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The habitability of terrestrial planet that is covered with ice but has an internal ocean

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Recently, extrasolar (bound) terrestrial planets and free-floating (unbound) planets have been discovered. It is important theme whether habitable bound and unbound terrestrial planets exist. On the other hand, snowball planets those are covered with ice shell are thought to have internal ocean melting by geothermal heat flow from the interior. The habitability of the internal ocean has been discussed in many papers. In this paper, for different values of the planetary mass, the distance from the central star, the water abundance, and the abundance of radiogenic heat sources, we discuss the conditions for bound and unbound terrestrial planets to have an internal ocean for the timescale of planetary evolution owing to geothermal heat flux from the planetary interior. We show that a planet with 1 Earth's mass without greenhouse gas can have an internal ocean if it has 0.5-8 times Earth's water abundance or more than 0.4 times Earth's abundance of radiogenic heat sources at 1 AU. If it has more than 8 times Earth's water abundance, high-pressure ice produced at the bottom of the ocean would make the internal ocean unhabitable. The condition for a planet to have an internal ocean strongly depends on the planetary mass. It is easier to have the internal ocean if the planet is super-Earth. A free-floating planet with 1 Earth's mass without greenhouse gas can have an internal ocean if it has 2-8 times Earth's water abundance or more than 2 times Earth's abundance of radiogenic heat sources. It could be unhabitable if it has more than 8 times Earth's water abundance. In the extrasolar and free-floating planets, terrestrial planets with internal ocean are more common than Earth-like "ocean planets." So, we should consider not only "ocean planets" but also "snowball planets" with internal ocean.

Keywords: exoplanets, terrestrial planets, habitability, internal ocean, radiogenic heat, free-floating planets