1994LPI....25.1367S

THE THERMAL HISTORY OF THE LUNAR REGOLITH AT THE APOLLO 16 AND 17 SITES.

S. J. Symes, P. H. Benoit, D. W. G. Sears, Cosmochemistry Group, University of Arkansas, Fayetteville, AR 72701 USA.

In order to explore the thermal history of the lunar regolith we have measured the induced thermoluminescence (TL) properties of samples from the Apollo cores 60009/10, 60013/14, and 70001-70009. We observe a decrease in TL sensitivity and an increase in TL peak temperature with increasing maturity as measured by magnetic, petrographic, and inert gas measurements. The decrease in TL sensitivity with increasing maturity reflects the conversion of crystalline feldspar to nonluminescent glass and the increase in TL peak temperature reflects the partial or complete disordering of the structural state of the feldspar. Similar TL properties are displayed by basaltic meteorites and chondrite regolith breccias. Our results are consistent with considerable variations in maturity of the soil in lunar cores obtained at the Apollo 16 and 17 sites and they provide a quantitative evaluation of the temperatures associated with regolith processing.

Introduction. The Moon's heavily cratered surface is one indication that planetary bodies have been subjected to a continuous bombardment by external objects ranging from small dust specks to large bodies tens of kilometers in diameter. Depending on the magnitude of the event, impacts can cause shock deformation, heating, melting, and even vaporization of the surface materials. The small scale evolution of the lunar surface is dominated primarily by small impactors which both develop and garden the lunar regolith. Lunar core samples provide the only means for studying variations in regolith properties with depth. Estimated regolith thicknesses are 4-5 m in mare regions and 10-15 m in the highlands while the longest core is ~3m (70001-70009), thus the available cores sample a significant fraction of the regolith.

Experimental. We measured the induced thermoluminescence (TL) properties of samples from the lunar cores 60009/10, 60013/14, and 70001-70009 using the techniques and apparatus described by ref. 1. The maximum intensity of the luminescence (*i.e.* the TL sensitivity) and the temperature at which this occurs (the TL peak temperature) were measured. The TL sensitivity is primarily related to the abundance of crystalline feldspar, which is the major TL phosphor in ordinary and carbonaceous chondrites [2,3], HED achondrites [1,4], and lunar meteorites [1,4]. The TL peak temperature is related to the structural state (specifically the degree of order) of feldspar. Since feldspar melts at about 1500°C, and the temperature related to the order-disorder transition for calcic feldspar is ~600-800°C [13], both TL sensitivity and TL peak temperature are strongly affected by thermal history.

Results and Discussion. Figure 1 shows our results with the data coded according to maturity as determined by ferromagnetic resonance (Is/FeO) [5,6,7] and agglutinate measurements [8] for regions of the core adjacent to the TL samples. As expected, the TL sensitivity decreases and the TL peak temperature increases with increasing maturity at both sites. Similar changes in TL properties with maturity are observed for ordinary chondrite regolith breccias [9]. The agreement between TL properties and other maturity indices is not exact (*e.g.* some of the samples considered "submature" on the basis of Is/FeO are "immature" in terms of TL peak temperature), but sample heterogeneity and genuine variations in maturity between samples would explain these small differences.

We also observe a factor of ~4-5 difference in the mean TL sensitivity of the regolith at the Apollo 16 and 17 sites. Both highland and mare material contain plagioclase feldspar, consisting mainly of anorthite and lesser amounts of albite. However, the proportion of feldspar in the highlands is greater than that in the maria, consistent with flotation of this relatively light mineral in a magma ocean. This is probably the major cause of the higher TL sensitivity at the Apollo 16 site. However, the higher albedo of feldspar-rich materials will increase the apparent TL sensitivity (due to multiple scattering of the light in the sample pan prior to detection [14]) and there may be differences in the trace element content of the feldspars which would contribute slightly to the TL sensitivity difference between the sites. The same TL sensitivity relationship between highlands and mare basalts is observed for whole-rock lunar samples [10], but the core samples have peak temperatures < 160°C while the whole-rock samples have peak temperatures > 160°C. This implies that the whole-rock samples are in general more mature than the soil and suggests that

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System

1994LPI....25.1367S

forming soil from breccias is a less violent process than producing the rocks by the consolidation of soil [11].

