

EUG XI



Symposium OS11

Solid Earth Geophysics

Convenor

A.P. van den Berg

OS11

Solid Earth Geophysics

Wednesday PO Session

OS11 : WEpo01 : PO Inferring Crustal Structure and Composition from Heat-Flow Pattern: Experience from the Variscan Erzgebirge, Germany

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Surface heat flow (q) in the Erzgebirge was determined to range from 61 to 112 mW/m². The regional heat-flow pattern is controlled to first order by compositional heterogeneities in the uppermost crust. Zones of high heat flow coincide with the distribution of the Variscan granites emplaced in metamorphic basement rocks. Typically, these granites display high heat production (A), usually between 4 and 10 μ W/m³, depending on chemical type, degree of fractionation, and intensity of alteration.

Heat-budget calculations, considering crustal models derived from seismic and gravimetric surveys, define the thickness (D) of crust enriched in radioactive elements to 15 km, the rate of reduced heat flow (q^*) to 30-34 mW/m², and the mantle heat flow to 20-30 mW/m². These data are in contradiction to what is implied from the constructed q - A plots, which usually form a basic source for crustal models. Although the q values were corrected for lateral or vertical heat-flow disturbance, neither the thickness of crust enriched in radioactive elements nor the rate of reduced heat flow (usually associated with the lower crust or upper mantle) is correctly portrayed in these plots. In fact, D (5-8 km) and q^* (45-52 mW/m²) obtained from the q - A relation represent exclusively the thickness and the heat flow at the base of the uppermost and most enriched part of the crust, which here is the granite layer.

Thus for a crust strongly heterogeneous in upper-crustal heat production, inferences from q - A plots about the structure and composition of the crust as well as the heat flow through the Moho are suspect and must be viewed with caution. In this situation, traditional interpretation of these plots significantly overestimates the amount of mantle heat flow and underestimates (by 30-50% in the Erzgebirge) the thickness of the crust enriched in radiogenic elements. It is concluded that the q - A plot provides reasonable results only in the situation that the heat production of granites and their country rocks are similar. Consequently, the unexpectedly high mantle heat flow and low thickness of enriched crust reported for several tectonothermal stable provinces in the world may be related to these shortcomings of the q - A plot. In conclusion, to minimize chances for incorrect interpretation of q^* and D values, q - A plot construction should be performed routinely in concert with heat-budget calculations. This requires that principal information on both the structure and composition of the crustal segment is available from geophysical and geochemical data.

OS11 : WEpo02 : PO Paleomagnetic Signatures of the Late Cretaceous Igneous Massifs of Sines and Monchique (Portugal)

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A paleomagnetic study has been carried out at eight sites in Late Cretaceous igneous massifs of Monchique and Sines (Portugal). The studied massifs have been related to a postulated deep-seated NNW-SSE trending fault, the Sintra-Sines-Monchique fault. Samples were collected from syenites of the Monchique massif and gabbros and diorite rocks from Sines massif. This study is based on 58 useful oriented samples. In the beginning some samples were demagnetized by thermal and alternating field methods. However, AF demagnetization has proved to be the best one to individualize magnetic components. Two components were identified from the collected sample set: one with a low coercivity or low blocking temperature and easily removed until 20 mT or 400 °C; the other, a higher-coercivity component, that has been considered as the characteristic remanent magnetization of these rocks. The characteristic components were evaluated by least squares fitting of linear segments to orthogonal vector plots during progressive demagnetization. The mean directions from Monchique were included in two different groups: one with $dec/inc = 209.4^\circ/-37^\circ$ values ($\alpha_{95}=4.2^\circ$, $K = 57.7$, $N = 23$) and a second one with $dec/inc = 185.8^\circ/-39.4^\circ$ values, (α_{95}

$= 7.1^\circ$, $K = 24.9$, $N = 18$). Previous works have also discussed paleomagnetic results from Monchique igneous rocks and the directions are: $dec/inc. = 182^\circ/-37^\circ$ (Van der Voo, 1969), $dec/inc. = 181^\circ/-42^\circ$ (Storetvedt et al., 1990) and $dec/inc. = 174^\circ/-40.6^\circ$ (Gomes et al., 1992). However these directions are from sites geographically near to the second group presented here. The differences essentially associated to declination values may be explained by tectonic regional events: the different groups are separated by a regional important fault (Portimão-Monchique fault). However aspects like: record of variations of the magnetic field ("excursions"), processes and structural control of emplacement of the massifs, and a possible existence of different absolute ages units, must be considered. The mean direction obtained from Sines is $dec/inc. = 17.4^\circ/39.2^\circ$ ($\alpha_{95} = 2.9^\circ$, $K = 153.5$, $N = 17$) and is interpreted as an intermediate value of the two groups deduced from Monchique samples.

