PRIMITIVE MATERIAL IN LUNAR HIGHLAND SOILS. P.H. Benoit[1], J.D. Batchelor[1,2], S.J. Symes[1], and D.W.G. Sears[1]. [1]Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701, USA. [2]Analytical Services, Reynold's Electric and Engineering, P.O. Box 98521, Las Vegas, NV 89193.

The surface of the Moon, the source of all current lunar samples, has been heavily processed since its formation. The lunar highlands are particularly interesting in this regard; they represent the first material to crystallize on the Moon and they are the most heavily modified by subsequent impact processing. In fact, virtually all lunar highland samples are heavily brecciated. In this paper we present induced thermoluminescence data for Apollo 16 and 17 soil samples and 16 lunar rocks (including three lunar meteorites); we find that there is feldspar in the lunar soils which has been less thermally processed than most highland rock samples. On the basis of these data we suggest that simple comminution to produce soil is thermally a less extreme process than brecciation and hence the least thermally altered highland material in the lunar collection may be found in the lunar soil.

Introduction. The search for "primitive" lunar highlands material in the lunar sample collection has been a difficult and only partially successful one. A number of monomict breccias have been recognized which can be considered as chemically "pristine" [1]. However, these breccias have been subjected to a fair degree of thermal processing associated with the brecciation event(s). Even rarer are the true igneous highland rocks, which show no signs of brecciation. The collection of lunar highland samples is thus heavily dominated by brecciated, if not partially or wholly impact-melted, material.

Induced thermoluminescence (TL) measurements are useful in the study of the thermal history of brecciation and regolith processing; we have previously conducted studies of ordinary chondrite regolith breccias [2] and present results for lunar cores at the current meeting [3]. There are two separate types of data obtained from the TL glow curves. The maximum intensity of the TL signal (TL sensitivity) reflects the abundance of phosphors in the sample. In the case of most lunar, achondrite, and ordinary chondrite samples feldspar is the dominant phosphor. The peak temperature in the glow curve reflects the average degree of order in the feldspar. Ordered high-Ca feldspar has a TL peak temperature of 90°C, while the disordered form has a peak temperature of 240°C [4].

The induced TL data were collected using the same technique and apparatus that we have used to study achondrites [4]. Sample processing was limited to gentle grinding. Thermoluminescence sensitivity values are reported relative to Dhajala (H3.8) which was used as a laboratory standard throughout these and previous measurements. Our samples include various depth intervals in the lunar cores 60009/10, 60013/14, and 70001-70009, the impact melt rocks 14310, 60315 and 68415, and the lunar highland meteorites ALHA 81005, Y82192 and MAC 88104/5 in addition to various mare basalt samples.

Results. Our results are summarized in Fig. 1. Although a number of rock samples show inflections at low glow curve temperatures which may be caused by polymorphs of quartz (*e.g.*, 60315, 12021), no other glow curve peaks aside from those associated with feldspar were observed. As noted by Symes *et al.* [5] the highland rock samples have higher TL sensitivities than the mare basalt samples but have TL peak temperatures which are similar to the mare basalts. While the TL sensitivities of the two Apollo 16 cores are very similar to those of the highland rock samples, their TL peak temperatures are significantly lower. The Apollo 17 core samples show low sensitivity levels similar to mare basalts, but also have significantly lower TL peak temperatures than either the mare basalts or the highland rock samples.

Discussion. As described by Symes *et al.* [5], the hiatus between the highland and mare basalt samples in TL sensitivity reflects differences in feldspar abundance between these two broad classes of lunar samples, with the highland rock samples having much higher feldspar abundances compared to mare basalts [1]. The high peak temperatures of the highland rock samples are, however, related to thermal history. It is apparent that the feldspar of highland cumulate rocks crystallized from a magma and cooled slowly, allowing the growth of large crystals. Under such conditions feldspar should be highly ordered, as is the case for terrestrial analogues. The high degree of feldspar disorder, as shown by their high TL peak temperatures, in the three impact melts (14310, 60315, and 68415) is not unexpected; virtually all the feldspar in these rocks crystallized during very rapid cooling. The variation in the peak temperatures of these samples may reflect mixing of disordered feldspar crystallized from the melt with more ordered surviving clasts. Alternatively, the variation may reflect differing degrees of felspar order as a result of different cooling rates, with 68415 having a lower cooling rate than 60315 and 14310; the differences in texture between 68415 and 14310 (an impact melt breccia) is evidence for this possibility [1]. The explanation for the difference between 60315 and 68415 is less certain, but 60315 contains more mesostasis than 60415 and hence may have cooled more rapidly.