The non-linearity in the data for the Apollo 16 core samples suggests that there are changes occurring during regolith processing which can be observed along the length of a single core, although it is not yet clear what is causing the non-linearity. Comminution tends to concentrate feldspar in the finest fractions [12] which might contribute to this effect because it would cause a small increase in the amount of feldspar in the more mature samples. Alternatively, since the non-linearity is observed only in Apollo 16 samples, it could be a compositional effect. Consistent with this, we have found a correlation between TL sensitivity and the amount of anorthositic component, as determined by mixing models, in our 60009/10 data but not in the Apollo 17 data.

Conclusion. We have found that the TL sensitivity decreases and TL peak temperatures increase with increasing regolith maturity. These changes reflect very different processes being experienced by the feldspar, namely, conversion to nonluminescent glass and structural disordering, respectively. The TL data confirm petrographic and magnetic data which indicate considerable variations in the degree of regolith maturity along the length of these lunar cores and they provide new insights to the temperatures involved during regolith processing.

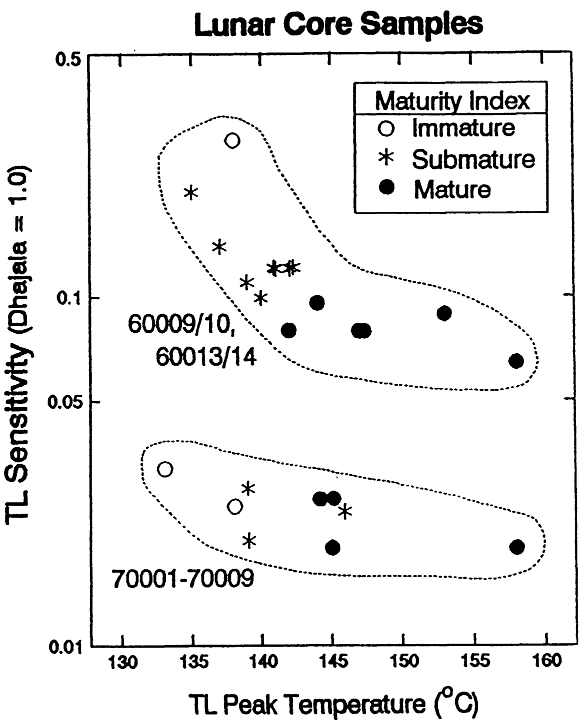

Fig. 1. Plot of TL sensitivity against TL peak temperature for lunar cores from the Apollo 16 and 17 sites with the data coded to indicate regolith maturity. With increasing maturity the TL sensitivity decreases as feldspar is destroyed and the TL peak temperature increases as feldspar is transformed to the disordered phase.

[1] Batchelor J. D. and Sears D. W. G. (1991) *Geochim. Cosmochim. Acta* **55**, 3831-3844. [2] Lalou C. *et al.* (1970) *C.R. Hebd. Seanc. Acad. Sci. (Paris) Serie D* **270**, 2401-2404. [3] Keck B. D., and Sears D. W. G. (1987) *Geochim. Cosmochim. Acta* **51**, 3013-3021. [4] Batchelor J. D. (1992) Unpublished Ph.D. Thesis, University of Arkansas. [5] Morris R. V. and Gose W. A. (1976) *Proc. Lunar Sci. Conf.* **7th**, 1-11. [6] Morris R. V. *et al.* (1979) *Proc. Lunar Planet. Sci. Conf.* **10th**, 1141-1157. [7] Morris R. V. and Lauer Jr. H. V. (1992) *Lunar Planet. Sci.* **23**, 935. [8] McKay D. S. *et al.* (1977) *Proc. Lunar Sci. Conf.* **8th**, 2929-2952. [9] Haq M. *et al.* (1989) *Geochim. Cosmochim. Acta* **53**, 1435-1440. [10] Symes S. *et al.* (1992) *Meteoritics* **27**, 294. [11] Benoit *et al.* (1994) *Lunar Planet. Sci.* **25** this volume. [12] Devine *et al.* (1982) *Proc. Lunar Planet. Sci. Conf. 13th*, in *J. Geophys. Res.* **87** A260-A268. [13] Hartmetz C. P. and Sears D. W. G. (1986) *Meteoritics,* **21** 388-389. [14] Sears D. W. G. (1980) *Icarus*, **44** 190-206.
This work supported by NASA grant NAGW-3519.

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System