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Hadean/Eoarchean plate tectonics and mantle mixing induced by impacts: A three-dimensional study

Paul Tackley and **Xavier Borgeat**
ETH Zurich, Institute of Geophysics, Department of Earth Sciences, Zurich, Switzerland (ptackley@gmail.com)

The timing of the onset of plate tectonics on Earth remains a topic of strong debate, as does the tectonic mode that preceded modern plate tectonics. Understanding possible tectonic modes and transitions between them is also important for other terrestrial planets such as Venus and rocky exoplanets. Recent two-dimensional modelling studies have demonstrated that impacts can initiate subduction during the early stages of terrestrial planet evolution - the Hadean and Eoarchean in Earth's case (O'Neill et al. 2017). Here, we perform three-dimensional simulations of the influence of ongoing multiple impacts on early Earth tectonics and its effect on the distribution of compositional heterogeneity in the mantle, including the distribution of impactor material. We compare two-dimensional and three-dimensional simulations to determine when geometry is important. Results show that impacts can induce subduction in both 2-D and 3-D and thus have a great influence on the tectonic regime. The effect is particularly strong in cases that otherwise display stagnant-lid tectonics: impacts can shift them to having a plate-like regime. In such cases, however, plate-like behaviour is temporary: as the impactor flux decreases the system returns to what it was without impacts. Impacts result in both greater production of oceanic crust and greater recycling of it, increasing the build-up of subducted crust above the core-mantle boundary and in the transition zone. Impactor material is mainly located in the upper mantle, at least at the end of the modelled 500 million year period. This is modified when impactors are differentiated into metal and silicate: the dense metal blobs sink to the CMB. In 2-D simulations, in contrast to 3-D simulations, impacts are less frequent but each has a larger effect on surface mobility, making the simulations more stochastic. These stronger 2-D subduction events can mix both recycled basalt and impactor material into the lower mantle. These results thus demonstrate that impacts can make a first-order difference to the early tectonics and mantle mixing of Earth and other large terrestrial planets, and that three-dimensional simulations are important so that effects are not over- or under-predicted.