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Re-analysis of Apollo heat-flow data -Estimation of the thermal properties of regolith from the periodic and transient components-

Jun Takita[1]; # Yasuyuki Saito[2]; Hagermann Axel[3]; Ki-iti Horai[4]; Satoshi Tanaka[3]

[1] Earth and Planetary Sci., Tokyo Univ; [2] Earth and Planetary Sci., Tokyo Univ.; [3] ISAS; [4] ISAS/JAXA

Measurements of lunar surface and subsurface temperatures were carried out in the Apollo 15 and 17 missions to estimate the lunar heat-flow value.

The thermal diffusivity of lunar regolith was estimated to be about 1E-8 m$*$m/s from the attenuation factor of annual temperature variations propagating into the lunar regolith (Langseth et al., 1976).

In this work, the main focus is to re-evaluate the thermal properties of lunar regolith from short term events such as the diurnal temperature variations and the lunar eclipse. We found the temperature variations caused by eclipses at the depth of 35cm in the Apollo HFE data. This greatly contributed to determine the phase lag of the temperature variations caused by the periodic lunation. In order to analyze these temperature variations, a simple model computation was utilized with uniform thermal properties.

In order to analyze the temperature variations during the diurnal cycle and the eclipse, we calculated one-dimensional equation of heat conduction by using finite difference method. As for the boundary condition, we assumed black body radiation at the surface and constant temperature at the bottom of the model for simplicity. If we assume thermal diffusivity of 1E-8 m$*$m/s, the amplitude of temperature variations in lunar eclipse and diurnal cycle is almost consistent with those recorded by the Apollo 15 temperature sensors. However, this model can explain neither the delay of heat transfer with depth nor the outline of the temperature profile compared to that of the recorded ones. In order to be consistent with each other, the thermal diffusivity is preferable to be 1E-6 m$*$m/s which is two orders lager than that was estimated by previous studies. The same results are obtained from almost all of the diurnal variation data detected in Apollo 15 and 17. For this reason, this problem is likely to be caused by either the instruments in HFE measurement system or the thermal properties of lunar regolith near surface.

It is notable that the wave forms produced by the model calculations are quite similar to that recorded on the moon even though the temperature amplitude is larger. One feasible explanation is that this was caused by the heat conduction through the bore-stem which must have high thermal diffusivity. Since the bore-stem is made of boron-epoxy, the thermal diffusivity is expected to be 2E-8 m$*$m/s . We calculated this effect by adding the large heat conduction of the bore-stem in the model. However, the temperature profiles could not be made consistent with that of the observed data.

Another possibility is that the thermal diffusivity of the regolith is as high as 1E-6 m$*$m/s, and the amplitude of temperature was attenuated by another mechanism. When we look at the configuration of the measurement system, we found a small gap between the wall of the bore-stem and the sensor part. We inferred that heat was predominantly transferred by radiation for the short term temperature variation, then the amplitude of the temperature variations were expected to be attenuated.

The possibility caused by the heat conduction on the cables connecting probes to electronics box on the surface is also worthwhile to consider. With heat dissipation from the cable, temperature attenuates more than the case of no heat radiation. The phase lag subjects to the different attenuation constant from that of temperature amplitude in this case. Thus, there is possibility for this to explain both the phase lag and the attenuation of amplitude.

The thermal diffusivity estimated from annual phase lag is 1E-6 m$*$m/s. Therefore, we cannot explain each component of data systematically. It is important to clarify the mechanism that the thermal diffusivity estimated from short term events differs that of annual. If the heat transfer along the cables effects temperature sensor in HFE measuring system, the thermal diffusivity estimated from the annual attenuation has to be re-evaluated.