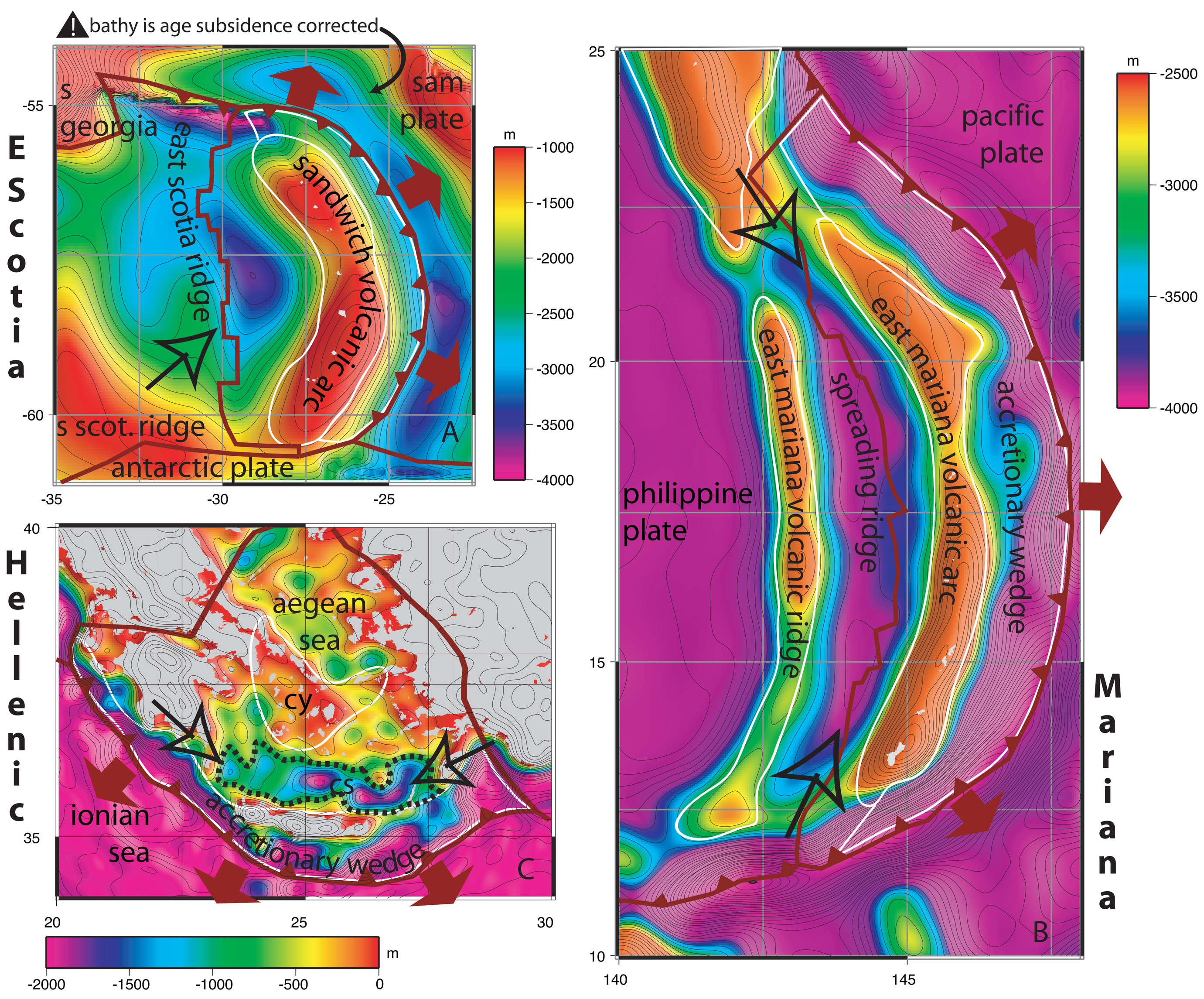
Dynamic topography above retreating slabs : Bathymetry, Theory, Tomography, Gravity

or : Why Guam should be bigger than Sicily !

