Trans-Lithospheric Diapirism as a Possible Mechanism for Ophiolite Emplacement?

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Trans-Lithospheric Diapirism as a Possible Mechanism for Ophiolite Emplacement? (EGU24-568)

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Introduction

Oceanic obduction and ophiolite emplacement represent processes that result in positioning of more dense oceanic lithosphere on top of less dense continental crust. While obduction is known to be related with the processes of oceanic closure, exact mechanisms of the permanent emplacement of ophiolites are still controversial. Moreover, this proved to be a rather difficult process to model numerically. Some notable successes were achieved in the last decade. Firstly, by utilizing reversal of convergence rate of plates [1] succeeded in permanently emplacing significant portions of obducted oceanic lithosphere. More recently [2] showed that far-traveled ophiolites can be accounted for by triggering the continental extrusion mechanism. Here we present our ongoing research on an another possible mechanism that could emplace ophiolites, namely trans-lithospheric diapirism of the subducted continental crust. We follow the the similar approach of activating the continental crust at high P-T conditions in order to sever the obducted oceanic lithosphere. However, we try to do so not by triggering continental extrusion but rather investigating if trans-lithospheric diapirism could lead to a similar result. The process of trans-lithospheric diapirism of the continental crust was recently modelled [3] in the context of continental collision and formation of European Variscides. We try to develop a similar mechanism in the context of retreating intra-oceanic subduction (Fig. 1) that reaches the continental margin and triggers continental subduction.

Methods

For the purposes of simulating the geodynamic processes in this research, we use thermo-mechanical numerical modelling. A 2D model is created and time evolution of the geodynamic system is calculated based on solution of equations governing the thermo-mechanical system. These consist of the Continuity equation, Stokes equations in x and y directions as well as the Temperature equation:

$$\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}=0 \qquad \frac{\partial \sigma'_{ii}}{\partial x_i}+\frac{\partial \sigma'_{ij}}{\partial x_j}-\frac{\partial P}{\partial x_i}=-\rho g_i \qquad \rho C_P\frac{DT}{Dt}=-\frac{\partial q_x}{\partial x}-\frac{\partial q_y}{\partial y}+H$$

where v is velocity, σ' deviatoric stress tensor, ρ density, g gravitational acceleration, T temperature, P pressure, Cp heat capacity and q heat flux, while H accounts for different heat sources; i and j represent coordinate indices. To solve these equations geodynamic numerical code I2VIS is employed [4]. The code is based on conservative finite-differences formulation of the geodynamic equations combined with marker-in-cell approach. Advection is solved by moving the markers according to the velocity field via utilizing a fourth-order Runge-Kutta advection schemes.

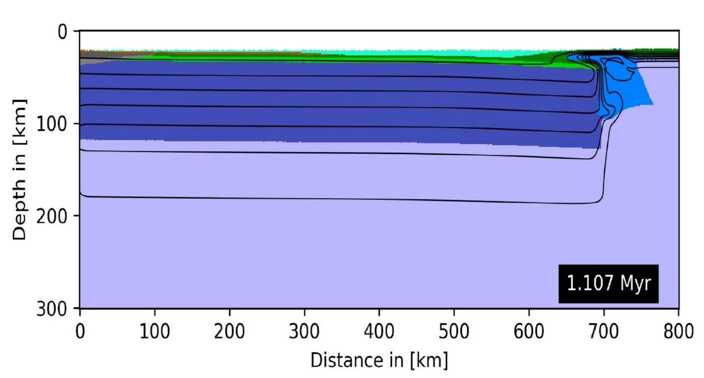

Figure 1. Initiation of a spontaneous intra-oceanic subduction along a transform fault.

