MSMEET

Modelling Support for Monitoring Earth Evolution through Time, MSMEET

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In Short

- Modelling Earth's thermochemical evolution with mobility-, topography- and sediment flux- dependent lithospheric strength.
- Evolution of different geochemical proxies and and studying water cycle in global convection models
- Modelling of crust production and studying plume-lithospheric interaction in 3D geometry.

1 | Motivation. Despite its fundamental importance, the evolution of the Earth System and feedbacks between its reservoirs (from Earth's core to atmosphere) are not yet fully understood, especially for the early Earth. This is primarily because ancient rocks are rare, altered, or lack diagnostic information on the geochemistry of highly mobile elements and volatiles. This limits our knowledge of critical issues such as the compositional evolution of the Earth's mantle and its interaction with the core; the rate of continental crust production and recycling; the onset timing of plate tectonics on Earth and the controlling rheological factors behind it; the presence of liquid water and its exchange between surface and deeper regions of the mantle, and even the origin of life. Plate tectonics drives the carbonate-silicate cycle, in which carbon gets subducted and recycled into the mantle and later degassed during volcanic eruptions at the surface. The outgassing of greenhouse gases such as CO_2, H_2O, N_2 regulates the surface temperature (and the long-term climate), thereby having a strong impact on the potential habitability of a planet. Despite its unquestionable importance for modern geodynamics, there is still no agreement about when and how plate tectonics started and what controls its evolution through Earth's history. The current project will address these fundamental issues by developing an innovative approach that relies on synergy between geochemistry, petrology, and geodynamics.

The European Research Council (ERC) Synergy Grant is a prestigious and competitive ERC Grant awarded to International groups of researchers addressing fundamental scientific problems. Prof. Stephan Sobolev and collaborators were awarded this grant, named Project MEET, which began in November 2020.

MEET will address the major questions outlined above and offer an unprecedented look at the evolution of Earth from 4.4 Ga to the present day, from the atmosphere to the core. The MSMEET computational project will be focussed on the numerical modelling of the physical processes responsible for the thermo-chemical evolution of Earth and therefore will provide modelling support for the ERC Project MEET.

2 | Methods. To achieve our goals, we will use comprehensive numerical tools solving system of geodynamic partial differential equations describing mantle convection and plate tectonics. We will consider two numerical thermo-mechanical fully MPI parallel codes for our modelling: open-source code ASPECT [1] and ETH Zurich code StagYY [2]. The advantage of using the finite element code ASPECT is its ability for mesh refinement and flexibility in using strongly non-uniform meshes. The advantage of the StagYY code is that this code has been extensively developed and tested for the modelling of coupled core-mantle-crust evolution on global scales with up to ten orders of viscosity variations [3–6].

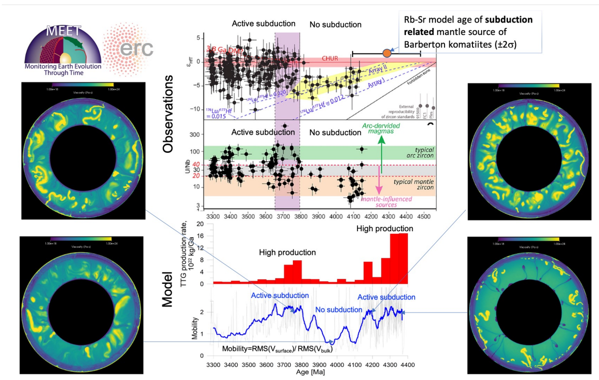

Figure 1: Apparently contradicting geochemical observations suggesting either absence or presence of subduction in the Hadean time are reconciled by the numerical model computed using StagYY showing oscillatory mobile-lid regime (subduction) during the first billion years of Earth's evolution.

3 | Goals. Building upon the success of the results obtained from our previous project bbk00014 (see Fig. 1 and main proposal text), we aim to address the following three research goals. Firstly, we will be working on coupling mantle convection codes (StagYY and ASPECT) with landscape evolution code (Fastscape) in 2D geometry. Proof of concept details for one-way coupling between StagYY and Fastscape are provided in the main text where StagYY topography outputs (see Fig. 2) are used as an initial condition in Fastscape to calculate sediment fluxes, which can then be used to iteratively refine our geodynamic models. The existing two-way coupling between ASPECT and Fastscape shown on regional-scale [7] will also be adapted for global-scale models. Secondly, we will further develop our 2D spherical annulus StagYY models that allow crust production to study water cycle and introduce additional geochemical parameters in cooperation with our MEET geochemical partners based in Grenoble and Madison. Finally, we will continue to extend our model setups from 2D to 3D geometries (see Fig. 3 for example) that weren't fully realised during the previous HLRN project. We expect mantle plumes to have a limited impact on lithospheric dynamics and crust production in 3D when compared to 2D cases. These models are computationally expensive and we are requesting similarly high computational resources as last year.

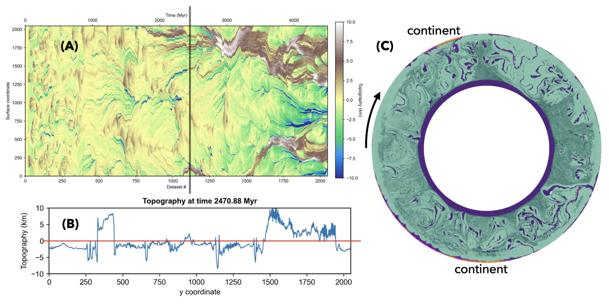

Figure 2: ***(A)*** *Surface topography datasets obtained from the reference model using StagYY stacked together for the entire 4.5 Gyr of evolution. On the x-axis, dataset # represent time going forward. On the y-axis, surface coordinates from 0-2048 represent the spherical surface of the model.* ***(B)*** *Cross-section of topography (blue line) after 2470 Myr of evolution time with sea level (red line) considered here at 0 km.* ***(C)*** *Composition snapshot of the model at the same evolution time showing two big continents (orange) representing the regions with high topography. The black arrow marks the beginning of the surface coordinate.*

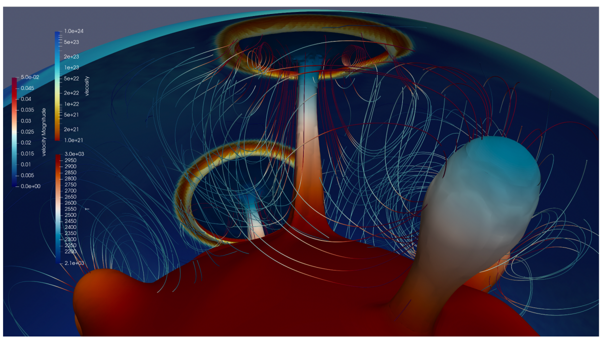

Figure 3: *3D global-scale spherical shell ASPECT model demonstrating realistic plume-plate interaction within appropriate viscosity range. The plumes (shown as temperature field) reaching the lithosphere (shown as viscosity field) initiate subductions at 105 Myr. The streamlines illustrate the asthenosphere's motion and the velocity magnitude.*

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https://www.gfz-potsdam.de/en/section/geodynamic-modeling/overview/

More Information

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Project Partners

Computational Infrastructure for Geodynamics, University of California at Davis; University Grenoble Alpes, France; University Wisconsin-Madison, USA; ETH Zurich, Switzerland

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DFG Subject Area