Laurent Husson, MIT (lhusson@mit.edu)



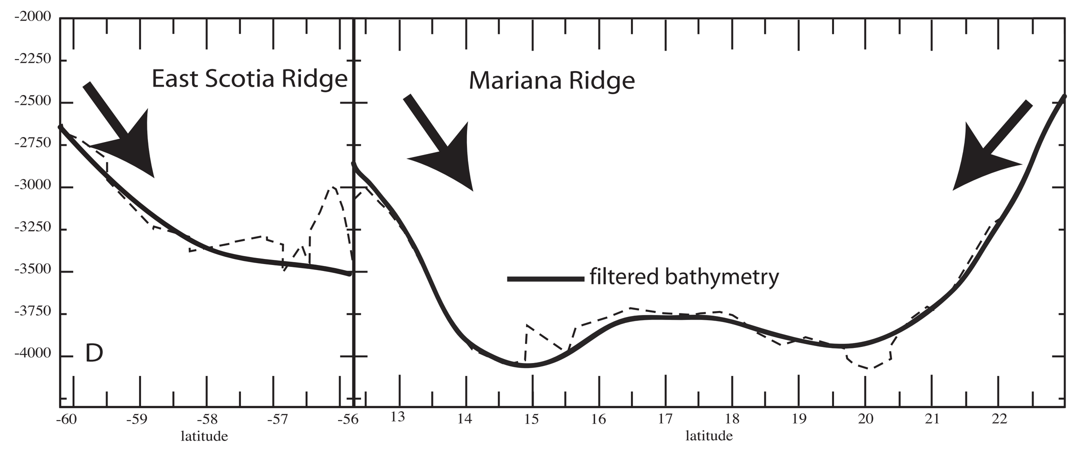
1) Bathymetry

Is there a systematic morphology above narrow retreating subductions and should there be ? A close look at the rare good candidates (East Scotia Sea (A), Mariana (B), Hellenic (C)) show :

i) an obvious arcuate shape, sometimes referred to as the “ping-pong ball” effect.

ii) a not-so-obvious non-isostatic depression next to the trench, across-strike, but also along-strike. For the 2 back-arcs (Scotia Sea and Mariana) the bathymetry of the ridges outlines it, since it should be constant for uniform mineralogy + temperature. The Cretan Sea *(cs)*, to the South of the Aegean Sea, is deep but the crust is rather thick; thus it has to be non isostically compensated. The bathymetry of all 3 areas is, however, complicated by the presence of continental units, island arcs ...

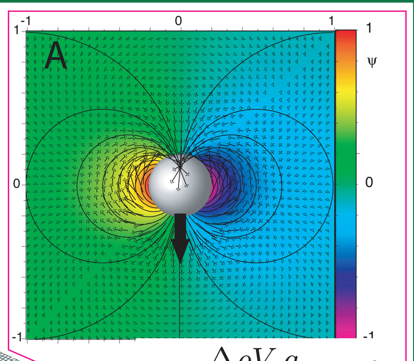
Mantle flow deforms the subducting slabs to give them their arcuate shape (i). Could it be responsible for the vertical deflection of the seafloor (ii) as well ?



2) Theory

A convenient way to evaluate the mantle flow is to discretize the density field into elementary spheres for which the Stokes stream function Ψ is known (A). These Stokeslets can be summed up linearly to give the overall flow. The drawback is that the viscosity is assumed to be uniform. This flow induces a vertical stress σ_{zz} (independent from the viscosity) normal to the surface :