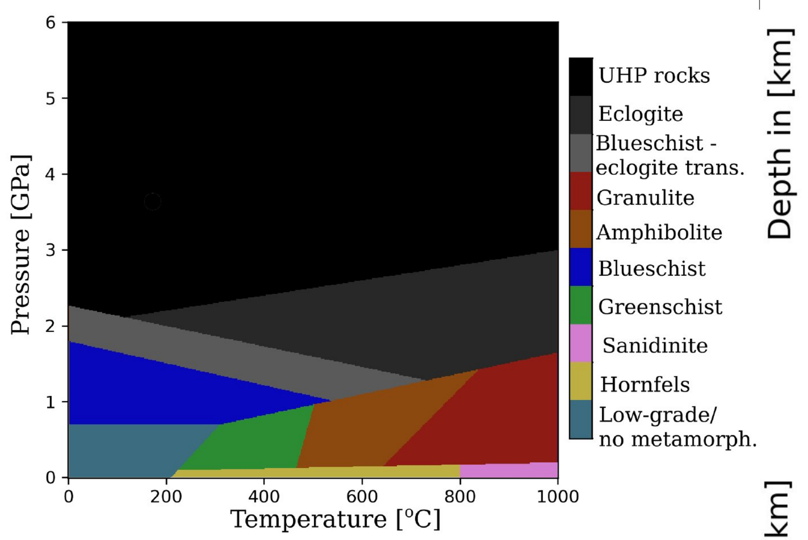

Figure 2. P-T diagram of metamorphic facies used to categorize subducted crustal rocks.

Position (x,y) and P-T conditions of crustal markers related to the continental margin are traced in time. Additionally, while the crustal rocks are monitored, they are also categorized based on theoretical metamorphic peak at the given P-T conditions. This categorization is based on a simplified diagram of metamorphic facies (Fig. 2) . The metamorphic facies assigned for a given material marker represents its peak metamorphic state. Any possible subsequent retrograde metamorphism is ignored. Differences in rheology after metamorphic changes in rocks are also ignored in this simulation.

Results and Discussion

Retreating intra-oceanic subduction is initiated spontaneously at a transform fault (*sensu* [5], Fig. 1) located some 600 km from the passive continental margin. The older and more dense left slab subducts and retreats towards the continent. This is accompanied by asthenospheric upward flow that results in generation of a new young lithosphere in the volcanic arc region. This mode develops spontaneously for 5 Myr until the trench reaches the continental margin followed by the onset of continental subduction (Fig. 3). The continental subduction is regulated by significant slab pull of the old slab and the presence of a very young and thin overriding lithosphere. As the continental crust descends deep into mantle, reaching depths of up to 300 km, most rocks reach P-T conditions corresponding to high pressure eclogite facies, while many reach even UHP conditions (Fig. 4,5). Crustal rocks become rheologically activated. They decouple from the rest of lithosphere and migrate vertically upward. The crust first starts the process of underplating beneath the thin lithosphere. This is then followed by upward piercing and detachment of the obducted oceanic lithosphere from the rest of the oceanic domain. By 13 Myr from the the onset of the simulation, a significant portion of the young oceanic lithosphere is located on top of the continental crust, separated from the remains of the overriding plate by a new highly metamorphic complex of recycled crustal rocks. In the terminal phases of the simulation, the subducted oceanic slab undergoes detachment. This occurs at the depth of around 250 km and results in subsequent uplift of the remaining mantle lithosphere, thus permanently emplacing the obducted ophiolite rocks. A new passive margin is formed some 200 km away from the old one (Fig. 6). It should be noted that in this modelling, partial melting and melt extraction were neglected. These processes might significantly alter the course of development of the ophiolite emplacement.

Implications of the result of this modelling include: i) proposition of another theoretical mechanism for ophiolite emplacement and ii) possible better understanding of the specific ophiolites of volcanic arc type found in the vicinity of highly metamorphised complexes. In further research we plan: i) to explore the influence of different initial configurations of subducting plate age and length, ii) to take into account partial melting and iii) to try to ensure the updating of material properties based on metamorphic reactions.

