Volume expansion of Ganymede due to temperature change and phase change of ices.

M. Yoda[1], J. Kimura[2], Y. Sekine[1] and K. Kurita[3], [1]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo (1st author : yodamasa93@gmail.com), [2]Osaka University, [3]Earthquake Research Institute, The University of Tokyo.

Abstract: Surface features could provide important constraints on interior dynamics and evolution of solid planetary bodies. Voyager and Galileo spacecrafts have revealed that a wide variety of surface geomorphologic features exist on the surface of Galilean moons. On Ganymede, younger geologic units, the Bright terrain, is tectonically and chemically distinct from older units, the Dark terrain [2]. The geological age of the Bright terrain is estimated as ~2 Gyr ago using crater chronology [3]. In Uruk Sulcus, Galileo's target area of the Bright terrain, stratigraphic units with coherent parallel ridges and troughs have modified preexisting horst and graben units [1]. These parallel ridges and troughs would have been formed by extensional stress due to global volume increase (5-8% in volume) [4][5]. From a calculated strain in each unit, different deformation styles have been suggested to cause the formation of each unit [4][6]. The occurrence of different deformation styles with various strain rates implies that some processes caused the global expansion in the lithosphere through Ganymede's evolution [4][7].

Differentiation, freezing of the subsurface ocean and silicate dehydration would be candidates for the volume expansion that can cause the extensional stress [7]. However, these events should have occurred in the early stage of evolution, and, thus, it would be inconsistent with the geologic age of the Bright terrain. Phase changes of water upon the thermal evolution have led a global expansion. During a resonance passage, Ganymede's subsurface ocean would have been formed by tidal dissipation between low-density and high-density ices [9]. Melting of the high-density ices would have resulted in a large volume expansion in the early stage of resonance (~2.5%) [10]. In this case, Ganymede would have been tectonically/cryovolcanically resurfaced due to melting. However, other process in a later stage is necessary in order to explain the multiple deformations in the Bright terrain.

We focus on volume expansion in Ganymede's ice shell, coupling with the thermal evolution. Ganymede's ice shell is divided into the upper elastic lithosphere, and lower plastic asthenosphere, due to a large viscosity contrast. In the lithosphere, thermal expansion coupled with thermal evolution could generate surface stress through a part of Ganymede's evolution [11]. The asthenosphere is composed of high-density ices (Ice II, Ice III, IceV and Ice VI) [12]. Phase change from high-density ice to low-density ice, such as ice II to ice Ih, could generate a large amount of volume expansion. Since the temperature drastically decreases in the lithosphere toward the surface, the detailed thermal profile and its temporal change are critical to evaluate quantitatively a degree of the volume expansion.

Here, we show the results of numerical simulations for phase and volume changes coupled with Ganymede's thermal evolution using the mixing length theory [13]. We discuss accumulated stresses in the elastic lithosphere, especially during the intermediate stage of Ganymede's evolution. In our simulation, we find that the largest contribution to the volume expansion is associated with a phase change of Ice Ⅱ to IceIh, which can overcome the volume decreases due to growth of high-density ices (Fig. 1). Our results suggest that the phase change of ices generates a large volume increase during the intermediate stage of Ganymede's evolution.

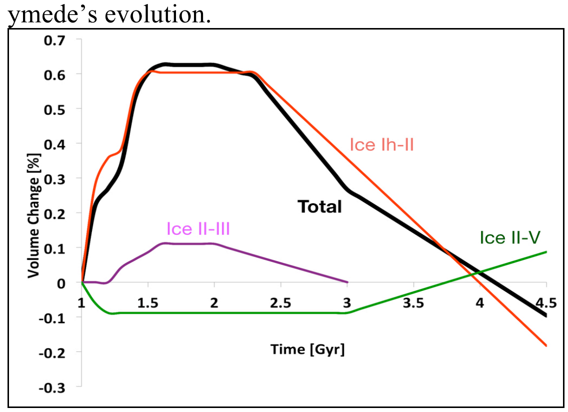

Fig. 1 : Volume changes due to phase change of ice after 1Gyr. Black, Red, green and purple solid line are volume changes of total, Ice Ih-II, Ice II-V and Ice II-III respectively.

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