$$\sigma_{zz} = \sum_i \frac{3\Delta\rho V\, g z^3}{\pi r^5}$$



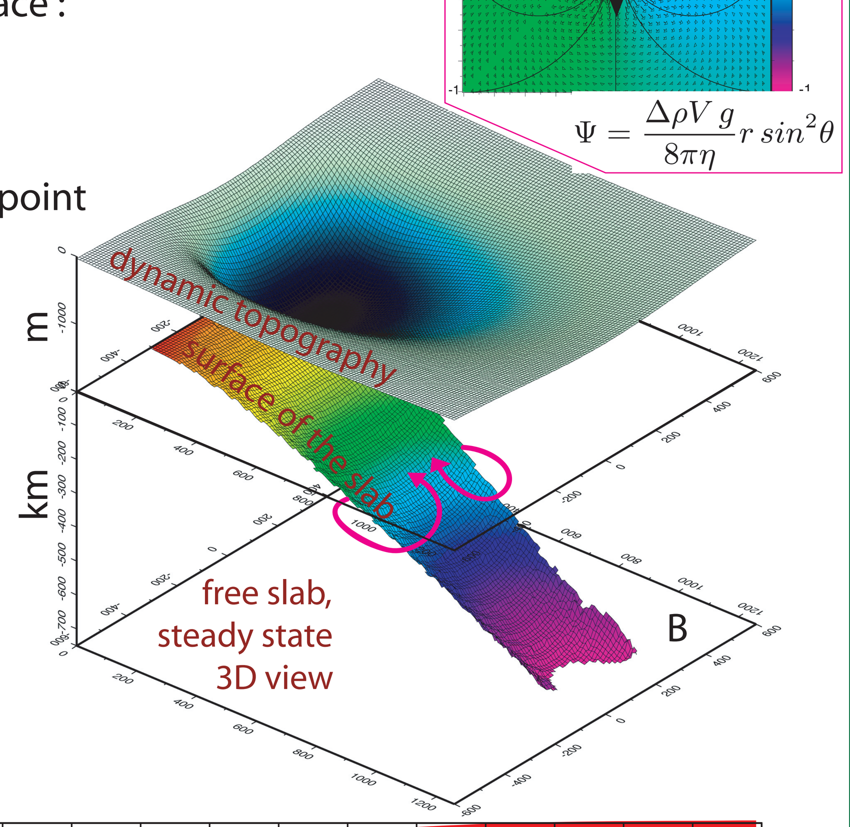
$$\Psi = \frac{\Delta\rho V\, g}{8\pi\eta} r \sin^2\theta$$

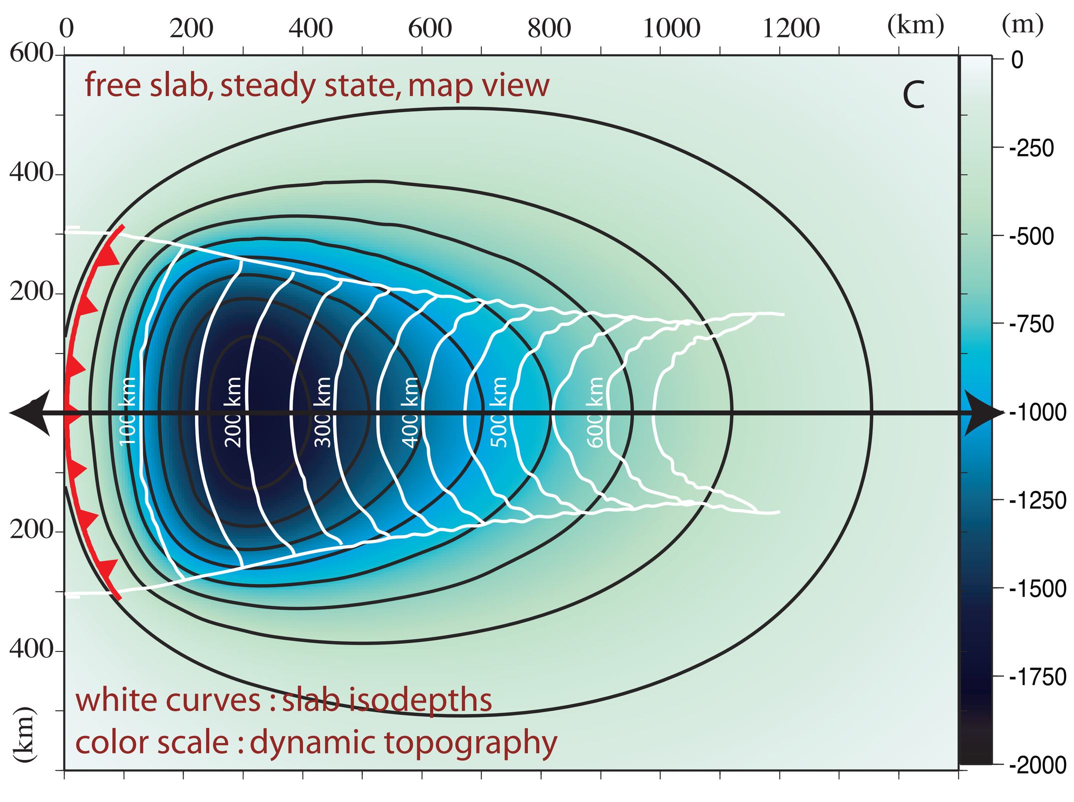
where $\Delta\rho V$ is the mass heterogeneity, z the depth and r the distance from the point of observation at surface level and the elementary sphere i. This vertical stress can be balanced by a surface deflection h :

