The influence of surface environment on mantle evolution

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Recent developments in the numerical modeling of mantle convection make it possible to infer the influence of surface environment of terrestrial planets on their mantle evolution. Plate tectonics, one of the most prominent features of the earth, occurs only when (a) the mechanical coupling at plate margins is weak enough to allow relative motion of adjacent plates by ridge push force, but (b) the mechanical strength of plate interiors is high enough to inhibit spontaneous development of new subduction zones. This condition is satisfied on the earth since the water on the earth's surface works as a lubricant at plate margins, while the rather low surface temperature of the earth makes the plate interiors mechanically strong enough. The efficient recycling of oceanic crusts by plate tectonics makes the earth's mantle evolve in accordance with the decay of radioactive elements. At the earliest stage of the earth's history, the strong internal heating by the readioactive elements in subducted oceanic crusts repeatedly induces mantle overturn and make plate tectonics chaotic. As the radioactive elements decay and internal heating rate declines, the subducted oceanic crusts begin to coagulate to form stable superplumes on the core mantle boundary, and plate tectonics becomes more stable. The rather stable plate motion induces a significant fluctuation in mantle evolution as the number and size of plates fluctuate undeterministrically. On terrestrial planets without water on their surfaces, in contrast, the mechanical coupling between plates is strong enough to inhibit plate tecotnics; crustal recycling into the mantle is inhibited, too, if the blanketing effect of the atmosphere is limited and the surface temperature is sufficiently low (e.g., moon). In such planets, mantle magmatism occurs mostly on the early stage of their history, probably under the influence of magma ocean. The magmatism lets radioactive elements concentrate to the crust leaving behind a strongly depleted mantle. The mantle, then, evolves as a simple relaxation toward a steady state characterized by chemically homogenous and rather cold mantle without significant magmatism. If the blanketing efffect of atmosphere is strong and the surface temperature is high enough to make the lithosphere rather ductile (e.g., Venus), in contrast, some amount of crustal recycling would occur. The interrnal heating due to the recycled crust would induce hot spot type mantle magmatism that continues throughout the history of the planet. Without the help of plate tectonics, however, superplumes would never develop in the mantle of such planets.