Influence of melt weakening in plume-lithosphere interaction

Magmatic weakening in plume-lithosphere interaction: insights from numerical modelin

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In Short

- Numerical modeling of plume-lithosphere interaction
- Investigation of influence of melt weakening on the lithospheric strength
- Study of different responses to plume-lithosphere interaction

The earth mantle rocks, starting from depth of 8km-70km and extending until core-mantle boundary (at 2900 km depth), are solid materials, which can flow and convect in interior of the Earth. Convecting system evolves to an adiabatic temperature profile in the mantle in which rocks may melt and rise towards the surface. This happens usually below oceanic islands or at plate boundaries like mid-oceanic ridges or subduction zones. There are three mechanisms for melt generation, that are: a) increasing of the temperature, b) decreasing of pressure and c) addition of volatiles. All rocks have a specific melting point. If heat is brought upward by convecting rocks this results in increasing of rockÕs temperature, which may reach the melting point leading to the mantle melting. Since in the mantle the temperature gradient is mainly adiabatic, indicating no transformation of heat by convection, melt induced by temperature increase is not a common mechanism in the mantle. Melting of mantle rocks due to pressure decrease, known also as decompression melting, is the most common mechanism of melt generation in mid-oceanic ridges and upwelling mantle plumes. Adiabatic rising of mantle rocks with no conductive heat loss leads to decrease of pressure, which promotes melting. The last way of melt generation is the reduction of melting point due to the addition of volatiles like water into the mantle. The common example of this kind of melting is melt generation in subduction zones, where dehydration of down-going slabs results in adding of water into mantle, causing mantle melting at lower temperature.

When melt is produced since it is less dense than the surrounding rocks it moves upwards faster than the rest of the upwelling mantle. The extracted melt is crystallized at shallow depths and built oceanic crust. The extraction of melt and its migration toward surface weakens the lithosphere. The mechanisms of melt migration and magmatic weakening is among one of debating issues in geosciences. Different melt weakening scenarios have been proposed in previous numerical modeling studies. [1] assumed that melt weakening only occurs in the partially molten asthenosphere. He argued that the overlying lithosphere is only affected indirectly by slightly increase of buoyancy forces. Some scientists (e.g., [2]; [3]; [4]; [5]) claimed that the lithosphere above the melting source may be weakened both thermally and mechanically by penetration of magma via dykes. The other group of authors (e.g., [6]) proposed that the main mechanism in lithospheric weakening is transformation of heat to the lithosphere by magma. According to these studies, the magmatic heating results in thinning of the lithosphere, which may eventually lead to break-up.

In our previous study, [5], we used I3ELVIS code in which the weakening effect of ascending melts is included by incorporation of a weakening factor, lambda. The melt in this method is transported upward from the source region via sharply localized zones (dykes). During melt extraction, the long-term brittle strength of rocks is decreased by lambda, which varies from 0 to 1, with 1 corresponding to no weakening and 0 to maximum weakening. Since the exact degree of melt-related weakening is unknown a wide range of lambda was explored in previous modeling studies. Using 2-D numerical hydromechanical models [4] denoted that the lambda in the areas of intense magmatism can be of the order of 0.0001-0.01. They indicated that the localized magmatic weakening of the lithosphere can lower the long-term lithospheric strength in the area of magmatism to a few MPa. Based on mechanical energy dissipation balance they showed that the long-term effective strength of the melt-weakened lithosphere is a strain-averaged rather than a time-averaged quantity whose magnitude is defined by the ratio between melt pressure and lithostatic pressure along dykes during short episodes of dyke emplacement.

One of the problem of using lambda as it is incorporated in I3ELVIS is that it leads to evenly reduction of the lithosphereÕs strength above the magmatic source dramatically - it can decrease the strength of lithosphere as low as a few MPa [4]. However, in the Earth, we expect that the weakening of the lithosphere is related to the melt flux, which is not necessarily constant in the area above the molten rocks. In this study we aim to explore the effect of simplification of lambda. We introduce a new formulation for lambda, which can present a magmatic

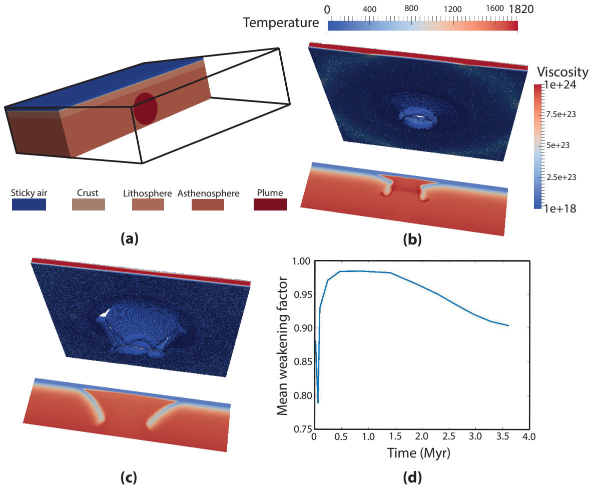

Figure 1: *(a) Initial model set-up. (b)-(c) Evolution of model. (d) Temporal evolution of lambda.In (b) and (c) the upper panel shows the viscosity structure of the lithosphere and the lower panel illustrates temperature field of a cross-section cutting through the middle of model. The color bars in (b) refer to temperature and viscosity fields in (b) and (c).*

weakening factor closer to that in the Earth. We test this new formulation by setting up a series of experiments for plume-lithosphere interaction. Comparing the results of this study with those in [5] and [4] will shed lights on better understanding of the melt weakening process on the Earth.

Figure 1 shows the model set-up (a) and model results (b-d) of our first 3-D numerical model. The model consists of a 20-km-thick sticky air layer with low density and viscosity, a 20 Myrs old oceanic lithosphere, asthenosphere and a spherical plume (Figure 1a). Figure 1b-c shows the temporal evolution of the model. Plume rises upward, penetrates into the lithosphere and forces the oceanic lithosphere to subduct. Figure 1d shows the temporal variation of the average lambda, which is not constant and changes in time and space.

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More Information

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Project Partners

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