MSMEET

Modelling Support for Monitoring Earth Evolution through Time, MSMEET

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In Short

- Coupled evolution of mantle convection and surface erosion processes.
- Crust production, water cycle and evolution of geochemical proxies in global convection models.
- Studying transient tectonic regimes in 3D.

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].

3 | Goals.

Firstly, to investigate the effect of surface processes on plate tectonic evolution, we will adapt the newly implemented ASPECT-Fastscape C++ interface, currently working for cartesian box models, and couple it to the 3D global spherical models. We are now able to simulate mesh deformation for topography (Figure 1), in the next stage, the topography will be altered by erosion using a two-way coupling.

Secondly, in cooperation with our MEET geochemical partners based in Grenoble and Madison, we will continue to implement the evolution of Samarium-Neodymium, Lutetium-Hafnium isotopic systems and Thorium, Lead, Cerium trace elements in our 2D spherical annulus StagYY models (Figure 2). We are already testing composite rheology models with full dislocation creep (as opposed to a proxy used before) and we will also study the rheological effect of water on early Earth dynamics by introducing water-dependent viscosity.

We have successfully illustrated the dominant role of effective friction on the plate tectonics style (subduction- vs. plume-driven, Figure 3). Now, we will examine the transition from one style to the other by investigating the role of local strain-dependent friction weakening processes as well as extreme global events such as "Snowball Earth" on the global effective friction.

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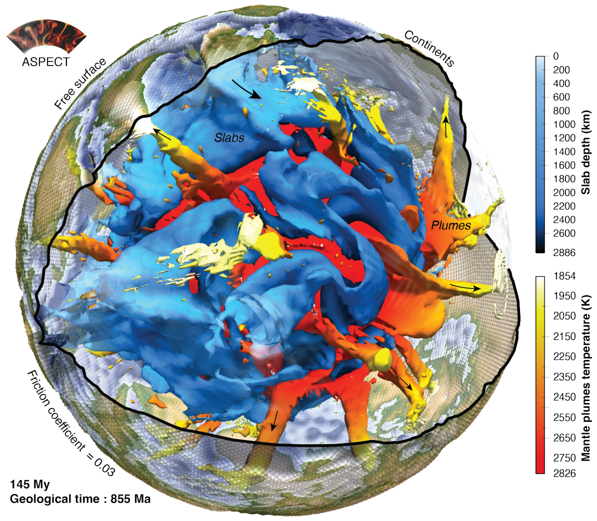

*Figure 1: **Reference 3D model computed with ASPECT.** The model shows topography generated from self-consistent geodynamical processes with ∼50 km surface resolution. Cold subductions (blue) are sinking into the mantle whereas warm mantle plumes (red) are rising towards the surface.*

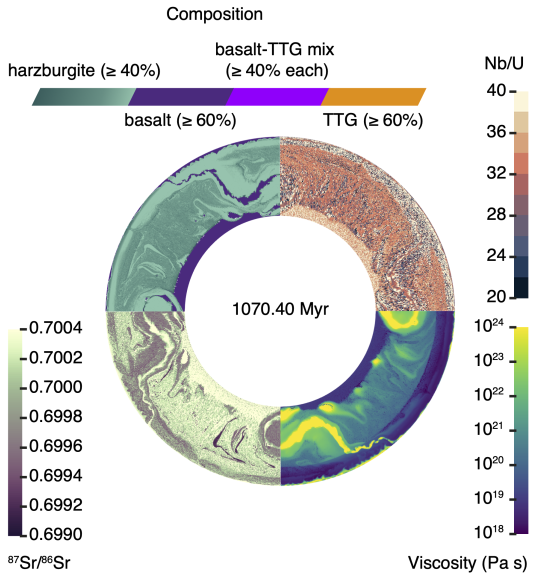

*Figure 2: **StagYY model with geochemical proxies after 1 Gyr of evolution.** The four quadrants represent different fields (clockwise from top left: composition, Nb/U, viscosity, $^{87}Sr/^{86}Sr$).*

More Information

[1] Heister, T., Dannberg, J., Gassmöller, R., Bangerth, W. (2017), High Accuracy Mantle Convection Simulation through Modern Numerical Methods – II: Realistic Models and Problems. *Geophysical Journal International*, 210(2):833-851, doi:10.1093/gji/ggx195

[2] Tackley, P. J. (2008). Modelling compressible mantle convection with large viscosity contrasts in a three-dimensional spherical shell using the yin-yang grid. *Physics of the Earth and Planetary Interiors*, 171(1-4):7-18, doi: 10.1016/j.pepi.2008.08.005

[3] Jain, C., Rozel, A. B., van Hunen, J., Chin, E. J., Manjón-Cabeza Córdoba, A. (2022). Building Archean cratonic roots. *Frontiers in Earth Science*, 10, 966397, doi: 10.3389/feart.2022.966397

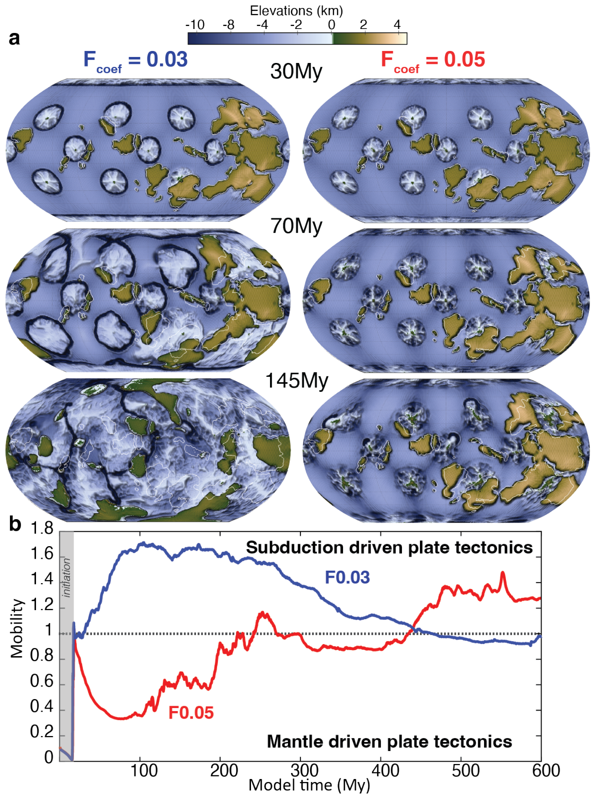

*Figure 3: **Comparison between two global models computed with ASPECT showing different plate tectonics styles. a** Model with friction coefficient of 0.03 (left) comparable to present day and a model with friction coefficient of 0.05 (right) comparable to 850 Myr ago before "Snowball Earth" event. **b** Mobility indicating different plate tectonic styles exhibited by the two models.*

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

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