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Turning point in differentiation history of giant icy satellites induced by dehydration of pristine hydrous rock

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From gravity data, it has been found that Ganymede has a small value of the moment of inertia (MoI) factor (0.3115), which suggests a highly differentiated interior (an outermost H_2O layer, a rocky mantle, and a metallic core). Also, existence of the intrinsic magnetic field strongly supports the existence of a (at least partially) liquid, iron-rich core. However, process of the internal differentiation including the core formation is highly unclear, and the size of Ganymede implies that only accretional heat is insufficient to segregate the water, rock, and metallic materials completely. On the other hand, Callisto has similar size to Ganymede but show larger value of MoI (0.355) implying incomplete differentiation. Many hypotheses to explain this contrasting characteristic between two moons have proposed. Here we suggest another hypothesis for the internal evolution in early stage and focus on a dehydration process of pristine rock-metal-mixed core.

Although Ganymede and Callisto share similar size and mass, estimated masses of rocky component including metal derived from the mean density of both moons are considerably different each other in the viewpoint of the thermal history. Assumed that both moons consist of two components (water with density of 930 kg^{-3} and rock with density of 3,300 kg m^{-3}), the mass of rocky component is equivalent to a rocky core with radius about 1,980 km for Ganymede and 1,750 km for Callisto. This means that the radiogenic heat amount is different (Callisto has about 70 % amount of Ganymede's radiogenic heat source), assumed the same concentration of radioactive elements. However a preliminary evaluation shows that the temperature of the primitive core in both moons will be exceed the liquidus of metallic component (1250 K) and the metallic core will be formed within 1-2 Gyr, given the viscosity law of dry peridotite for the primitive cores. This result contradicts the gravitational data and its aspect to the differentiated state. Therefore it is difficult to create the dichotomy of internal state between two moons only by the difference of their silicate fraction (which corresponds to the radiogenic heat source), and thus another factor is needed.

Dehydration of hydrous rock and associated rheological change might be a key to create the dichotomy. We assume rocky component is possibly hydrated during the accretion, and hydrous rock-metal-mixed pristine core starts to warm due to radiogenic heat after the end of accretion. Once the dehydration starts to occur, the temperature of rocky core would increase more rapidly and exceed the melting point of the metallic component, and thereby metal segregates from rocky material. If Ganymede which has larger amount of radiogenic heat has experienced the dehydration, and if Callisto has not, the dichotomy in differentiation state between both satellites would be explained.

To test above idea, we performed numerical simulations for the internal thermal evolution taking into account the heat transport by convection and conduction. In a reasonable range of viscosity is assumed for hydrated rocky core, model Ganymede experiences the dehydration of the pristine mixed-core and possibly the metallic component could segregates from the rocky materials in case of the high silicate content and/or higher viscosity of hydrous rock. On the other hand, Callisto does not undergo dehydration because of the smaller amount of radiogenic heat. The difference of radiogenic heat and the dehydration process have potential to create the dichotomy between two moons. Moreover, this may also explain the geological records on Ganymede showing the occurrence of global extension after the period of heavy bombardment. Global mapping with high spatial resolution in future mission on giant icy moons and improvement of accuracy in cratering chronology (e.g., current estimate on Ganymede's bright grooved terrain has uncertainty of an order of Gyr) are needed to examine our hypothesis.