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# Extrusive and Intrusive Magmatism Greatly Influence the Tectonic Mode of Earth-Like Planets

D. Lourenco, **P. J. Tackley**, A. Rozel and M. Ballmer
Institute of Geophysics, Department of Earth Sciences, ETH Zurich, Switzerland (ptackley@ethz.ch / Fax: +41 44 633 1065)

## Abstract

Plate tectonics on Earth-like planets is typically modelling using a strongly temperature-dependent visco-plastic rheology. Previous analyses have generally focussed on purely thermal convection. However, we have shown that the influence of compositional heterogeneity in the form of continental [1] or oceanic [2] crust can greatly influence plate tectonics by making it easier (i.e. it occurs at a lower yield stress or friction coefficient). Here we present detailed results on this topic, in particular focussing on the influence of intrusive vs. extrusive magmatism on the tectonic mode.

## 1. Modelling results

### 1.1 Extrusive magmatism

In this study, reported in [2], we use numerical simulations to address the question of whether melting-induced crustal production changes the critical yield stress needed to obtain mobile-lid behaviour (plate tectonics). Our results show that melting-induced crustal production strongly influences plate tectonics on Earth-like planets by strongly enhancing the mobility of the lid, replacing a stagnant lid with an episodic lid, or greatly extending the time in which a smoothly evolving mobile lid is present in a planet. Finally, we show that our results are consistent with analytically predicted critical yield stress obtained with boundary layer theory, whether melting-induced crustal production is considered or not.

### 1.2 Intrusive magmatism and Plutonic Squishy Lid mode

Volumes of intruded magmas are observed to be ~4−9 times larger on Earth than erupted magmas. Therefore, intrusive magmatism is thought to play a role in the dynamics of the lithosphere. In this study reported in [3], we use thermo-chemical global mantle convection numerical simulations to systematically investigate the effect of plutonism, in conjugation with eruptive volcanism. Results reproduce the three common tectonic/convective regimes usually obtained in simulations using a visco-plastic rheology: stagnant-lid (a one-plate planet), episodic (where the lithosphere is unstable and frequently overturns into the mantle), and mobile-lid (similar to plate tectonics). At high intrusion efficiencies, we observe and characterise a new additional regime called "plutonic-squishy lid". This regime is characterised by a set of strong plates separated by warm and weak regions generated by plutonism. Eclogitic drippings and lithospheric delaminations often occur around these weak regions. These processes lead to significant surface velocities, even if subduction is not active. The location of the plate boundaries is strongly time-dependent and mainly occurs in magma intrusion regions. This regime is also distinctive because it generates a thin lithosphere, which results in high conductive heat fluxes and lower internal temperatures when compared to a stagnant lid. The plutonic-squishy-lid regime has the potential to be applicable to the Archean Earth and Venus, as it combines elements of both protoplate tectonic and vertical tectonic models, such as horizontal plate motion and reprocessing of the lithosphere for the former, and lithospheric diapirism, volcanism, and basal delamination for the latter.

## 2. Summary and Conclusions

Magmatism makes a first-order difference to the scaling of plate tectonics on Earth-like planets. It facilitates plate tectonics, and large amounts of intrusive magmatism may result in a new "Plutonic-squishy-lid" tectonic mode that may be important in early Earth and on Venus. In recent results reported in [4] and presented separately, the plutonic-squishy-lid mode is shown to facilitate the formation of

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## References


[1] Rolf, T., and Tackley, P. J.: Focussing of stress by continents in 3D spherical mantle convection with self-consistent plate tectonics, Geophys. Res. Lett., Vol. 38, L18301, doi:10.1029/2011GL048677, 2011.

[2] Lourenco, D., Rozel, A., and Tackley, P. J.: Melting and crustal production helps plate tectonics on Earth-like planets, Earth Planet. Sci. Lett., Vol. 439, pp. 18-28, 2016.

[3] Lourenco, D., Rozel, A., Ballmer, M. D., and Tackley, P. J.: Plutonic-squishy lid: a new global tectonic regime generated by intrusive magmatism on Earth-like planets, Geochem. Geophys. Geosys., submitted.

[4] Rozel, A. B., Golabek, G. J., Jain, C., Tackley, P. J., and Gerya, T. V.: Continental crust formation on early Earth controlled by intrusive magmatism, Nature doi:10.1038/nature22042, 2017.