Understanding Subsurface Structures in Mare Frigoris on the basis of Kaguya/LRS Observation

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Mare Frigoris is known as a unique mare which is formed just around large basins and in which unique gravity anomaly such as Linear Gravity Anomaly (LGA) are found. In Mare Frigoris, spectroscopic observations and crater counting have been performed to identify the boundaries of the lava units and estimate the model age of the lava unit [Hiesinger et al., 2010; Kramer et al., 2015]. Subsurface echoes were also detected by Kaguya/Lunar Radar Sounder (LRS) in Mare Frigoris [Pommerol et al., 2010]. To understand the formation process of Mare Frigoris, it is useful to understand the stratigraphy from the subsurface structure by using subsurface radar. In this study, we focused on LRS data in the western-central region of Mare Frigoris (in 55-65˚N and 13-20˚W). We identified three subsurface reflectors (Reflectors 1, 2, and 3 from the shallowest, hereafter). Reflector 1 is found in 57.8-60˚N and 14-17˚W. It is almost horizontal within 14-15˚W and then gradually becomes shallower towards the west, and overlaps to the surface at around 17˚W. Reflector 2 is observed 58.5-59.6˚N and 14-16˚W. It is horizontal in the eastern area of 15˚W and inclined southward in the wester area of 15˚W. Reflector 3 is observed only within 58.5-59.6˚N and 14-16˚W. It is horizontal in the eastern area of 15˚W and inclined southward in the western area of 15˚W. The depths of reflectors 1, 2, and 3 are ~160m, ~260m and ~430m, respectively (assuming ε_r=6).

The followings are suggested from the reflectors found by LRS:

1. Since Reflectors 1-3 are found below Unit WCF1 (formed ~3.53 Ga, [Hiesinger et al., 2010; Kramer et al., 2015]). 2. Lava layer A between the surface and reflector 1 was accumulated on a terrain with eastward inclination and formed horizontal surface. 3. Lava layer B between reflectors 1 and 2 was accumulated on a terrain with southward inclination. Eastward inclination of the upper boundary of Lava layer B can be explained by the tilt of the beds after the horizontal accumulation of the lava flood, and by the limited expansion of the lava flow from the western area of 18˚W, in which lava flow units newer than WCF1 are found, and volcanic system was formed. 4. Lava layer C between reflectors 2 and 3 was accumulated within a subsidence area formed on the horizontal surface of older lava layer D. The southward inclination on the surface of lava layers C and D before the deposition of lava layer B is caused by tensional stress due to some loads below the surface.

From the above suggestions, the formation process of the Lava layers A-D are considered as follows:
(ⅰ)Lava layer D was deposited before 3.53 Ga (WFC1 deposition). (ⅱ)A graben or crater was formed on the surface of lava layer D. Lava layer C was deposited inside the graben or crater. (ⅲ)The southward inclination of the surface of Lava layers C and D was formed by tensional stress due to the load of lava accumulated in Imbrium in the southern area and/or dike in the northern area suggested by LGA in the northern area. (ⅳ)Lava layer B was deposited. Lava, erupted from the vents in the western area, which also produced newer lava flow units as WFC6 (formed after 3.11 Ga [Hiesinger et al., 2010; Kramer et al., 2015]), extends eastward up to around 15˚W due to limited eruption. The eastward inclination of Lava layer B surface could be. (ⅴ)Lava layer A (WCF1) was deposited.

Two hypothesis of subsidence area formation in (ii), graben and crater, were checked in this study. If the subsidence area was formed as graben, the latitudinal width of the graben and distance from the northern LGA are 38 km and 25 km, respectively. They were larger than those of the graben on the current lunar surface. According to Sawada et al.,2016 the width of large graben found in the average landscape

around LGA was about 200 km, which is much larger than those found in LRS data. The longitudinal width was 45 km. It was difficult to confirm with LRS data whether the graben was longer than 45 km in an east-west direction.

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