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Inversion of gravity anomalies over spreading oceanic ridges

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Abstract

Models of spreading ocean ridges are derived by Bayesian gravity inversion with geophysical and geodynamic a priori information. The aim is to investigate the influence of spreading rate, plate dynamics and tectonic framework on crust and upper mantle structure by comparing the Mid Atlantic Ridge (MAR), the Indian Ocean Ridge (IND) and the East Pacific Rise (PAC). They differ in mean spreading rate, dynamic settings, as attached slabs, and plume interaction. Topography or bathymetry, gravity, isostasy, seismology and geology, etc. are averaged along the ridges and guide the construction of initial 2D models, including features as mean plumes, i.e. averaged along the ridge. This is a gross simplification, and the results are considered preliminary.

Three model types are tested: (a) the temperature anomaly; (b) asthenospheric rise into thickening lithosphere; (c) a crustal root as had been anticipated before seafloor spreading was discovered. Additional model components are a mean plume, a non-compensated ridge uplift, an under-compensated asthenospheric rise, e.g. of partially molten material, and seismic velocity models for P and S waves. Model type (c), tends to permute to model type (b) from thick crust to thin axial lithosphere. Model type (a) renders 'realistic' values of the thermal expansivity, but is insufficient to fit the gravity data; partial melt may disturb the simple temperature effect. A combination of (a) and (b) is most adequate. Exclusive seismic velocity models of S or P waves do not lead to acceptable densities nor to adequate gravity fitting. The different ridges exhibit significant differences in the best models: ATL and IND show an axial mass excess fostering enhanced ridge push, and ATL, in addition, suggests a mean plume input, while PAC shows an axial mass deficit reducing ridge push, most probably due to dominance of slab pull in the force balance.

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Goodness of the gravity fit alone is no justifiable criterion for goodness of model, indeed minor modifications to each model within the uncertainties of the assumptions can make the fit arbitrarily good. Goodness of model is quantified exclusively by a priori information.

Keywords: Gravity; Inversion; Active ridges; Dynamics

1. Introduction

This paper presents different models of spreading ocean ridges with the aid of gravity inversion. Gravity as such is an ambiguous tool, but with sufficient a priori information good and bad models can be distinguished. Although plate divergence is a simple plate tectonic process, the deep structure and the influence of spreading rate, dynamics and tectonic framework are not well understood. From what depth does hot partially melting material rise? What is the influence of mantle heterogeneity and especially of plumes? Gravity inversion with a priori information is applied to mean Bouguer anomalies over the Mid Atlantic Ridge (MAR), the Indian Ocean Ridge (IND) and the East Pacific Rise (PAC). Topography or bathymetry is closely linked with gravity, e.g. via the Bouguer reduction, and is, of course, included in the analysis.

The a priori models tested are of three types: (a) anomalous temperature of cooling plates rendering the effective thermal expansivity; (b) asthenospheric rise into lithosphere thickening with age; (c) for a test, a crustal root, as had been anticipated before seafloor spreading was discovered. Optional model components are a mean plume, a non-compensated (or non-isostatic) ridge uplift, an asthenospheric rise, e.g. of partially molten material, and seismic velocity models for P and S waves. Inclusion or exclusion of the optional model components are varied systematically.

Hypotheses, to be tested include influences of spreading rate, plate dynamics and tectonic framework on crust and upper mantle structure. This is investigated by comparing the Mid Atlantic Ridge (MAR), the Indian Ocean Ridge (IND) and the East Pacific Rise (PAC) which differ in mean spreading rates and in dynamic settings, e.g. with plates that are, or are not, pulled by subduction. The depth from which hot partially melting material rises may vary. The influence of mantle heterogeneity and especially of plumes will affect ridge density structure.

Information on gravity is inseparable from topography or bathymetry belonging also to the a priori information. Important additional a priori information comes from seismology, thermal observations, geology, and models of plumes and isostasy, etc. These permit the construction of two-dimensional initial geometrical models, which can be tested, modified and optimized by Bayesian gravity inversion, applied to mean Bouguer anomalies over the mean ridges, with the aim of finding out whether these models can be fitted to the gravity anomalies in any "reasonable" way at all.

The results should be taken as preliminary first-order indications. Averaging includes such imaginary features as mean plumes, smeared out e.g. along the Mid-Atlantic ridge. More detailed studies of regionally restricted models are necessary in the future.

2. Data

The global spherical harmonic gravity field solutions by Rapp (1977) and GRIM3 (Reigber et al., 1982) are used as gravity basis. They are complete to degree and order 52 (RAPP) and 36 (GRIM3). Stacking results of two 1984 diploma theses (Fischer, 1984; Vesper, 1984) are taken for a quick preliminary