All three of the lunar highland meteorites in the present study are regolith breccias. Of the three, Y82192 and ALHA 81005 have very similar TL parameters while MAC 88104/5 has lower TL sensitivity and a higher peak temperature. It is likely that these observations reflect the different cooling histories of these meteorites. While MAC 88104/5 has relatively pristine interstitial maskelynite glass, the equivalent glass in Y82192 and ALHA 81005 is completely devitrified to submicrometer-sized crystals of plagioclase [6]. The higher TL sensitivity and lower peak temperatures of Y82192 and ALHA 81005 compared to MAC 88104/5 reflects the abundance of devitrified glass. In any case, although these meteorites have lower TL peak temperatures than two of the impact melts, it is clear that they still contain high abundances of disordered feldspar and hence have been heavily thermally processed compared to the supposed ordered parent rocks.

The lunar cores have the lowest TL peak temperatures of any of the lunar materials yet measured. In addition, however, as described by Symes *et al.* [3] we observe a trend of increasing TL peak temperature and decreasing sensitivity as a function of soil maturity. Thus, the lunar samples in our present database with the lowest TL peak temperatures are core samples from immature intervals in the stratigraphy. In the case of the 60009/10 core (Fig. 2), the TL parameters generally correlate with the abundance of the ferroan anorthosite component, calculated from bulk chemical analyses [7]. However, as is apparent from the grouping on the basis of maturity in Fig. 2, this trend is largely produced by a fortuitous correlation between ferroan anorthosite content and regolith maturity in this core.

There are two non-exclusive explanations for the low TL peak temperatures of feldspar from immature portions of the lunar cores. One possibility is that feldspar in these portions of the core have somehow been annealled at fairly high temperatures and slowly cooled, thus converting disordered feldspar to ordered feldspar. Since the only significant heat source is impact processing, however, this does not explain why it is the immature rather than the mature portions of the cores which have the highest degree of feldspar order. Another possibility is essentially a mixing model. In this case, primary ordered feldspar, produced by slow cooling after crystallization from a magma, is the source of much of the feldspar in the cores. Not surprisingly, much of this feldspar is associated with the ferroan anorthosite component (Fig. 2). During regolith processing a portion of the primary ordered feldspar is converted to disordered feldspar (in addition to some converted to non-luminscent glass). Thus, with increasing degrees of regolith processing, the average degree of feldspar disorder increases, which is reflected in the larger TL peak temperatures of mature portions of the cores.

In conclusion, our data indicate that the average degree of order in feldspar is greater in lunar cores (soils) than in any highland rocks examined to date and that the average degree of order is greatest in the most immature portions of the cores. We suggest that these data are best explained by relatively small amounts of thermal processing in the soil samples compared to the lunar breccias (rocks). Thus, from the standpoint of thermal reprocessing, portions of the lunar soil are more pristine than any of the highland rocks that we have yet measured.

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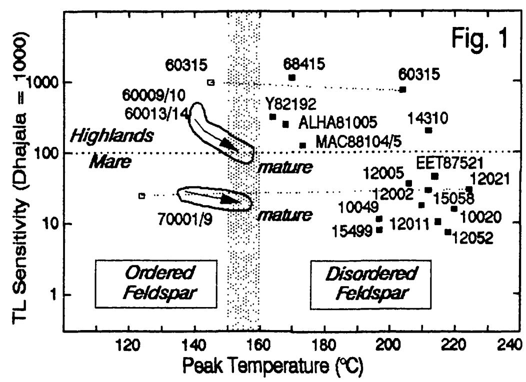
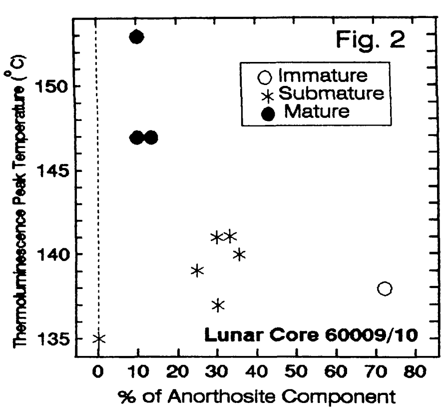


Fig. 1 (top). Induced TL sensitivity vs. TL peak temperature for lunar core and rock samples. The soil samples from cores 60009/10, 60013/14, and 70001-70009 have significantly lower TL peak temperatures than lunar rock samples. This indicates the presence of a greater amount of ordered feldspar in the soil samples compared to the rock samples. **Fig. 2 (bottom).** In the 60009/10 core there is a correlation between induced TL parameters (exemplified by TL peak temperature) and anorthosite component (taken from [7]). However, this alone cannot explain the trends observed in Fig. 1 and the apparent correlation is probably the result of a correlation between anorthosite component and maturity in this core.



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