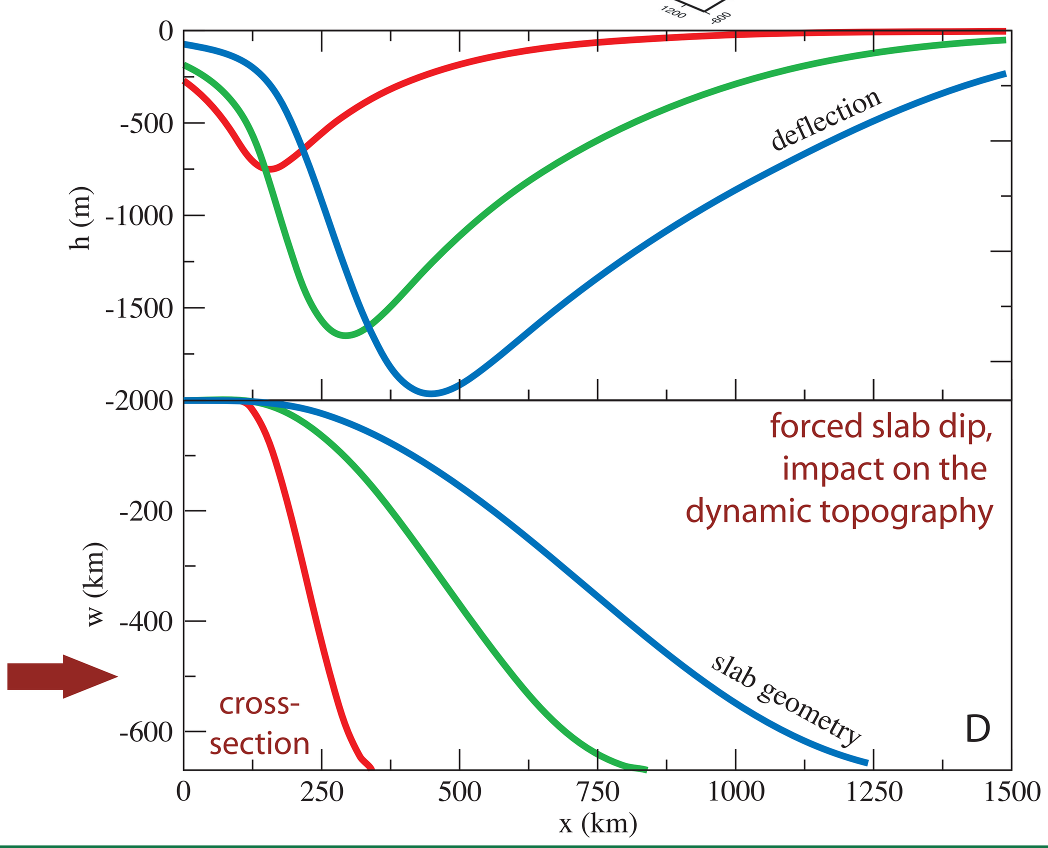
$$h = \frac{\sigma_{zz}}{g(\rho_m - \rho_w)}$$

$\rho_m - \rho_w$ is the density contrast between mantle and seawater.