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Storetvedt KM, Mitchell JG, Abranches MC & Oftedahl S, *Phys. Earth Planet. Int.*, 62, 109-125, (1990).
Van der Voo R, *Tectonophysics*, 7, 5-56, (1969).

OS11 : WEpo03 : PO Structure of the Lithosphere from Integrated Analysis of Geophysical and Geochemical Data. Examples from Siberia and Fennoscandia

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Mantle-derived xenoliths and xenocrysts can be used to obtain information on the thermal state and composition of the lithosphere using techniques developed by O'Reilly and Griffin (1996) and Ryan et al. (1996). These techniques provide an estimate of the paleogeotherm, which serves as a reference for determining the depth of origin of individual mineral grains (garnet, chromite) for which temperatures are determined by trace-element thermometers (Ryan et al., 1996). The depth to the base of the chemically defined lithosphere is determined by the change from depleted (lithospheric) to undepleted (asthenospheric) trace-element signatures in garnet (Griffin and Ryan, 1995). For the geophysical analysis, we use a method based on the wavelength relationship between gravity and topography data (Forsyth, 1985; Poudjom Djomani et al., 1995) to estimate the flexural rigidity (D) of the lithosphere, or equivalently its effective elastic thickness (Te). This technique is used to map major lithospheric domains with different geophysical properties.

On the Eastern Siberian platform, mantle sections constructed from the analysis of garnet and chromite concentrates reveal that the Archean terranes are underlain by typical depleted Archean lithosphere > 200 km thick, while the Proterozoic terranes are underlain by thinner and less depleted lithosphere. The estimation of the Te of the lithosphere refines these lithospheric boundaries, and reveals a major zone, ~ 150 km wide, of very weak lithosphere ($Te < 10$ km) running N-S across the western part of the craton. This zone coincides with thicker lithosphere, lower surface heat flow and thicker lower crust, as well as abnormally high sub-Moho P-wave velocities suggesting an anisotropy in the upper mantle. The kimberlite fields in the Archean part of the platform are localised on the western flank of this zone of weak lithosphere. We suggest that the low Te reflects a mantle shear zone which has been a preferred conduit for fluids (eg magmas) into the lower crust, and has controlled the location of kimberlite emplacement in the study area.

In Fennoscandia, the geophysical analysis shows a regional variation in elastic plate thickness from 8 km in relatively 'young' areas, to 70 km in 'older' areas. These results suggest that the lithosphere is strongest in the relatively stable Archean Province, weaker in the regions characterised by Proterozoic crustal formation, and lowest in the tectonically reworked and deformed Caledonian belt. Furthermore, the results show that there is a direct correlation between lithosphere strength (Te), the age of the last major tectonothermal event registered in the crust and lithospheric mantle composition. These broad correlations reflect thinner and more fertile lithosphere, and higher geothermal gradients, beneath regions of progressively younger crust.

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Poudjom Djomani YH, Nnange JM, Diamant M, Ebinger CJ & Fairhead JD, *J. Geophys. Res.*, 100, 22,047-22,070, (1995).

OS11 : WEpo04 : PO On the Evolution of the Martian Mantle: Results from Numerical Models of Mantle Convection Including Differentiation and Variable Thermal Conductivity

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Planet Mars shows evidence of widespread partial melting originating from mantle peridotite in hot diapiric upwellings. Conditions for partial melting on Mars are different from those on Earth due to its smaller size and hence reduced pressure compared to Earth. Such melting processes produce a thick layer of immobile harzburgitic material on top of a convecting mantle, forming an insulating outer shell, which is gravitationally stable over long periods in the order of several Ga.

We have studied the influence of a harzburgitic layer on the thermal evolution of Mars with a numerical two-dimensional finite-element model of whole mantle convection including the effect of partial melting, described by a variable degree of depletion. The variable degree of depletion resulting from partial melting is modeled by a particle tracer method thereby avoiding strong artificial chemical diffusion typical for Eulerian approaches.

The results show the rapid formation of an approximately 500 km thick harzburgitic layer and a substantial reduction of the surface heat flow by approximately 20%, compared to an evolution model without differentiation. Differences in the average mantle temperature of several hundred degrees are found between the models.

Therefore, thermo-chemical convection including pressure release partial melting is an important factor in the thermal evolution of terrestrial planets.

We have considered the role played by variable thermal conductivity, which for the Martian mantle is dominated by its temperature-dependence. The tendency of temperature-dependent conductivity under Martian mantle conditions would be to decrease with higher temperatures. Such a combination would lead to a positive feedback situation for increasing the interior temperature and decreasing drastically the rate of cooling of the Martian interior. The consequence of temperature-dependent thermal conductivity is to maintain the vigor of Martian convection much longer than for constant conductivity models and to fuel longer the surface volcanic activities, as imaged by the recent Martian Orbiter mission.

