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The effect of variable viscosity in the Earth's mantle on the stress field of the mantle and an overlying continent, moving self-consistently due to mantle flow

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In numerical two-dimensional experiments we investigate the spatial field of stresses in the mantle and continent and its evolution. A continent moves self-consistently with changing mantle flows. Velocity of a continent in the process of movement varies in accordance with time-dependent forces which act from underlying viscous mantle as well as with mantle forces acting on the end faces of continent. This model is described in [Bobrov, Trubitsyn, 2008]. Continent viscosity is equal to 1e5 with respect to average viscosity of the mantle. For convection modeling we used Citcom code with high Rayleigh numbers, strong viscosity variations and active markers for simulating continent [Moresi, Gurnis, 1996]. We consider three model laws for viscosity: isoviscous mantle case; *P*,*T*-dependent viscosity case and viscosity=*f*(*P*, *T*, stress_ invariant). For these three models we analyze how a form of viscosity.

law can change stress fields in the mantle and continent. We research what model law gives the results more close to actual data. The horizontal stress field in moving continent greatly depends on variations of horizontal velocity in the underlying mantle, and also on continent position between the ascending and descending mantle streams. Sub-continental upwelling mantle flows have the extensive effect; sub-continental downwelling ones- the compressive effect. Mantle plumes near continent's borders demonstrate compressive effect on continent, downwelling flows produce its extension. If the horizontal stresses are presented in dimensionless form then our cases show rather big but not principal differences. Thus, the mantle model with constant viscosity can be regarded as qualitatively representative. However, after transition to dimensional parameters it appears, that in isoviscous mantle model stresses values bigger in several times, than in the cases of variable viscosity. In this case isoviscous mantle model leads to strongly overestimated stresses and is not representative in this aspect. Mantle model with variable viscosity has typical horizontal stress values in the major portion of mantle — (2÷6) MPa; in continent at different stages of its movement — (2÷15) MPa.

It should be noted that all examined models should give approximately equal Nusselt number (i. e., should have the same efficiency of bearing-out of heat, as surface heat flow is the observational value). For this reason, the values of the adopted Rayleigh number Ra, in all computations, were different.

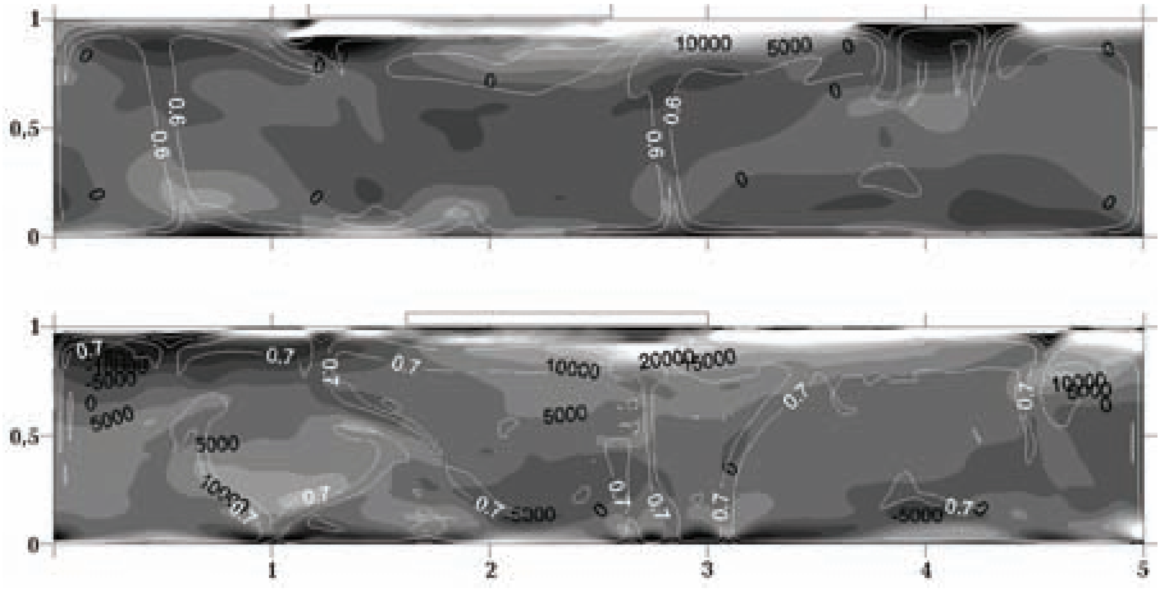
Figure presents a comparison of temperature and stress fields for the isoviscous mantle case and for the variable viscosity case. All values are given in dimensionless form. This comparison allows identification of a number of interesting effects.

Results. The models in this work are simplified in several aspects. However our purpose was to reveal only the main features and patterns of the process of mantle flow in the presence of floating continental material. From the numerical results, the following conclusions can be derived.

1. The distribution of horizontal stress in a moving continent over a viscous mantle greatly depends

on the spatial variations of mantle velocities in the subcontinental mantle and also on continent position between the ascending and descending mantle streams at the given moment. Subcontinental upgoing currents have an extensive effect on the continent, while subcontinental downgoing ones a compressive effect. On the contrary, suboceanic upgoing mantle plumes near continent's borders result in compressive actions on the continent, while downwellings result in its extension.

2. If the horizontal stresses are expressed in non-dimensional units for the three cases considered here (constant and variable viscosity), they show considerable, but not fundamental differences (Figure). It should be noted that the stress values in the case of variable viscosity are higher.



Dimensionless horizontal stress fields $\sigma_{xx}(x, z)$ for isoviscous model (upper panel) and P,T-dependent viscosity model (lower panel). Light grey depicts positive values, dark grey — negative values. The stresses $\sigma_{xx}(x, z)$ are determined by the relation $\sigma_{xx}(x,z) = p(x, z) - 2\partial v_x(x, z)/\partial x$, i. e., compressive stresses are considered to be positive. White isolines show the non-dimensional temperature field. The position of the continent is shown with a rectangle on the upper surface.

3. Transition to dimensional stresses (that is, to the stresses measured in MPa or bars) shows that for the isoviscous model the stress values are significantly higher than in the case of variable viscosity. This arises from the imposed condition of equality of the surface heat flow in both models. If we would not equalize the models by heat flow, but simply calculate them using the same Rayleigh number — that is, with the same intensity of convection — then we wouldn't have such significant difference. However, the difference in Rayleigh number values (namely, for account of increasing of viscosity in isoviscous model) leads to a difference of dimensional stresses. As a result, the isoviscous mantle model leads to overestimated dimensional stresses. This model, however, is necessary for comparison, as it allows to evaluate the effect of the variable viscosity on the final results.

4. For the considered model of variable mantle viscosity the following typical horizontal stress values are found: for the largest part of the mantle values between 2 to 5 MPa (that is 20—50 bars); in continent at different stages of its movement and in different areas 2—10 MPa, depending on the impact of the mantle these stresses may be compressive or tensile.

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