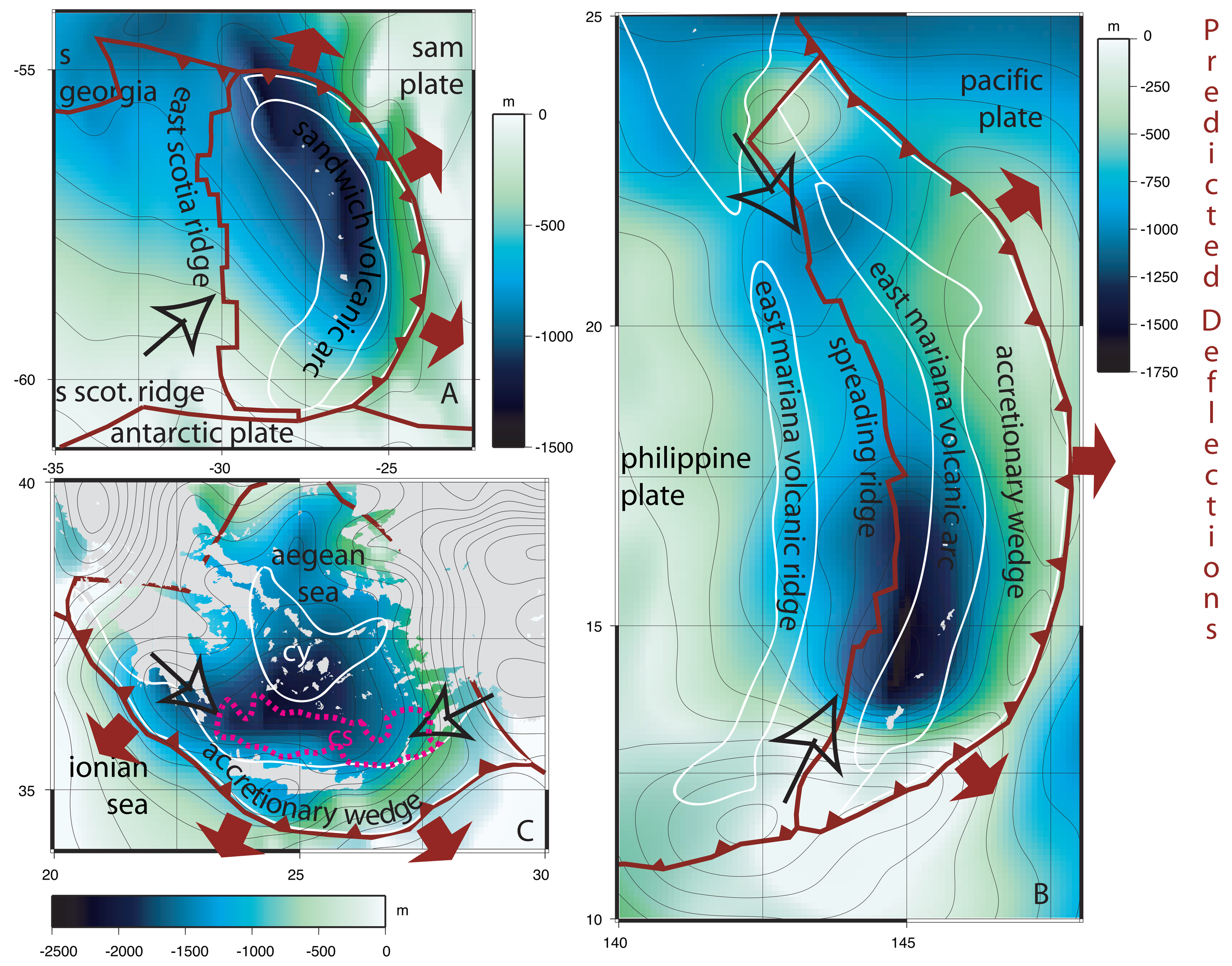
This technique allows the modeling of slab subduction, including the formation of the arcuate shape of the slab and the dynamic topography induced above it (B). For a 100 km thick slab, with $\Delta\rho$=50 kg m^{-3}, a 750 to 2000 m deep basin forms on the overriding plate (C), with a maximum depth located from 200 to 400 km from the trench, depending on the slab dip (D).

