The Long Term Temperature Variation in the Lunar Subsurface. Y. Saito[12], S. Tanaka[2], K. Horai[2], A. Hagermann[3], [1]The University of Tokyo (Hongo, Bunkyo-ku Tokyo email: saito@planeta.sci.isas.jaxa.jp), [2]Institute of Space and Astronautical Science (Yoshinodai, Sagamihara, email: tanaka@planeta.sci.isas.jaxa.jp), [3]Open University (a.hagermann@open.ac.uk).

Introduction: Lunar surface heat flow values were measured directly during the Apollo missions. These experiments were carried out on Apollo 15 and 17 for about six years between July 7, 1971 and September 30, 1977. The heat flow values derived from these two measurement sites were 21 mW/m^2 and 14 mW/m^2 respectively [1]. Langseth et al. concluded the representative global lunar heat flow to be around 18 mW/m^2 based on approximately the first 3 years of data until the end of the 1974 (see Figure 1).

Recently, Saito et al. (2006) succeeded in archiving the heat flow data from March 1 1976 until September 30th 1977 [2]. These data are very useful for identifying this very long-term variation because we could extend the period of data almost by a factor of two (from 3 years to 6 years) compared to the data archived previously. Because an anomaly had occurred on April 28th, 1976 on the Apollo 15 experiment, the data of Apollo 15 could not be expanded. Therefore, the data obtained by Apollo 17 were used for long term analysis.

The temperature increase over five years in the lunar regolith: instrument deterioration?: Langseth et al. (1976) interpreted that "aperiodic" temperature rise as a process to reach thermal equilibrium state, they indicated that these transients were initiated by astronaut activity. They estimated that, for the deepest sensors, 5-7 years would be needed to re-equilibrate [1]. However, the temperature must not increase without heat input. Saito et al. (2007) pointed out that the temperature profiles in the subsurface are affected by not only diurnal and annual change but also precession whose period is 18.6 years [3]. On the other hand, the 18.6 year precession only modulates the amplitude of annual variation of surface maximum temperatures (see Fig. 2 in [4]). Therefore, the lunar precession cannot increase the lunar surface temperature in the long term such as 18.6-year. Because there is a possibility that the instrument itself increases the temperature in the bore-hole, we need to assess the factors that were attributed to the instrument. We focused on three factors as following.

Heat input via cable or bore-stem: Manganin wire was used as the signal line in the cable between the probe and the electronics box located on the lunar surface. The thermal conductivity of Manganin wire and the bore-stem are also over ten times as high as lunar regolith. If there were heat input via cable or bore-stem, the time lag would not appear in the temperature profiles. Additionally, the amplitude of the diurnal thermal wave at a few meters in depth must be larger.

Heat generation of each sensor itself: The bridge is pulsed every 2.4 sec for 2.6 msec and the limit of self-heating is 0.1 μW [5]. The energized period is short and power is low enough, so the regolith surrounding the sensors does not heat. As a result of simulated calculation using the Finite Element Method, the temperature would increase by less than 10^{-6} K in one year by self-heating.

Long-term instrument deterioration: A multiplexer and an amplifier in the electrical box, which was put on the lunar surface, were used. The temperature-dependent offset voltages including the attenuator and mismatched differential impedances, which act with circuit impedances and amplifier bias currents to introduce variable offset voltages for each channel and different offsets between channels, are canceled by the ratio measurement technique [5]. The use of only one multiplexer and amplifier indicates the following two facts; the first is that the anomaly of the circuit in the electrical box cannot affect the probe sensors because the impedance of the amplifier is high enough. The second is that an error occurring in the electrical box should appear simultaneously in the all of the telemetry data because all of the telemetry data are processed by one amplifier after switched by multiplexer. However the time lag in the temperature profiles did not appear at same time; additionally, the degree of the temperature rise is not consistent among the sensors (see Fig. 1 in [3]).

As a result of the assessment, the factors above could not cause an increase of temperature over a few degrees. Because these factors are less likely, it seems that the instrumental factors may not be the reason.

Insolation duration and precession: As argued above, the precession only changes the solar phase angle on a 18.6-year cycle, and it causes the variation of the maximum temperature at lunar noon. This corresponds to the seasonal variation of the Earth: both positions of sunrise and sunset change on a 18.6-year cycle. By using the JPL DE405 ephemerides, the mean surface temperature during one lunation is proportional to the insolation duration approximately at a rate of 0.5 K per hour. The Apollo 17 landing site is located in a mountainous region on the southeastern rim of the Serenitatis basin, and the site is surrounded by three high, steep massifs. If the insolation duration is influenced by the topography, the mean temperature at the surface is reasonably expected to change with a 18.6-year period.

