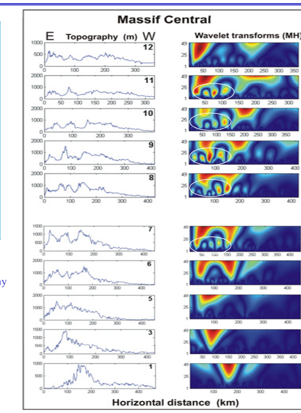
EIFEL AREA, Germany



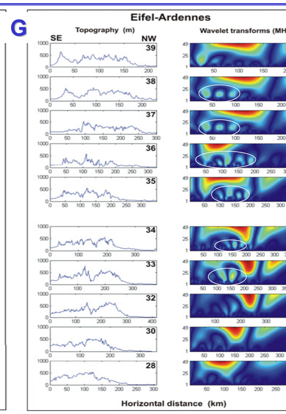
P-wave velocity perturbations, Eifel area (after Ritter et al., 2001)

P-wave low-velocity anomaly under the Eifeil area Contour=-1% iso-velocity anomaly (after Ritter, 2005).

G

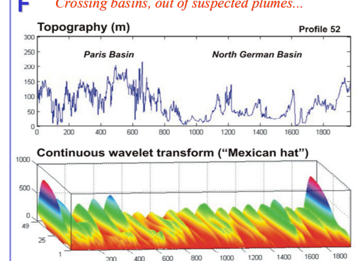


For profiles 7 to 11, high-energy coefficients are identified at medium-scales (white ellipses).

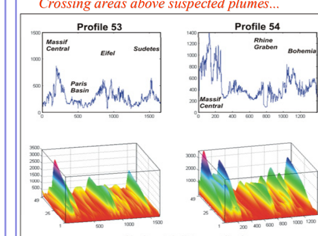


For profiles 33 to 38, high-energy coefficients are identified at medium-scales.

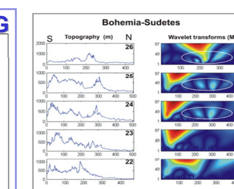
F *Crossing basins, out of suspected plumes...*



Crossing areas above suspected plumes... **G**



H



For profiles 24 to 26, some medium-scale medium-energy coefficients seem to be present beneath the Sudetes area.

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