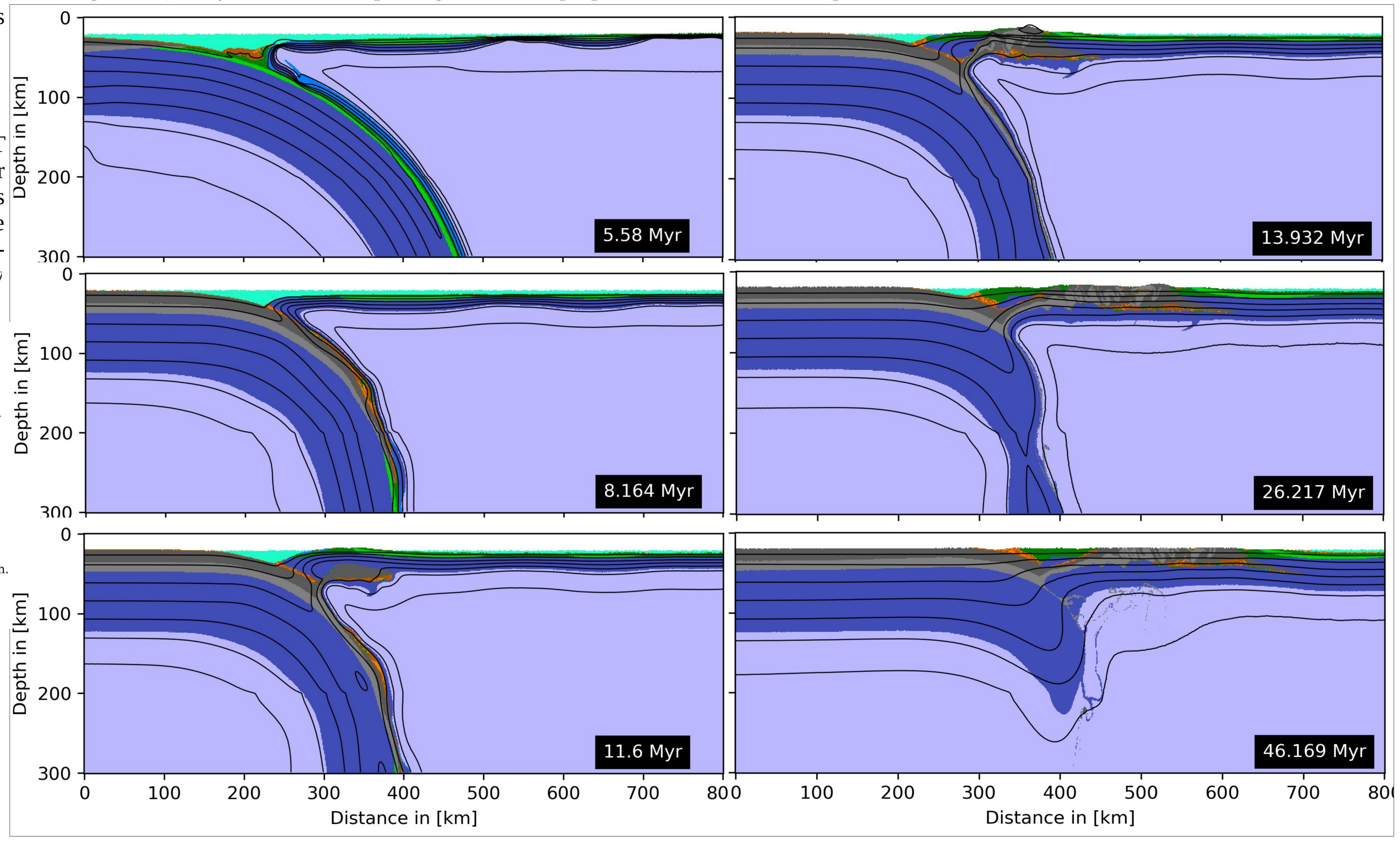

Figure 3. The time evolution of the model. Six characteristic time-steps show continental subduction, trans-lithospheric diapirism, ophiolite emplacement and slab detachment. Different colors represent different rock materials. Black lines denote isotherms, starting from 100 °C with the step of 200 °C