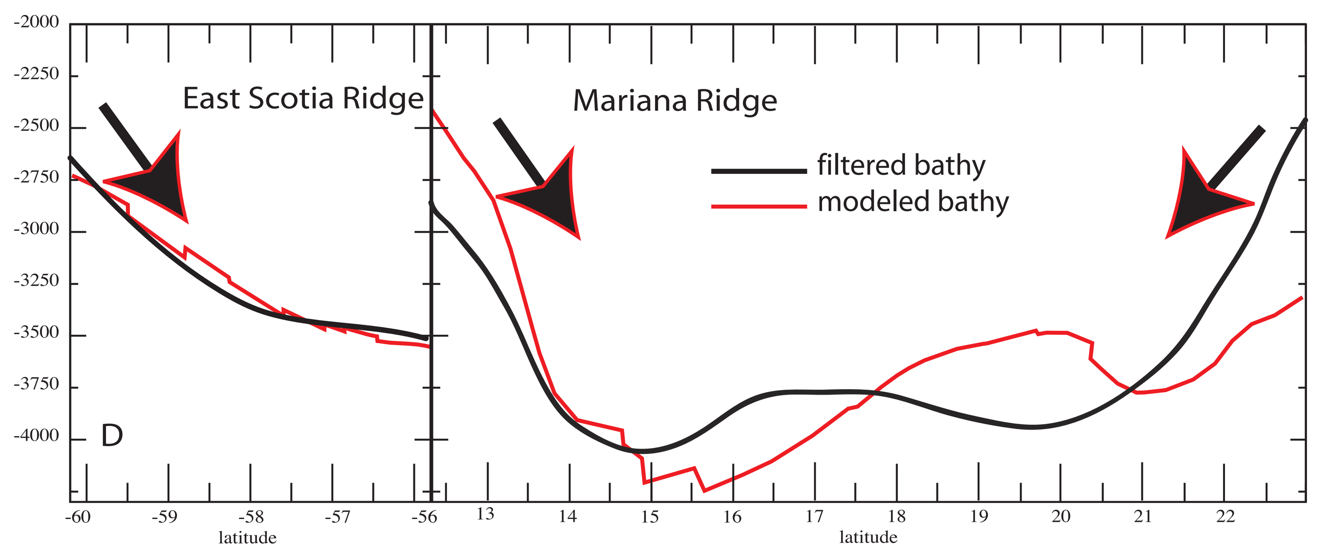






3) Tomography





Seismic tomography data can be converted on first order approximation into elementary masses of density heterogenity $\Delta\rho$: $\Delta\rho = \Delta V_P \boxed{\frac{\partial\rho}{\partial\Delta V_P}}$?

The conversion of tomographic data (Van der Hilst’s group data) into mass anomalies and their introduction into a Stokeslets flow model allow to calculate a dynamic topography (A, B, and C). The conversion factor $\frac{\partial\rho}{\partial\Delta V_P}$ can be retreived from the deflection of the East Scotia Sea and Mariana ridges if entirely dynamic. A very reasonable fit (D) is found with 18 kg m^{-3} / %.

