NEW INSIGHT INTO THE FINE SCALE PROPERTIES OF ANTARCTIC MICROMETEORITES FROM THERMOLUMINESCENCE ANALYSIS.

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Introduction: Extraterrestrial particles collected terrestrially with sizes less than 1mm are called micrometeorites (MMs) [1]. Micrometeorites constitute the majority of the mass accreted to the Earth from space [1, 2] and have an origin from asteroids, the Moon, Mars and comets [1, 3]. The main sources for these materials are the south polar ice cap [4, 5] and the stratosphere [6]. The compositions, mineralogy, and textures of micrometeorites [7], specifically of Antarctic micrometeorites (AMMs), have been reported [8, 9]. Micrometeorites, which are melted or partially melted, are mostly reported as highly unequilibrated material. They are more similar to carbonaceous chondrites by having lower content of Ni and S, and a different oxygen isotopic composition [9]. The study of micrometeorites has shown that un-melted micrometeorites are mostly similar to CI, CM, CO, and CV. Thermoluminescence (TL) is uniquely successful in evaluating the thermal history of extraterrestrial materials, including ordinary chondrites [10], CM, CV [11], and CO chondrites [12]. We report here on the first fine scale TL study of Antarctic micrometeorites collected at Cap Prudhomme.

Experimental: Eleven AMMs with sizes between 100-160 µm (Figure 1) from a previous study of the thermal history of AMMs [13] were gently crushed in a mortar and pestle. Using a micromanipulator, fitted with a 5 µm glass needle, 10-15 µm particles from the resulting fine fraction were picked, placed in the center of a 5 mm copper pan and imaged with a digital microscope (Figure 1). Individual samples were placed in a modified Nuclear and Daybreak TL instrument and their natural TL (NTL) measured by applying a linear temperature ramp up to 500 °C.

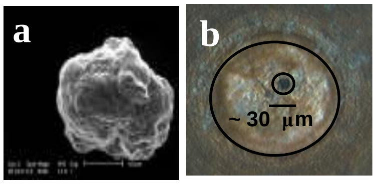

Fig.1 *a) an SEM image of a 200 µm scoriaceous micrometeorite and b) a 15 µm internal fragment.*

The individual fragments were then exposed to a 141 mCi ^{90}Sr beta source for 5 minutes and their induced TL measured. The induced TL (ITL) measurements were repeated 3 times to ensure reproducibility. Dark current and blackbody curves were produced prior to each sample measurement to monitor background noise and ensure equipment stability.

Results: The original TL study conducted on these AMMs displayed no measurable natural TL, which we assumed resulted from surface heating during atmospheric passage [13]. However, by crushing the micrometeorites and gaining access to fresh internal material we were able to measure relatively strong natural and induced TL signals for most of the 29 10-15 µm interior fragments from eleven AMMs. We can now reliably and reproducibly measure the natural and induced TL properties of material comparable in size to IDPs and Stardust particles.

Low and high peak temperatures for the induced TL were generally uniform across the particles (Fig. 2a, b).

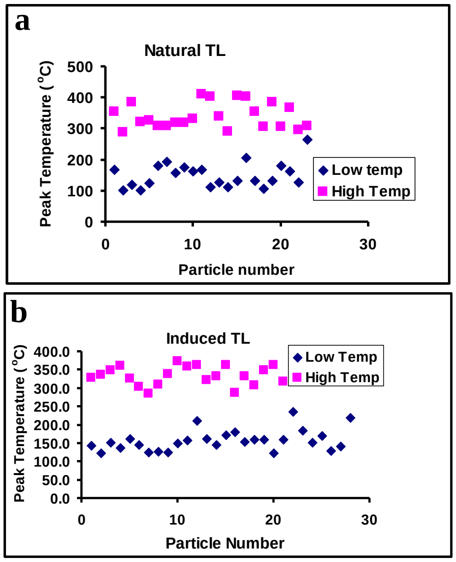

Fig. 2 *Peak temperatures for low and high temperature TL in 10-15 µm fragments from the interior of AMMs. (a) Natural TL peaks. (b) The TL induced by exposure to beta radiation in the laboratory. Most internal fragments showed measurable natural and induced TL with reasonably reproducible peaks at both high and low temperatures.*

Despite these grains coming from close proximity the natural TL intensities show significant variations while the induced TL properties are generally uniform. When expressed as ratios to reflect thermal and radiation history (see Fig. 3), the grains show evidence for considerable and independent variation in these parameters.