The variation of the insolation duration by topography: The lunar surface temperature changes about 100 K in two hours. It indicates that the observational insolation duration is determined by using the surface temperature profile with a determination error up to a few hours. Figure 2 shows the difference between the observational and the calculated time for five years from 1973. If there were no massifs around the landing site, this variation would not appear because the calculation result includes the effect of the precession etc. Insolation duration is affected by the topography.

As shown in Figure 2, the mean surface temperature during a lunation has been increased for five years at least. It means that the averaged surface temperature also increases for five years. Assuming the increment of insolation duration is 5 hours for five years, the averaged temperature at the surface is expected to increase a few degrees. After considering the amplitude attenuation during the propagation in the regolith we conclude that the temperature rise at 2 m in depth is possible. This result supports the temperature increase as a cause for the thermal wave of 18.6-year cycle, and that the result proposed by Saito et al. (2007) [3].

Conclusion: It is not likely that the temperature increase obtained by the Apollo Heat Flow Experiment for over 5 years is caused by the instrument deterioration. On the other hand, the variation of the insolation duration caused by topography may influence the Apollo measurements. It indicates that we should assess the effect specific to the measurement region including the future mission.

References: [1] Langseth, M. G. et al. (1976) *Proc. Lunar Sci. Conf., 7th*, pp.3143; [2] Saito, Y et al., *Japan Geosci. Union Abstracts #P232-P008*, 2006; [3] Saito, Y. (2007) *Proc. 38th Lunar Planet. Sci. Conf.,* Abstract #2197. [4] Wieczorek, M. A. & Huang, S. (2006) *Proc. 37th Lunar Planet. Sci. Conf.,* Abstract #1682. [5] Lauderdale, W. W. and W. F. Eichelman. (1974) In *Apollo Scientific Experiment Data Handbook.* TM X-58131.

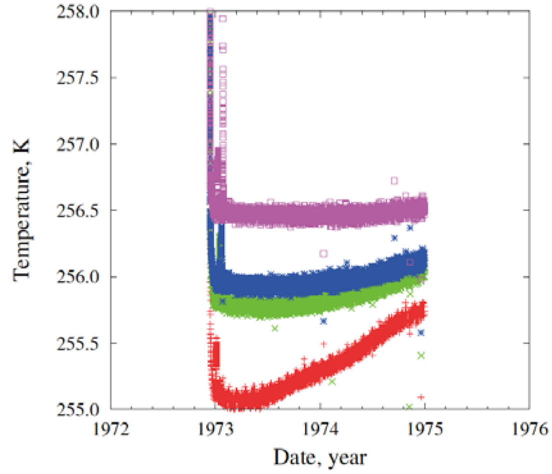

Figure 1: Apollo heat flow Experiment data obtained by Apollo 17 probe 1. As each probe has four gradient thermometers, temperature profiles in time series are measured at four depth points; 130cm (red), 177cm (green), 185cm (blue), and 233cm (purple).

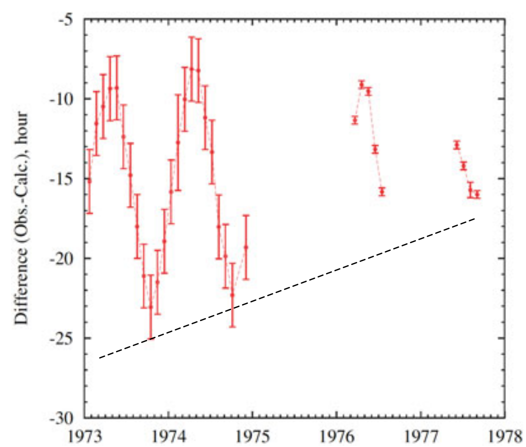

Figure 2: The variation of the insolation duration for 5 years from 1973 until 1977. The vertical axis means the difference between the observational and the calculated time. The reason why the difference is negative is the topographic effect because the existence of the massifs shortens the length of day. The difference had reduced during the Apollo observations. The data between the beginning of 1975 and February 29th, 1976 has been lost. There is no data between July 15 1976 and March 24 1977 because the Lunar Surface Profiling Experiment was carried out.