

STABILITY OF AN INTERNAL OCEAN IN GANYMEDE. J. Kimura¹, S. Vance², H. Hussmann³ and K. Kurihara⁴, ¹Earth-Life Science Institute, Tokyo Institute of Technology, 2-12-1 IE-12 Ookayama, Meguro-ku, Tokyo, 152-8550, Japan, ²Jet Propulsion Laboratory, California Institute of Technology, ³DLR Institute of Planetary Research, ⁴Earthquake Research Institute, The University of Tokyo.

Introduction: The outer solar system provides potential habitats for extra-terrestrial life. Most moons orbiting planets in the outer Solar System, at orbits beyond the snow line, such as Jupiter or Saturn, are covered with water ice and are referred to as "icy moons". Galileo spacecraft's detection of induced magnetic fields [1, 2] combined with imaged surface characteristics [3] and thermal equilibrium modeling of the moons [4] support that the Jovian icy moons Europa and Ganymede, and possibly Callisto may harbor liquid water oceans underneath the icy crusts. The presence of internal oceans in the icy moons means that a deep habitat different from Earth's biosphere may exist, located beyond the "habitable zone" of the Sun. Evidence for oceans is not definitive, however, and awaits confirmation measurements. Also, the depth and composition of the oceans remain unclear, as do their stability and variability through time.

Interior of Ganymede: Here we focus on Ganymede, the largest moon in the Solar System and the primary target of a new mission to the Jupiter system, the Jupiter Icy Moons Explorer (JUICE), which is planned by the European Space Agency (ESA) [5]. The bulk density of Ganymede, 1.936 g/cc, indicates a composition of approximately equal amounts of rocky material and water. Previous measurements of Ganymede's gravitational field [6] and intrinsic magnetic field [7] by the Galileo orbiter suggest that its interior is completely differentiated into three layers, a convecting metallic core at the center, a rocky mantle surrounding the conductive metallic core, and an outermost water-ice shell. The water-ice layer in total has a thickness of 800-1000 km [6]. A layer of melted, salty water that lies beneath the icy crust would be the best way to explain the signal of magnetic induction [2].

Long-term stability of Ganymede's ocean: To investigate the lifetime of an ocean (thickness change through time) assumed to be initially in an entirely liquid state, we performed numerical simulations for the internal thermal evolution using an one-dimensional spherically symmetric model for the convective and conductive heat transfer, with radial dependence of viscosity, heat source distribution, and other material properties [8, 9]. We take into account the energy due to decay of long-lived radioactive elements and also evaluate the effect of tidal heating. To calculate the temporal change of the boundary position between solid ice layers including ice shell and high-

pressure ice mantle, we also evaluate the energy balance at the phase boundaries between the solid and liquid H₂O layer, which are the upper and lower boundaries of the sandwiched liquid layer, and the movements of the positions of these boundaries are calculated by evaluating the heat balance between incoming and outgoing flux at the boundaries considering with latent heat (classically known as a Stefan problem).

Results and perspectives: Based on our simplified model of Ganymede's interior evolution, if the ocean was composed of pure water, it would have disappeared (completely solidified) within 1 Gyr, even if tidal heating for the current orbital state were included. Also, even if strong anti-freeze components (e.g., salts or ammonia) are dissolved in it, the longevity of the ocean is hardly prolonged because the ice crust effectively removes heat from the ocean through solid state convection. Dissolving into the ocean all the ⁴⁰K possibly contained in the rocky mantle can maintain the ocean for 3 to 4 Gyr.

These results indicate that significant tidal heating in the past is needed if an internal ocean in Ganymede is confirmed by future JUICE observations. Coupling between internal tidal dissipation and orbital evolution will be considered in our model. Future work should also consider potential limitations on oceanic convection due to saline stratification or double-diffusive convection [10], possibly in isolated liquid layers underneath high pressure ices [11]. Based on our preliminary results, if Ganymede's eccentricity is 10 times or larger than the current value, a highly tidally heated ocean has the potential to survive until the present.

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