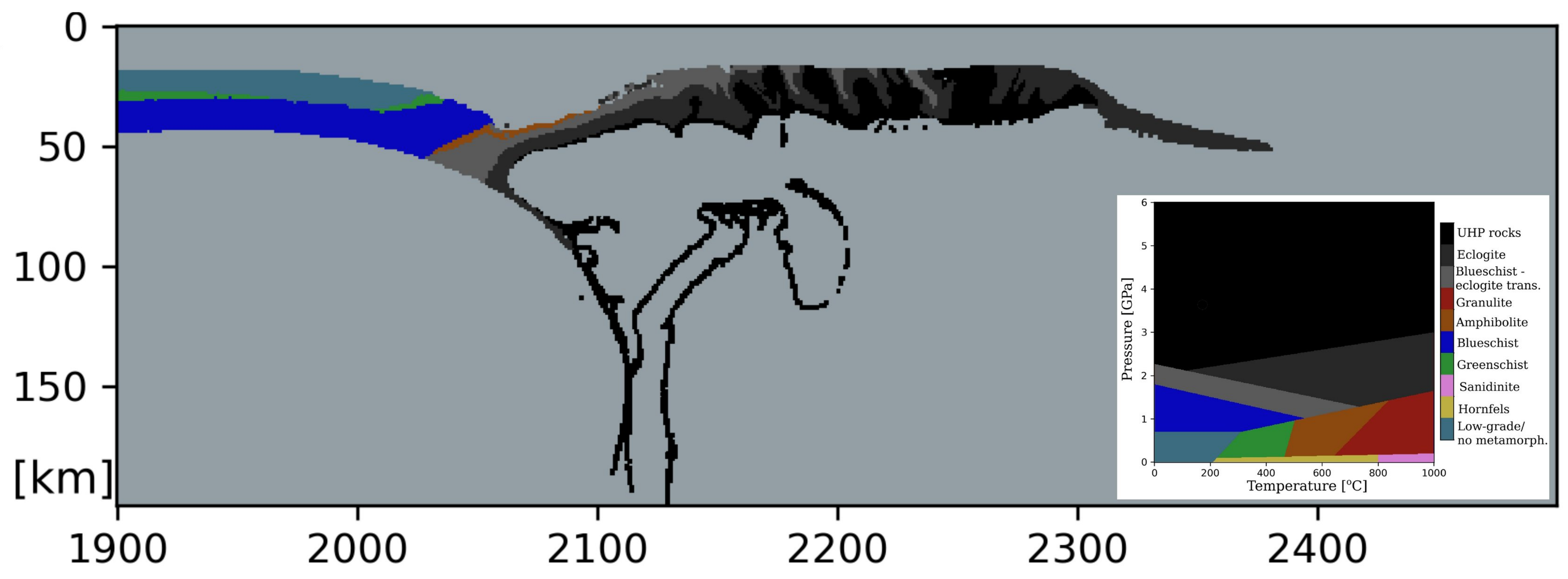

Figure 4. Spatial distribution of estimated peak metamorphic facies of a section of continental crustal rocks after 39 Myrs. This time corresponds to the period after most of the subducted continental crust had already reached the surface. Colors represent different metamorphic facies as designated on Fig. 2 (included here on the bottom-right for brevity).

