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Modelling delamination as a process of lithosphere thinning determined by magnetotelluric measurements

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Motivation

The aim of this work is to develop a geodynamic model of our measured area in Mongolia [1] using the knowledge from our magnetotelluric model and other fields, such as geology. In this geodynamically active region, where we observe volcanism and uplift, a thin lithosphere is determined by the magnetotelluric data. One possible process for lithosphere thinning is delamination, which is coupled to convective processes.

It has been shown that features in magnetotelluric data can be linked to viscosity structures [2], and these can be investigated with geodynamic models. The combination of magnetotellurics and geodynamics is a new approach which we use to bring further insights into the geological history of Mongolia.

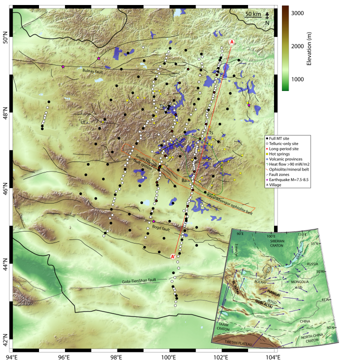

Figure 1: The map shows the study area with topography. The circles are magnetotelluric stations between the endpoints of the profile A and A'. The map also contains geodynamic features like volcanic provinces, hot springs, fault traces and ophiolite belts. The little map is a large overview of the studied area. [1]

Hypothesis

An important observation of the magnetotelluric explorations is a large low-resistivity zone that can be described with hydrous minerals [1]. These hydrated minerals are dynamically weak and have a lower viscosity, compared to unhydrated minerals.

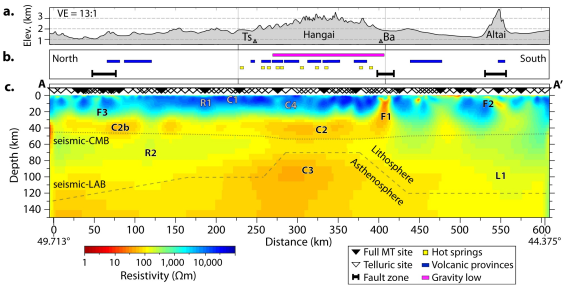

Figure 2: The resistivity model (c) from the 2-D inversion of the magnetotelluric data along the profile A-A' [1]. The elevation along the profile is illustrated in (a). The listed geodynamic features are shown in (b).

Furthermore, the magnetotelluric model shows an upwelling of the asthenosphere (region C3 in Fig. 2 c) connected to a surface uplift response (cf. Fig. 2 a). The presence of many volcanic provinces in this area suggests an increased temperature (cf. Fig. 2 b). Additionally, there is geological evidence for some dense mineral, such as eclogite, in the lower crust [3].

Model

Based on the hypothesis we created a geodynamic model. At the begin there is a layered structure (Fig. 3 a) with a dense eclogite block (red part in density field). This block and the 25 kilometres above are weaker by a factor of 100 than the surrounding material. We have a velocity influx from the right side, which corresponds to a movement from the south. This means plate movement from the Himalayas towards the Siberian Craton. The temperature distribution of our model is taken from geochemistry [4].

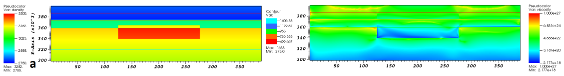

Figure 3: The initial setup of our geodynamic model. The density structure is illustrated on the left side and the viscosity structure on the right side. Additionally, in both figures the temperature contour lines are included.

The horizontal extension of the model area is chosen to match the length of the magnetotelluric profile. The height of the system is limited to the top 400 km. The viscosity and density structure comes from the magnetotelluric model and the physical parameters from other literature [5]. The velocity boundary conditions are a combination from [5] and tectonic plate motion, the Indian Plate moves against the Eurasian Plate.

The numerical thermal convection code used is ASPECT [6]. Our preliminary model approach allows us to systematically investigate the behaviour by changing physical parameters, such as block density and viscosity.

Results

The temporal evolution of the model shows the lithosphere thinning as a cause of delamination. The process starts with the whole block moving downwards and thickening (Fig. 4 b). If the block becomes gravitationally unstable, the lower part of the dense material sinks into the mantle (c-d). Finally, the whole block is removed leaving a thinned lithosphere (e). The resistivity model and these geodynamic models are comparable: both show the thinned lithosphere and a bulged asthenosphere with an elevated temperature.

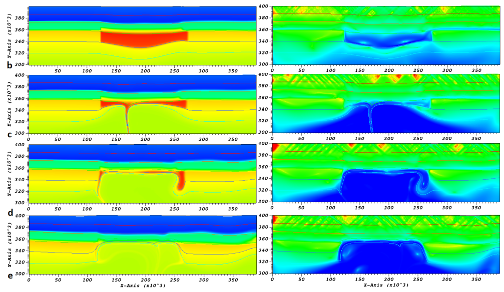

Figure 4: Temporal evolution of the top 100 km of the model, which shows the process of delamination. The density structure is illustrated on the left side and the viscosity structure on the right side. The colour bars are the same as in Fig. 3.

Topography

The topography of the two time-steps (a) and (e) are shown in figure (5). Before the delamination process we have a minimum in the topography on top of the weak crust. This area is easier to deform, so the whole lower crust moves downwards. With the thinning of the lithosphere the topography increases. After the delamination we have a high topography over the removed block because the increased temperature pushes this area upwards.

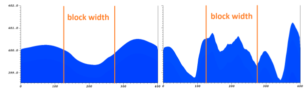

Figure 5: Modelled topography before (left) and after (right) the delamination.

Physical parameters

For the better understanding of the process we systematically varied single parameters. Two examples of these investigations are presented in figure (6), where we changed the density contrast and the viscosity of the block and determined the time delamination started and ended.

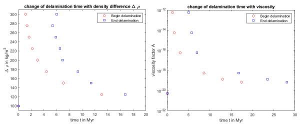

Figure 6: Variation of delamination time with respect to the density contrast (left) and viscosity (right)

If the density contrast is high the delamination starts earlier, but if the contrast is too low delamination does not occur. A critical density contrast for delamination to appear in these models is $\Delta\rho = 125\ \frac{kg}{m^3}$. If the viscosity is low, i.e. the block is weak, delamination starts earlier, but if the viscosity is high, i.e. the block is strong, delamination does not happen at all. In our model the viscosity of the block needs to be the same or weaker than the surrounding material to allow for delamination.

Summary

Setting up a geodynamic model based on results from the magnetotelluric model and geological observations we observe a thinning of the lithosphere and bulging of the asthenosphere due to delamination. The resulting surface topography resembles that found in Mongolia. An increased temperature below the crust matches the expectations for Mongolia given the volcanic setting.

Outlook

For a more realistic model, the density difference within the block should be growing with time because of a phase transition (e.g. eclogitization), rather than assuming a dense block from the beginning.

References

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