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Numerical Models in Planetary Geology – Specifics of One-Plate Planets

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Impact craters, volcanic constructs and compressional and extensional fracture zones are typical landforms found on terrestrial planets. Features characteristic of plate-tectonics like on Earth are generally lacking. An exception are the surfaces of Ganymede and perhaps Europa where indications of lateral displacements of surface units have been observed. Planetary geologists modeling tectonic features often resort to studies of features on Earth such as Graben formation of which Valles Marineris on Mars is a giant example or shield volcanoes where Olympus Mons is another giant example. Scaling laws can be used, for instance for shield volcanoes to relate their height and base diameter to the value of the planet's gravity. More specific for numerical modeling of landforms on terrestrial planets is the formation of impact craters, which can be more easily studied on airless bodies or planets of low atmospheric pressure such as Mercury, the Moon, and Mars. Impact modeling relates crater diameters and morphology to the size and mass of the impactor. Very large impacts may even be affecting the mantles and cores and have been modeled, for instance, to study the heating and melting of a planet's deep interior. The giant impact hypothesis for the formation of Earth's moon has been tested by modeling. Such studies have only been possible due to significant improvements of so-called hydrocodes over the last couple of decades, specifically in terms of material modeling. The consideration of elastic-plastic material behavior taking ductile and brittle deformation, fracturing, and the compaction and opening of pore space into account was recognized to be key for a better understanding of impact crater formation. As a consequence of the advancements in material modeling the classic term "hydrocode" is actually no longer justified and is now often replaced by the term "shock physics code".

Another tectonic feature that is more specific to terrestrial planets are lobate scarps that result from cooling of a one-plate planet. They can be used to constrain the cooling history and even the amount of contraction associated with e.g., inner core growth. The formation of lobate scarps as well as the buckling of the lithosphere is related to the thickness of the lithosphere and its growth on a single plate planet. A significant amount of numerical work has been related to understanding the formation of continuous lithospheres or stagnant lids on terrestrial planets. These studies have shown under which conditions stagnant lids will form and how these lids will grow, thus, to a large extent, shaping the tectonic and thermal history of a planet. A substantial progress was possible in the 90's when modelers started to consider a strongly temperature dependent viscosity. The transition to plate-tectonics requires a more complex modeling of the mantle rheology, a problem that has become of particular interest to the growing field of exoplanet studies for which plate tectonics is important as an element of habitability.