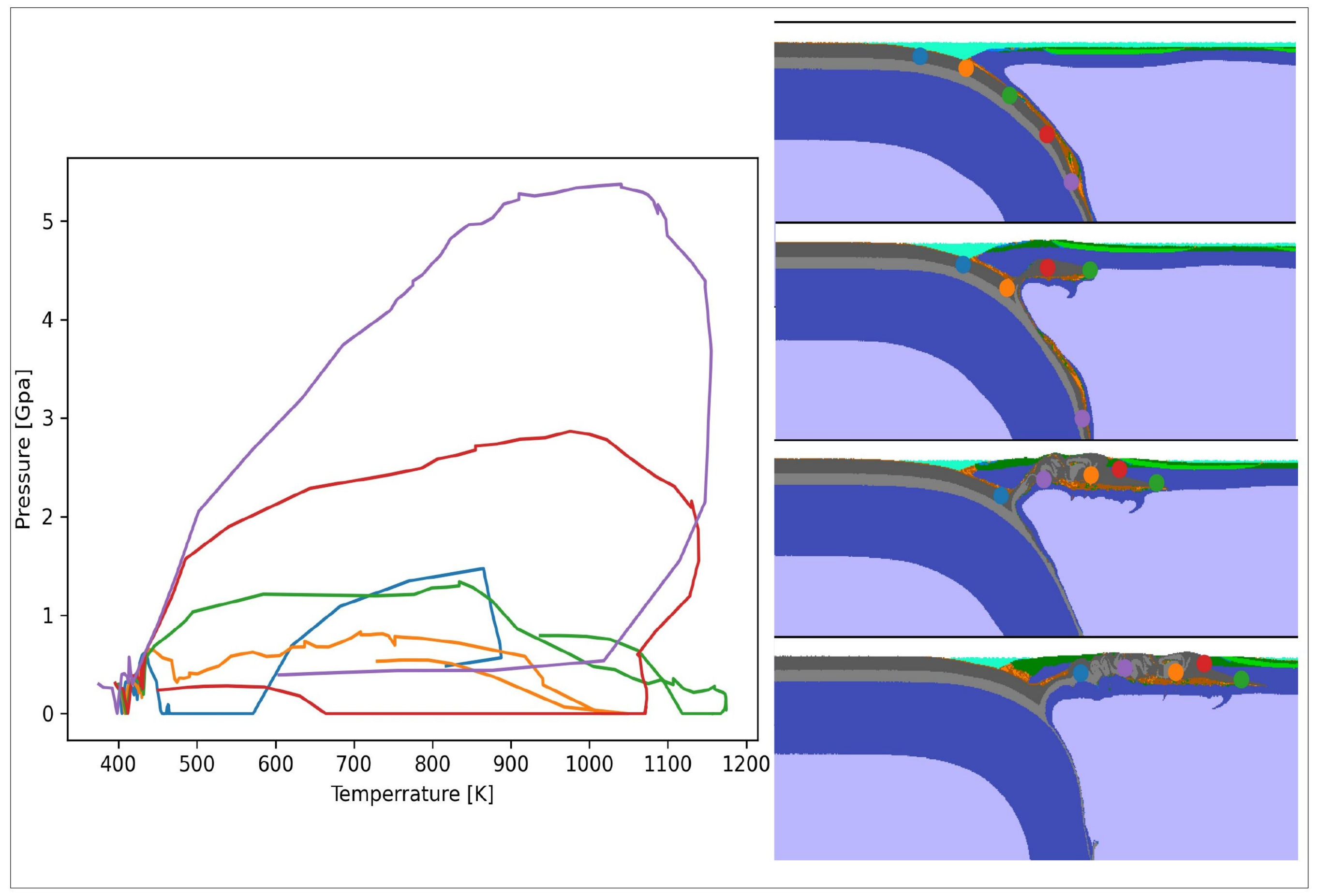

Figure 5. P-T paths of five crustal markers (left), and the positions of the five markers at four characteristic time-steps (right). Colors of the lines in P-T diagram correspond to the colors of the circles denoting the marker positions.

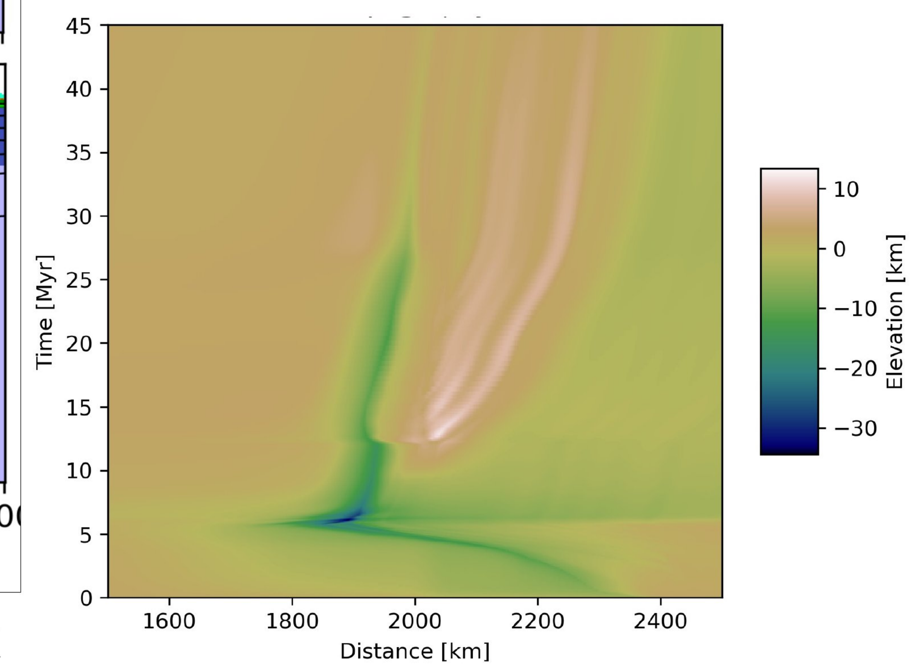

Figure 6. The evolution of topography with time. Values represent height/ depth with respect to sea level. Colors denote elevation in km.

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Acknowledgement

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