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The Condition Dividing 'Ocean Planets' and 'Land Planets'

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Having liquid water is very important condition for a habitable planet, but a planet having liquid water on its surface isn't necessarily like the Earth because the distribution of liquid water on a planet can depend on atmospheric circulation while the distribution of liquid water on the Earth is rather controlled by the distribution of 'oceans' those occupy low altitude regions. We define the 'ocean planets' as the planets like the Earth and the 'land planets' as the planets on which the distribution of liquid water depends on atmospheric circulation. A land planet with small obliquity possesses liquid only on high latitudes (Abe et al., 2005) and has a broader habitable zone than an ocean planet has in the same atmospheric condition because the distribution of water, which makes climate unstable by runaway greenhouse effect and ice albedo feedback, is limited at low latitudes (Abe et al., in prep.). Moreover the localization of liquid water should affect the carbon cycle and the tectonics of a land planet. Planets having no land should be also distinguished from the planets like the Earth and the land planets in respect of habitability because its carbon cycle and tectonics can be very different from these two types. Therefore we divided planets having liquid water on their surface into three groups: land planets, ocean planets with land and ocean planets without land. The sufficient condition of an ocean planet is having an ocean connecting globally and the necessary condition of a land planet is having only disconnected lakes. The amount of liquid water required for occupying the critical water area fraction or making the entire planet under water depends on the scale of topographic relief. For the same amount of liquid water, a planet with large topographic relief has large land area fraction while one with small topographic relief has large water area. Therefore we established the models constraining topographic relief.

We regarded topography as waves on planets and expected that topography having large amplitude compared with the wavelength cannot exist because the elastic stress exceeds material strength. We found that viscous relaxation of topography has two modes with different time-scales. One mode equalizes the thickness of the crust, and whose time-scale is ~1Gyr when we employed the parameters appropriate for the Earth. This time-scale is insensitive to the wavelength of topography. The other mode restores isostasy and whose time-scale is inversely proportional to the wavelength of topography. The time-scale varies from ~1kyr to ~100Myr for the parameters.

We calculated the duration time of topography that exceeds certain amplitude using the elastic and the viscous models. Such duration time gives the frequency of the topographic-building events required for keeping topographic relief.

For given amount of water the water covered area increases as the amplitude of topography decreases. Thus, we can expect the frequency of topographic-building events required for preventing a land planet from becoming an ocean planet or an ocean planet with land from becoming an ocean planet without land as functions of the amount of water. Moreover we can classify planets with liquid water on their surfaces into four types by the amount of water: (1)planets likely to lead land planets (2)planets likely to lead ocean planets with land (3)planets likely to lead ocean planets without land (4)planets always leading ocean planets without land. We revealed that the classification can be also adopted when planets are covered with different types of crusts like the Earth.

The habitability of land planets and ocean planets without land is very difficult to guess because the various processes are involved complexly, but at least we revealed that the amount of water required for an ocean planet with land is limited to rather narrow range unless the viscosity of the crust is very low.