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Reconstruction of paleoselenoid using surface shapes of mare basalts and flow directions of sinuous rilles

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It is believed that the Moon has kept synchronous rotation throughout the history of the Earth-Moon system. However, the current selenoid (geoid of the Moon, an equipotential surface) has imbalances in its degree-2 coefficients as pointed out by Garrick-Bethell et al. (2006). For a synchronously rotating satellite, the ratio of the centrifugal potential to the tidal potential becomes 1:3. Then the ratio between C_{20} (=-J_2) and C_{22} should be 10:3 in hydrostatic equilibrium. However, the ratio determined recently with Kaguya is 9.09 (Namiki et al. 2009), that is, J_2 is too large relative to C_{22}.

In order to further study this problem, we try to recover a snapshot of the ancient selenoid during the heavy bombardment period using the surface shapes of lunar maria. We use the results of laser altimeter (LALT) of Kaguya in order to reconstruct the shape of selenoid when mare basalt filled the basins. We will also use the data of the terrain camera (TC) to discuss flow directions of sinuous rilles and difference between the current and past selenoid.

We investigate if the mare surface in a mascon basin is parallel with the present day selenoid by comparing topographic data from LALT (Araki, et al., 2009) and the lunar gravity model (SGM100h, Matsumoto et al., 2010). Because basaltic lava of the Moon has a viscosity lower than any lava flows on the Earth (Murase and McBirney, 1970), its surface might preserve the fossil selenoid when the lava solidified. This was the case for the three mascon basins, Imbrium, Serenitatis, and Humorum, i.e. the LALT data showed subtle curvatures consistent with the selenoid shapes within the basins calculated from the lunar gravity model. In addition to the localized curvatures, selenoid shapes within these basins showed overall tilt relative to the average lunar sphere. The estimated two-dimensional gradients of the Maria Humorum and Serenitatis showed directions consistent with the hydrostatic degree-2 shape (J_2: C_{22} = 10:3), but the Mare Imbrium showed anomalous gradient. Although the Mare Imbrium should have a (upward) slope toward SE under hydrostatic equilibrium, the observed slope was toward SW. In short, the Mare Imbrium seems to have an unexplained westward slope.

In order to confirm this with other evidence, we analyzed the TC topographic data and flow directions of sinuous rilles. Sinuous rille, a channel or valley, is considered to have been formed by thermal erosion of basaltic lava flow. Their flow direction should be downward relative to the current selenoid like rivers on the Earth. R. Nakamura (2011, pers. comm.), however, found an intriguing case that the sinuous rille, Rimae Plato (northeast of Imbrium) seems to have flown upward relative to the current selenoid. This might suggest certain fossilized differences between the present and ancient selenoid. Lots of sinuous rilles exist around the Mare Imbrium, and some sinuous rilles, including Rimae Plato, showed upward flow relative to the current selenoid. Then we found some interesting cases in these sinuous rilles. For example, Rima Suess, which is in the SW of Mare Imbrium, seems to have flown against gravity relative to the current selenoid. However, this flow becomes downward if we correct for the unexplained tilt of Mare Imbrium region assuming that it occurred after the rille formation. So this might support the abnormal tilting of Mare Imbrium. Some sinuous rilles, such as Rima Suess, showed similar signatures, but others did not. So we will systematically survey the flow directions of these rilles to establish a possible scenario of the tilting motion of the Mare Imbrium.

Keywords: Moon, Selenoid, sinuous rille, basaltic lava, Mare Imbrium