For all 3 subductions, well defined non-isostatic basins are predicted, surrounded by their arcuate trenches. Their magnitudes and locations correspond to those of the theoretical models and also match the bathymetry of selected areas of the upper plates:

i) the East Scotia seafloor is tilted to the NE,

ii) the ridge of the Mariana back-arc is depressed in its center, and

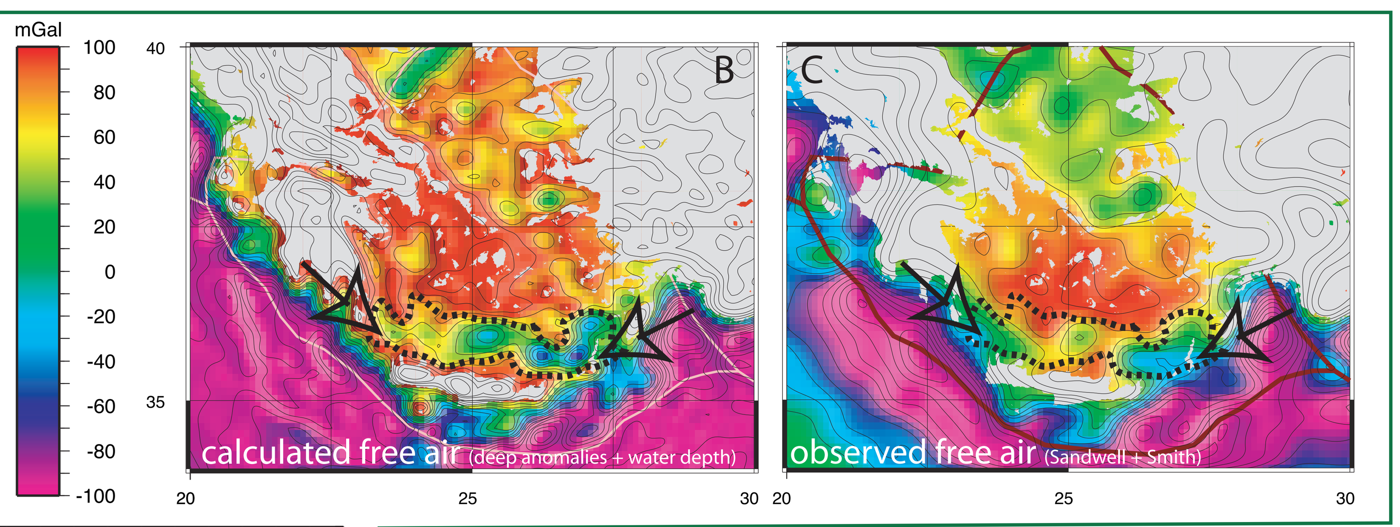
iii) the Cretan Sea trough matches the predicted deflection of the Aegean Sea.

