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Thermo-chemical-tectonic evolution of terrestrial planets: the key influence of magmatism

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Convection of the rocky mantle is the key process that drives the evolution of Earth's interior: it causes plate tectonics, controls heat loss from the metallic core (which generates the magnetic field) and drives long-term volatile cycling between the atmosphere/ocean and interior. It is now possible to numerically model the evolution of a terrestrial planet from the magma ocean stage to the present day using a 2D or 3D model of the mantle-lithosphere system couped to a parameterized model of the core (and sometimes, atmosphere), including the effects of magmatism and variations in tectonic mode. Previous works have identified stagnant lid, episodic overturn and mobile lid (plate tectonics) as possible tectonic modes, depending on the effective strength of the lithosphere and convective parameters. Simple scalings [1] as well as more complex models [2] indicate that plate tectonics should be easier on larger planets (super-Earths), other things being equal. Our recent models find that melting has several key effects on planetary evolution. Firstly, it produces compositional heterogeneity in the lithosphere, including continental cratons [3] and basaltic crust [4], which facilitate plate tectonics by focussing or producing stresses, making it 'easier' for the lid to break. Thus, scaling laws that are based on purely thermal convection cannot be literally applied to planetary evolution. Secondly, magmatism acts as a thermostat on mantle temperature, losing large amounts of heat when the mantle is hot, when internal heat production is high such as early in a planet's evolution [5] or in a stagnant-lid mode – [6] showed that in a stagnant-lid Venus-like planet most of the heat loss is accommodated by magmatic heat pipe volcanism. Thirdly, it can produce compositional stratification in the deep mantle, which modules heat flux from the core, determining geodynamo evolution [7]. Additionally crust may be substantially weaker, and regional models that take this weakness into account find that significant crustal deformation or even internal convection may take place under Venus-like conditions [8], which would mean that Venus-like planets do not have a real stagnant lid but rather a "squishy-lid" tectonic mode.

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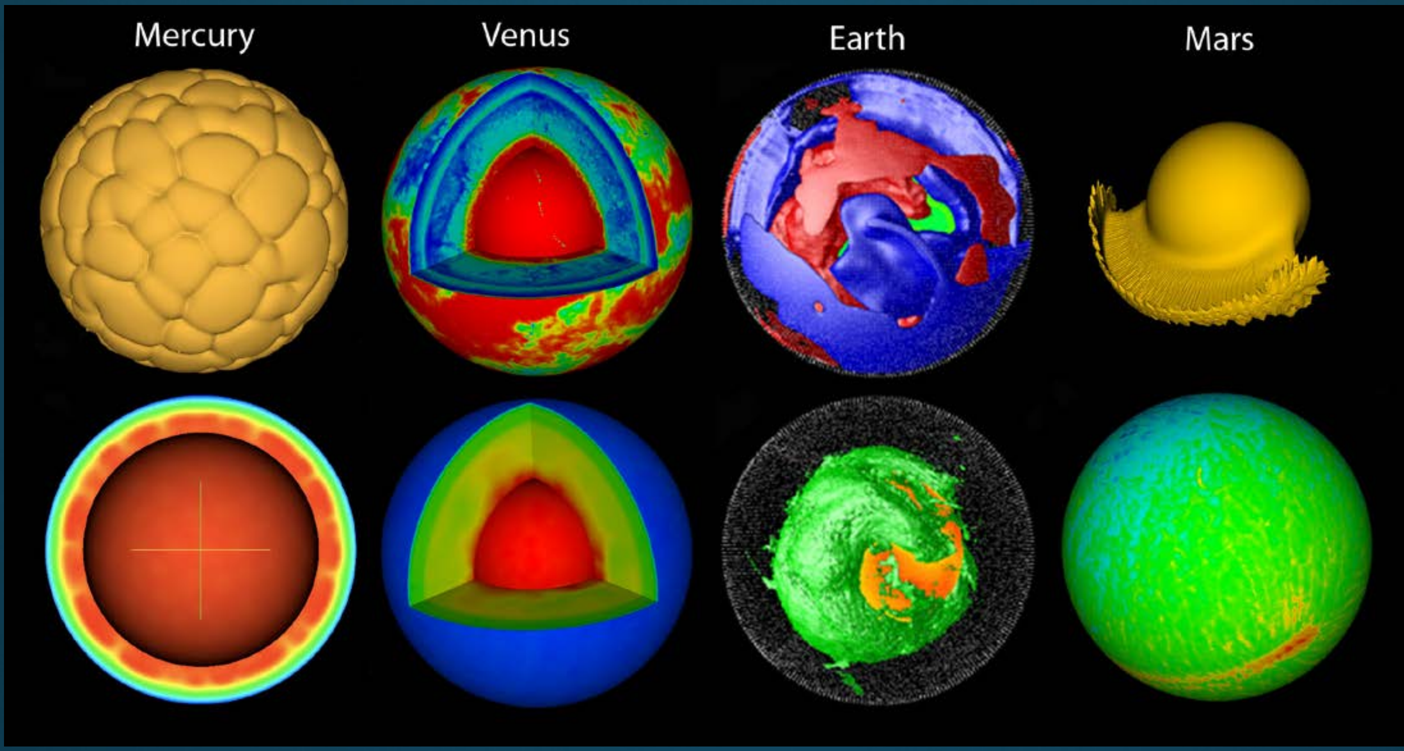

Figure 1. Simulations of the terrestrial planets as labelled.

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Key words Mantle convection, plate tectonics, Mars, Venus, stagnant lid.