Plate boundary dynamics

Geodynamic modelling of the crust, lithosphere and mantle

***S. Brune, A. Glerum, X. Yuan, D. Neuharth, F. Zwaan, J. Liu, K. Li, M. Pons, G. Gianni, A. Koptev, A. Yu, Y. Li, R. Reitano, X. Ding, H. Khalil, A. Lavecchia**, Institut für Geowissenschaften, Universität Potsdam; GeoForschungsZentrum Potsdam*

In Short

- Elucidate fundamental geodynamic processes shaping continental rifts, subduction zones and transform boundaries
- Integrate geophysical, geodetic and geological observations into high-performance thermo-mechanical forward modelling
- Bridge spatial and temporal scales of plate boundary deformation, fault network evolution and erosion and sedimentation.

1 | Motivation. Tectonic plate boundaries offer insights into the geodynamic system of Earth. Here we study the three different plate boundaries types (convergent, conservative, divergent) to quantify the processes that shape the evolving surface of our planet.

Convergence of tectonic plates leads to strong deformation of the plates involved, to thickening of the continental crust and associated uplift of major mountain ranges. Large stretches of present-day plate boundaries are convergent boundaries, like the west coast of South America, where subduction of the Nazca plate has formed the Andes, the longest continental mountain range. Another example is the Himalaya-Tibet collision zone of the Indian and Eurasian plates.

Conservative plate boundaries are formed by transform faults, where plates slip past each other without creating or consuming plate. Famous examples are the San Andreas Fault Zone connecting a divergent plate boundary with a convergent boundary, the North Anatolian Fault and the Dead Sea Fault. Significant earthquakes occur along such transform boundaries.

Divergence within continental plates induces rifting. Although at present continental rifts comprise only a small portion of the plate boundaries, during the break-up of Pangea more than 100,000 km of rifted continental margins were formed, defining the majority of Earth's coastlines and ultimately opening for example the Atlantic Basin. Besides the East African Rift, we focus on the rifted margins of the South China Sea, the Apennines in Italy, as well as the pre-orogenic rift in the Pyrenees and Alpine region.

A fundamental problem of geodynamic research is that key processes take place at inaccessible depths and can only be studied indirectly. We address this problem by joining multi-disciplinary observations from seismology, geology, and laboratory-based rheology with physical conservation laws through thermo-mechanical forward modelling. In doing so we elucidate fundamental geodynamic processes that shape continental rifts, subduction zones, and transform boundaries. This is achieved by means of a comprehensive multi-scale numerical modelling design, where we investigate and connect geodynamic processes ranging from several 100 meters to more than 3000 kilometers.

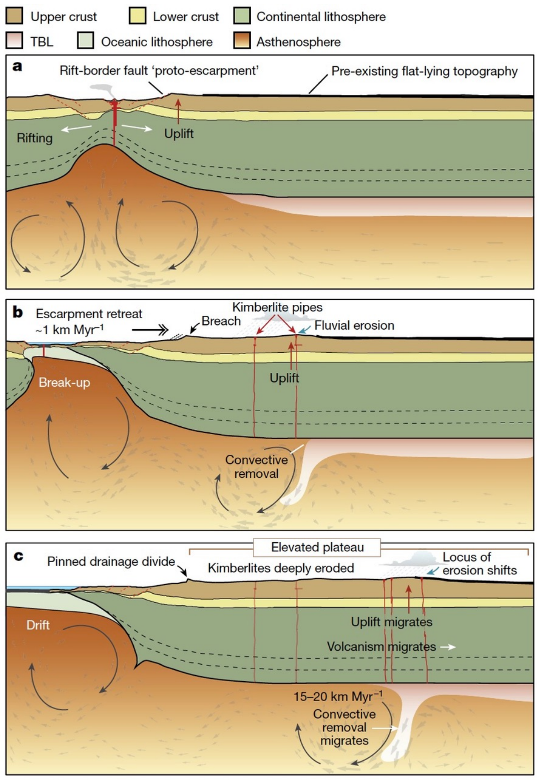

***Figure 1:** Simplified conceptual model of rifting, escarpment formation and exhumation of craton interiors. (From Gernon et al. 2024 [7])*

2 | Methods. We use the open-source massively-parallel finite-element code ASPECT [1], which is designed to solve the equations for thermally and chemically driven convection and long-term tectonic deformation. ASPECT employs fully adaptive meshes, which enable us to resolve small local objects in the flow field such as faults without refining the mesh for the whole model. We recently coupled ASPECT to a surface processes code [3] to incorporate the effect of erosion and sedimentation on tectonics.

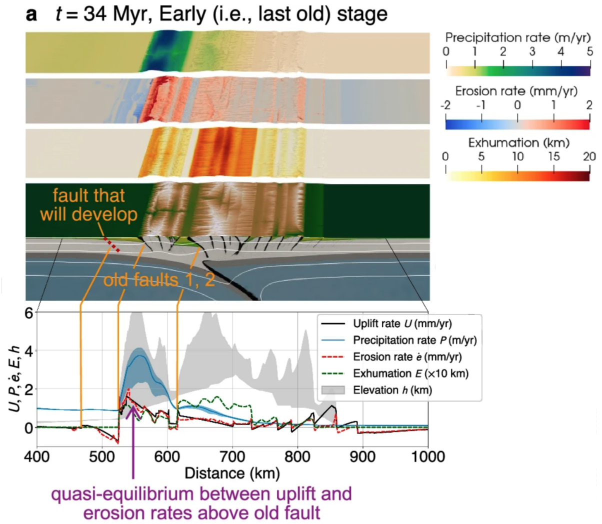

Figure 2: *2D convergence model with surface processes, showing the surface and underlying tectonics. (Modified from Xuan et al., 2024. [8])*

3 | Goals. The key objective of our Geodynamic Modeling section is to transcend the scales of geodynamics through innovative modelling techniques. ASPECT's adaptive mesh refinement and time stepping, efficient non-linear solvers as well as its excellent scalability will be used in this project to bridge the scales between 1) crustal processes, magmatism and mantle convection (e.g. Fig. 1)) fault network evolution and the plate-boundary scale deformation of the lithosphere at divergent, convergent and transform plate boundaries; and 3) surface erosion and sedimentation and the tectonics of all types of plate boundaries (Fig. 2). To accomplish this goal we combine recent implementations of visco-plasticity [2] and strain-dependent rheology, mesh deformation and surface processes code coupling [3]. We will build on recent numerical modelling studies of self-consistent subduction ([4]), continental rift dynamics [3] and strike-slip fault basin formation [5].

In this project, we focus both on fundamental aspects of plate boundary process and on the formation of major georesources such as ore deposits [6] and natural hydrogen [7].

WWW

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

More Information

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Project Partners

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