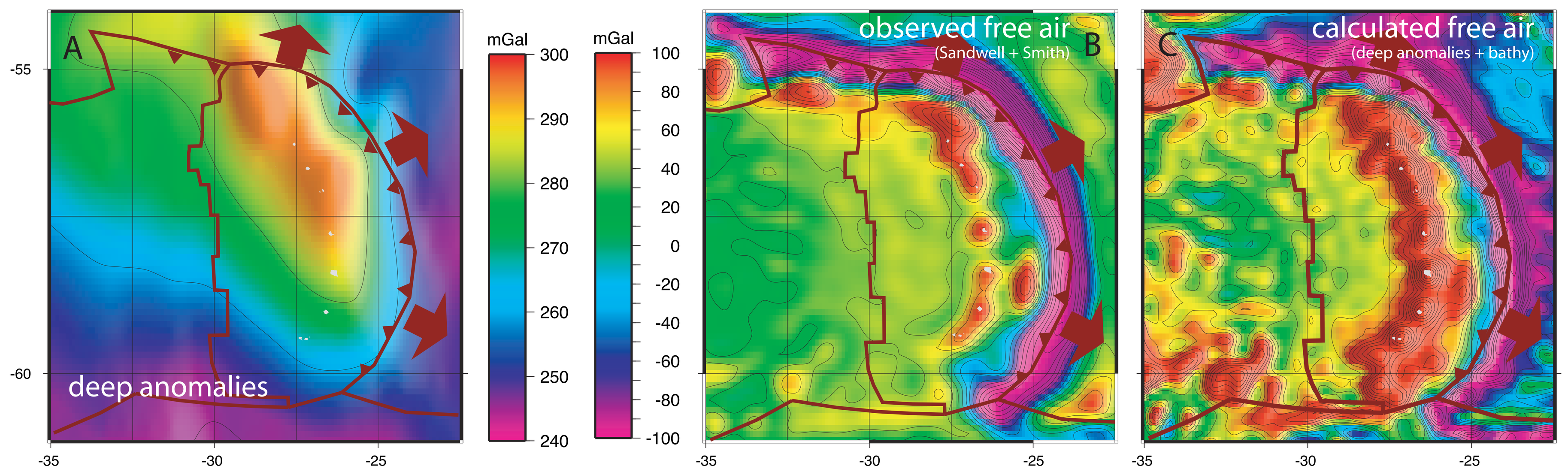
4) Gravity

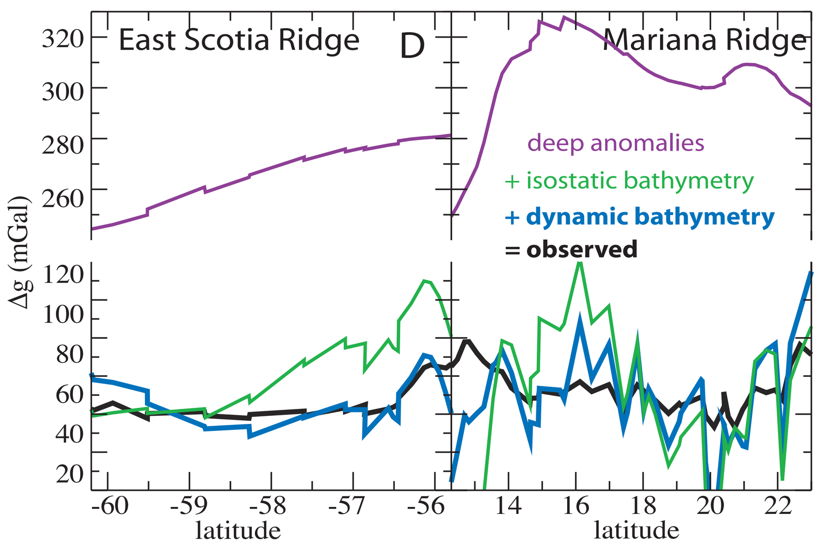
The gravity anomaly deduced from seismic tomography at depth (A) is highly positive (250-300 mGal) and increases toward the center of the basin by more than 50 mGal, while the observed free air anomaly (B) is moderately positive in the basin (50-100 mGal) and decreases towards the center. Thus the water depth is at least partly a dynamic feature which produces a negative anomaly that balances that of the deep masses (C) :

$g_F = g_{deep} + h\,(\rho_w - \rho_c)$, where g_F is the free air gravity, g_{deep} is the gravity signal due to the masses at depth, h is water depth.

The good fit (B/C and D) between observed (B) and predicted (C) is an additional evidence of the dynamic component of the topography. The anti-correlation between free air gravity and the gravity anomaly of the deep heterogeneitites is due to the substraction of the short wavelength dynamic component (varies like $\Sigma_i z_i^3/r_i^5$) to the long wavelength deep signal (varies like $\Sigma_i z_i/r_i^3$) .







5) Conclusions

- Bathymetry above retreating subductions is dynamically deflected by ~2000 m downwards. Critical parameters are density contrasts and slab dip.

... otherwise, the Aegean sea would not be a sea, the Sanwich islands and Guam would be bigger than Sicily !

- Geophysical evidence (seismic tomography + gravity) confirm that dynamic processes explain :

i) the deflection of the E. Scotia Sea and Mariana ridges. No chemical variations are required.

ii) the existence of the non-isostatic Cretan Sea trough. No crustal thinning is required.

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