OS11 : WEpo05 : PO Sensitivity of Mantle Convection Models for Thermodynamic Parameterization

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We have investigated the influence of consistent thermodynamical formulations based on different thermodynamic databases in numerical models of mantle convection. Usually mantle convection models are based on simplified formulations of the thermodynamic parameters using either constant values or depth dependent properties independent of temperature. In these approximations discontinuities in the parameters across phase boundaries are ignored. In a seminal paper Ita and King (1994) have shown the importance of using a more consistent thermodynamical formulation in mantle convection models. Here we present first results of mantle convection modelling using a formulation based on a new equation of state (Jacobs and Onk, 2000)

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and recent thermodynamic data for the MgO, FeO, SiO₂ ternary system (Jacobs et al., 2000). We also make use of earlier thermodynamic data of Fei et al. (1991) as a reference and to investigate the sensitivity of mantle convection results to the underlying thermodynamic database. The mantle convection code uses a primitive variable finite element method for the momentum equation in the anelastic liquid approximation using quadratic elements for the velocity field and first order elements for the energy equation.

Jacobs MHG & Oonk HAJ, *Phys. Chem. Phys.*, **2**, 2641-2646, (2000).

Jacobs MHG, Oonk HAJ & de Jong BHWS, *in preparation*

OS11 : WEpo06 : PO Delayed Cooling of the Earth-Consequence of Temperature-Dependent Thermal Conductivity

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The issue of cooling of the Earth by mantle convection has traditionally been assessed with constant thermal conductivity model. Yet it is well known that mantle thermal conductivity has both a temperature and pressure-dependence and has been quantified recently by a solid-state model by Hofmeister (1999). The behavior of such a thermal conductivity with temperature is similar to that of viscosity. The higher the temperature, the lower is the conductivity. Such a dependence together with internal heating due to radioactivity would provide a scenario for positive feedback in an analogous manner to global warming by increase of CO₂, which acts also to trap the internal heat. We have studied the systematic delay in earth cooling by the combined effects of variable thermal conductivity and time-dependent heating by radioactive mantle sources. A decay time of 2.5 Gyr has been taken for the mantle radioactivity and we have varied the initial amount of radioactive heating from chondritic value to 4 times the chondritic value. An adiabatic boundary condition has been assumed at the core-mantle boundary and the mantle viscosity is assumed to be constant, with the thermal conductivity containing the sole temperature-and pressure dependence. A significant delay in the cooling process of at least 1 to 2 Gyr is found for a surface Rayleigh number of between 5×10^6 to 10^7 . The mantle temperature can be heated up by 300 to 400 degrees for initial heating value characteristic of the Archean. We find the strongest deviations from the constant conductivity case for a silicate model by Hofmeister (1999) and intermediate values for an enhanced radiative conductivity model comparable to the model of Shankland (1979). Such high mantle temperatures maintained for a long time by variable thermal conductivity would have important consequences on mantle thermal evolution, such as enhanced tendency to some layering in the early epochs and possibly cataclysmic overturn events caused by a superheated lower mantle, kept deliberately warm by this feedback between internal heating and variable thermal conductivity.

OS11 : WEpo07 : PO Results of the Seismic Tomographic Simulation on a Profile Cape 'Tolstik- Khibiny'

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The ray seismic tomography on travel times enables to retrieve the velocity performances of environment. With this purpose tomographic simulation is applied for obtain the a velocity model along a profile Cape "Tolstik-Khibiny" Sources of seismic rays are the special seismic shots and industrial shots of operating ore mines. The distances between reception points and shot points are equally to the first kilometers up to 170-180 kilometers, and the average distance are equally 73 kilometers. The preliminary analysis of the data is made, which includes the statistical analysis, the reduction of times rays of arrival. The rays are connected with exceeding of Khibiny. The greatest concern from the calculated statistical characteristics represents the standard deviation, the defining criterion of stop in the iterative process. This process lies in the base of the seismic tomographic simulation. The prior

data about velocity distribution is used as a fundamentals for the choice of the initial approximation .It is approximated by the specific class of the functions and is used further for the solution of the direct problem. The solution of the direct task defines the reliability of the selected initial model. The class of the approximating functions were used at the choice: 1. Linear functions 2. Exponential functions The solution of the seismic tomographic task is carried out on the basis of the program FIRSTOMO (Ditmar, Roslov). The calculation of the direct problem is made by a method. Decision of the inverse problem by the made of method of search of the most equal solution Two miscellaneous grids were used at the solution of the 2D-velocity model: 50×11 (4.009 kms x 2.054 kms) 150×30 (1.319 kms x 0.7083 kms) The obtained results are step functions and smooth functions as velocity layers. The area of blank is a cell, in which rays are absent. Apart from 2D velocity models on P_v, S_v waves, values of the velocity parameter $K = V_p / V_s$ and Poisson's coefficient are calculated. Reliability of results of the seismic tomographic processing was evaluated, and calculation of an error was conducted also.

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