



Some remarks on the models for plate tectonics on terrestrial planets: From a point of view of mantle rheology

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Plate tectonic mode of convection is unique in that it helps maintain habitable conditions on planetary surface through global volatile circulation. Motivated by the discovery of super-Earths, a number of models have been proposed to understand under which conditions plate tectonics style of convection might occur. However, previous studies on this topic have two major limitations in the way in which the rheological complexities of planetary materials are incorporated in the model. A common approach is to compare driving force by convection with the resistance force caused by the strength of the lithosphere. When the force (stress) caused by convection exceeds the resistance force determined by the strength of the lithosphere, then plate tectonics is considered to operate (otherwise stagnant-lid mode of convection occurs). In the previous formulation, this question was examined using two parameters related to the rheological properties, “average” viscosity and the viscosity contrast between the deep (average) mantle and the lithosphere. There are two major issues in this approach. First, the pressure dependence of viscosity was ignored in most cases. This is not justifiable, because of a large pressure range expected in super-Earths (to ~ 1 TPa or more) where viscosity could change more than 100 orders of magnitude if one uses a conventional model. Second, the resistance against lithosphere deformation has not been properly formulated: (a) The “strength” of the lithosphere is affected by shear localization, but the existing theoretical formulation of shear localization or weakening lacks the key aspects of micro-structural heterogeneity. (b) The lithosphere thickness versus planet size relationship assumed in the previous models did not consider some key elements such as the influence of planetary size on the dehydration depth. Possible implications of new experimental results or theoretical considerations on the conditions of plate tectonics will be discussed.