Subsurface Magnetized Source Layers underneath the Mare Crisium Observed by Lunar Radar Sounder. Y. Bando[1], A. Kumamoto[2], N. Nakamura[1], and H. Nagahama[1], [1]Graduate School of Science Institute of Geology and Paleontology, Tohoku University, Japan, (yuu.bando@gmail.com : Y. Bando), [2]Planetary Plasma and Atmospheric Research Center, Tohoku University, JAPAN.

Introduction: It has been known that the moon currently has no internally generated magnetic field. However, the palaeomagnetic data of the Apollo return samples [1] showed a rapid increase in intensity around 3.9-3.6 Ga to a value of ~100 μT [2,3]. Many speculations have been reported linking these data to the lunar dynamo theory [2,4,5]. [5] proposed that transient increase in core heat flux, suggesting the existence of the lunar dynamo. However, [6] that re-evaluated paleomagnetic data suggested previous measurements were affected an overprint from exposure to a small magnetic field and they doesn't support the existence of lunar dynamo. In addition, [3] reported that the lunar core dynamo would not have been able to generate a power, considering the small size of the core and the required surface magnetic field strength. On the other hand, recent studies [7,8] proposed alternative mechanisms for dynamo generation of the Moon. The differential rotation between the Moon's core and mantle may have powered the ancient lunar dynamo [9]. As the example of lunar dynamo, [10] reported that magnetic anomaly in Mare Crisium imply thermoremanent magnetization of impact melt rocks in a steady magnetizing field. Iterative forward modeling yielded a paleomagnetic pole position isn't far from the present rotational pole and 1 km thickness for the source layer, assuming the mean magnetization intensity is ~1 A/m, suggests a core dynamo magnetizing field.

According to [11], the thickness of lunar crustal magnetic sources are important quantities for evaluating whether a steady core dynamo field existed. A source that is more than 1 km thick or deeper may imply the formation acquired over a longer time period in a steady field. On the other hand, a shallower, surficial source may have magnetized via shock in a transient field generated during the impact process. However, some previous studies [10,12,13] have only discussed based on the magnetic records from Apollo return samples due to not knowing the magnetized layer thickness. We could not evaluate the magnetic field without fixing the magnetized thickness. Therefore, we have to focus on the lunar subsurface structure to determine the magnetized thickness.

Lunar Radar Sounder (LRS) onboard the Kaguya spacecraft made it possible to observe the subsurface structure. Here, we evaluated a subsurface stratigraphy and its thickness of mare basalt flow as magnetized source layers for Mare Crisium by means of the LRS data to reveal the existence of lunar core dynamo.

Data: LRS data was utilized. Synthetic Aperture Radar (SAR) analysis [14] used for lunar subsurface images. SAR-analyzed subsurface images were provided by Dr. T. Kobayashi. In the SAR analysis, the permittivity of the surface material is assumed to be 6.25. The raw echo power data used in A-scope display (a plot of signal amplitude versus depth) was acquired from JAXA-SELENE data archive. LRS uses the HF band (5 MHz), enable us to observe a depth of several kilometers [15, 16]. The range resolution of LRS in space is 75 m [15,16].

Results: LRS subsurface image shows stratifications underneath the Mare Crisium. According to [10], northern magnetic anomaly locates between N20° to N24°, but it's not easy to discriminate subsurface stratifications underneath this region than the other one. So we focus on the well-stratified region around N14°. The surficial formation age of this region was evaluated around 3.47 Ga on the basis of crater chronology [17]. In the region, two prominent and one obscure reflectors are observed. A-scope display (a plot of signal amplitude versus depth) [18], with an expected intensity of a subsurface echo power [19], suggestes the third obscure reflector should be existed. The thicknesses of first, second, and third layers are estimated 120, 260 and 500 meter, respectively.

Discussion: According to [20], it is necessary for a hundred million years to form the regolith of 15 centimeter thickness. Therefore, we estimate that the respective regolith layers require at least a hundred million years to form and could calculate the formation age of the subsurface cryptomare basaltic layers. The first layer with 120 meter in thickness was formed around 3.47 Ga from a crater chronology [17]. The second and third layers with 260 and 500 meter thickness were formed at least 3.57 and 3.67 Ga respectively based on the previous accumulation rate. Basaltic lava flows might be extensive [21] due to the low viscosity of the lunar rock, suggesting the third basaltic layer of 500 meter thickness extend to the magnetic anomaly region.

We considered the cylinder model, which is composed of the basaltic layer with respective thicknesses and adopted the expected maximal paleointensity driven by continuous mechanical stirring [7]. Predicted paleointensity of the first layer formed around 3.47 Ga is 5 μT in their model. Similarly, the second and third layers formed around 3.57 and 3.67 Ga respectively is 6 μT and 8 μT. Acquired thermo remanent magnetization (TRM) applied these external fields to iron samples was evaluated using the results of [22]. Assuming the cylindrical radius to be 120 km [10], the density of the basalt to be 3000 kg/m^3 [23], and lunar basalt contains 0.1 % metallic iron [24,25], which is capable of carrying remanence, we found the total magnetization is 1.30×10^{11} Am^2. The result is two orders of magnitude weaker than the previous results of [10]. On the other hand, It has been reported that there is a basaltic rock which has excess metallic iron (up to 1 %) [24, 25]. Assuming the lunar basalt contains 1 % metallic iron, the total magnetization became 1.31×10^{12} Am^2 on the same conditions as the above. Nevertheless, the result is one digit smaller. The results indicates it's impossible to explain the total magnetization driven by continuous mechanical stirring model [7], suggesting a stronger paleomagnetic field should be required.

Conclusions: At least three subsurface reflectors have been found in Mare Crisium. Based on the crater chronology and required time for regolith formation, we deduced the formation age of these basalt layers and evaluated the total magnetization in Mare Crisium. Compared with the previous findings [10], we found that it's impossible to explain the total magnetization driven by continuous mechanical stirring [7]. Therefore, our results imply that stronger paleomagnetic field than expected in [7] should be required to explain the magnetic anomaly in Mare Crisium. In addition, deeper magnetization may contribute to the total magnetization. Our results imply lunar core dynamo had been driven at least during 3.47 Ga to 3.67 Ga. The result is consistent with previous results reported in [1].

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