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Thermal History of Planetary Objects: From Asteroids to super-Earths, from plate-tectonics to life (Runcorn-Florensky Medal Lecture)

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Convection in the interiors of planetesimals (asteroids), planets, and satellites is driving the thermal and chemical evolution of these bodies including the generation of possible magnetic fields. The wide size range induces a wide of range of time scales from hundreds of thousands of years for small planetesimals to a few tens of Gigayears for massive super-Earths. Evolution calculations are often based on energy (and entropy) balances parameterizing the transport properties of the interior in suitable ways. These thereby allow incorporating (in parameterized forms) interesting physical processes that depend in one way or another on the transport properties of the interior. The interior will usually be chemically layered in mantles and cores and include ice layers if icy satellites are considered. In addition to magnetic field generation calculated via energy balances of the core and using semi-empirical dynamo strength relations, processes that can be considered include sintering and compaction for small bodies and mantle (or ice) melting, differentiation and even continental growth for full-scaled terrestrial planets. The rheology of the interior is considered temperature and pressure dependent and the concentration of volatiles can be important. For super-Earths, probably the most critical consideration is how the mantle rheology would vary with pressure and thus with depth. It is possible that the increasing pressure will frustrate deep mantle convection thereby reducing the vigor of mantle convection. Possibly, the generation of a magnetic field in a putative iron-rich core will be impossible, if super-Earths at all have earth-like cores. On a much smaller scale, the decay of short-lived radioactives suffices to heat and melt planetesimals, the melting being helped by the low thermal conductivity of the initially porous body. This allows planets to form from pre-differentiated planetesimals thus helping to differentiate and form cores rapidly. On active planets – like the Earth – the volatile budget matters for the interior evolution. With plate tectonics, large-scale volatile cycles are invoked. On the Earth, even the biosphere is speculated to interact with the interior. It has been argued (e.g., Rosing et al. 2006; Sleep et al, 2012) that the formation of continents could be a consequence of bioactivity harvesting solar energy through photosynthesis to help build the continents and that the mantle should carry a chemical biosignature. A model is presented that includes mantle convection, mantle water vapor degassing at mid-oceanic ridges and regassing through subduction zones, continental crust formation and erosion and water storage and transport in a porous oceanic crust that includes hydrous mineral phases. The biosphere enters the model through its effect on continental erosion and through a reduction of the activation barrier to metamorphic reactions (e.g., Kim et al., 2004) in sediment layers. An abiotic world is found to have a much drier mantle than the present Earth but may have a similar surface coverage by continents. The reduced rate of continental crust production on the abiotic world would be balanced by a reduced rate of continent erosion. Through the effect of water on the mantle rheology, the biotic world would tend to be tectonically more active and have a more rapid long-term carbon-silicate cycle.

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