Discussion: Before discussing the thermal and radiation history of these particles, it is worth mentioning the mineralogical implications of our data. First, the relatively narrow range of TL peak temperatures and the existence of high and low temperature peaks suggests a fairly simple uniform mineralogy and that the luminescence is being produced by a common mineral. Typically this is feldspar, but in these particles a detailed analysis of peak widths and temperatures suggested that it was forsterite. Second, these data distinguish the AMMs from the CI and CM meteorites since except for one metamorphosed CM chondrite [14]; these classes do not produce a measurable induced TL signal. Fe-rich, hydrated minerals and amorphous materials do not have the crystalline structure with the appropriate lattice defects or impurity atoms. On the other hand, CO or CV chondrites show a wide range of strong induced TL signals depending on their metamorphic history [11, 14].

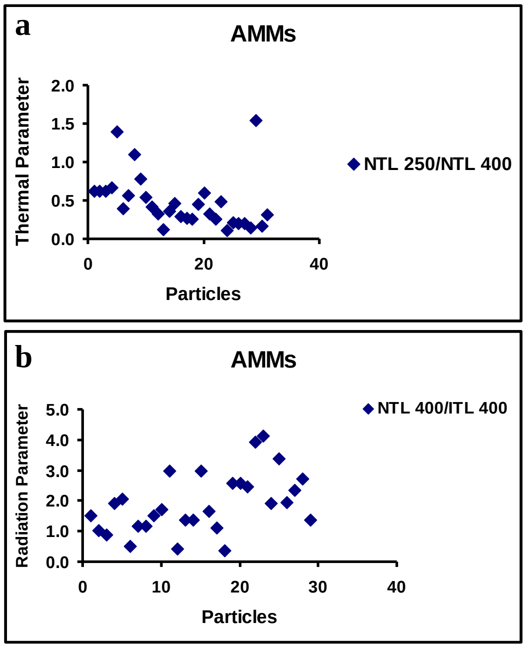

Fig. 3. *The natural and induced TL data expressed to reflect the (a) thermal and (b) radiation history of the individual AMM fragments. The higher the NTL(250)/NTL(400) ratio (thermal parameter) the less thermal exposure. The higher the NTL(400)/ITL(400) ratio (radiation parameter) the greater the radiation dose absorbed. Both parameters show a range of a factor of about six and the fragments appear to have had independent thermal and radiation histories.*

The presence of large variations in thermal history for these internal fragments is consistent with large temperature gradients induced during atmospheric passage with the surface of the micrometeorite at the melting point and the interior essentially unheated. Such steep profiles are consistent with theoretical treatments of small particles passing through the atmosphere [15] and with published mineralogical and compositional data for micrometeorites [7]. It is possible for micrometeorites to pass through the atmosphere with complete melting, or with little or no melting.

The presence of large variations in the apparent radiation history suggests that either the radiation environment is highly localized and reflects distance from the nearest radioactive mineral grain, or strong radiation profiles in space. Laboratory measurements and theoretical treatments indicated that cosmogenic profiles are very smooth, they do not show factor of six variations over 200 µm distances [16]. An exception, are the very steep profiles produced by solar energetic particles which have millimeter penetrability [17]. This would require that the micrometeorites were their present size during irradiation in space and were never part of larger objects. Steep gradients due to grain-to-grain irradiation are probably responsible for the heterogeneity in the radiation histories reported for 10-15 µm fragments of the Semarkona matrix [18], which might also contribute to thermal heterogeneities.

Conclusion: We have been able to reliably and reproducibly measure natural and induced TL properties of twenty-nine 10-15 µm particles from a suite of Antarctic micrometeorites. This size range is comparable to IDPs and Stardust particles. Glow curve shape and induced TL levels are basically uniform suggesting a common mineralogy. The TL data are inconsistent with a CI- or CM-like mineralogy. The data suggest considerable heterogeneity in thermal and radiation histories for the individual 10-15 µm fragments which are reasonably, if not unambiguously, interpretable.

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