**THERMOLUMINESCENCE AND THE HISTORY OF COMETARY PARTICLES.** D. W. G. Sears[1,2] and J. P. Craig[1]. [1]Arkansas Center for Space and Planetary Sciences, (dsears@uark.edu), [2]Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR, 72701, USA.

**Introduction:** Cometary particles have the potential for a wide variety of physical histories prior to leaving the vicinity of the comet [1]. These histories will leave an imprint on their thermal, radiation and mineralogical properties. Thermoluminescence analysis is one highly sensitive means of determining these properties, especially when the majority of the particle is amorphous [2].

For many decades thermoluminescence (TL) has been in routine use in attempting to decipher the history of extraterrestrial materials. For 14 years the natural ("as received") TL was reported in the *Antarctic Meteorite Newsletter* as part of the initial investigation of Antarctic meteorites. The data provided information on the thermal and radiation history of the meteorites and thus their terrestrial ages and orbits [3]. Starting in 1980, the induced TL signal, appropriately normalized, has been in routine use to determine the metamorphic history of meteorites. Beginning with unequilibrated ordinary chondrites [4], then for a variety of meteorite classes, such as CO [5], CV [6] and HED [7] and chondrules [8] and inclusions [6] from meteorites and lunar samples [9]. We recently reported studies of the TL properties of micrometeorites [10] and fragments of matrix from the Semarkona LL3.0 ordinary chondrite [11].

The studies described above, especially the later studies, represent steady progress in analyzing particles of ever smaller size by the TL technique. Bulk measurements are made on 4 mg powders, the chondrules were 150-450 μm in size, the inclusions were a few hundred μm, the micrometeorites were ~150 μm and the Semarkona fragments were 100 μm to 400 μm. In a companion abstract we report our progress on attempting to reliably and reproducibly measure the TL properties of 10-15 μm particles of material removed from the Semarkona meteorite. This size range is comparable to IDPs and Stardust particles. Here we review some ideas by which TL studies can shed light on the history of cometary particles.

**History of cometary particles:** The Giotto mission to Comet Halley[12], the Deep Space 1 mission to Comet Borelly [13], the Deep Impact mission to Comet Tempel 1 [14] and the Stardust mission to Comet Wild 2 [15] indicated that comet nuclei are coated with a refractory, cratered crust with vents through which dust and gases escape. These vents were predicted by Whipple in the 1950s on the basis of non-gravitational movements shown by certain comets and they have sometimes been optically observed. Laboratory simulation experiments, shown in Fig. 1, suggest a structure with both mass and heat transport.

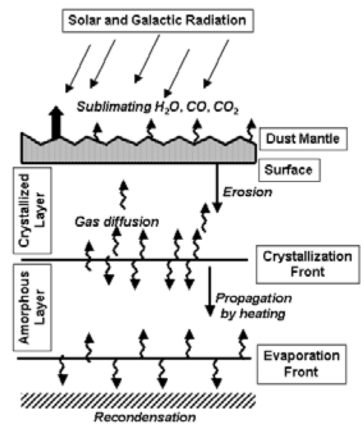


*Fig. 1. Mass movement in the upper meter or two of a comet nucleus as inferred by laboratory simulation experiments. [Ref. 16, and sources therein.]*

We suggest four scenarios for particles passing through various parts of the environment suggested by Fig. 1. Particles that experienced high radiation doses by being on the surface and are then stored at low temperatures by burial (Category A). Particles that experienced high doses by being on the surface and that were never buried will have experienced both high doses and high temperatures (Category B). Particles that spent virtually all their time buried and were excavated immediately prior to capture will have experienced low doses and low temperatures (Category C). Particles that were buried and therefore shielded from radiation that were brought to the surface and collected at a time before radiation exposure was significant (Category D).

**Theory of natural TL:** The ratio of the natural TL level observed to the saturated TL value (the maximum value possible) is described by:

$$\frac{\phi_N}{\phi_S} = \frac{1}{1 + [\, s / \alpha R \exp(-E/kT) \,]} \qquad (1)$$

where $\phi_N$ (Gy, 100 Gy = 1 rad, a unit of absorbed dose) is a measure of natural TL, $\phi_S$ (Gy) is the measure of TL at saturation, dimensionless parameter s is the Arrhenius factor, $\alpha$ is the rate constant ($s^{-1}$) for de-excitation, R is the dose rate (Gy/s), E is the trap depth (eV), k is Boltzman's constant (eV/K) and T (K) is temperature. Most of the parameters appearing in Eq. 1 are characteristics of the material which can be measured by laboratory methods or assumed uniform for a given type of material. The exceptions are the two environmental factors, specifically, the radiation dose rate and storage temperature. These two factors capture much about the physical scenarios presented by Fig. 1 and the four categories of particles mentioned above.

The thermoluminescence that is emitted over a range of temperatures up to 500°C in the present case comes from about eight discrete peaks each with its own set of parameters. These parameters determine the stability of the peaks which range from half lives of a few thousand years at low emission temperatures to half lives greater than the age of the solar system at high emission temperatures [17]. The sample to sample variation in TL that can be caused by mineralogical and petrological differences can be removed by normalizing the natural TL to the TL induced by a standard test dose and when this normalized ratio is plotted as a function of emission curve temperature the resulting curve is referred to as the plateau curve.

**Natural TL as a window on comet particle history:**

Thermoluminescence plateau curves for the four categories of particles mentioned above are shown in Fig. 2. These curves are qualitative and the temperatures should not be taken too seriously but they illustrate how natural TL would vary with particle history. Exposure to high radation doses will move the level of the plateau to higher values. This is the basis for dosimetry methods and pottery dating which are the two most common applications of TL. Exposure to high temperatures will drain the low temperature TL. Thus the temperature at which the onset of the plateau occurs will increase with an increase in the environmental temperatures experienced.

**Induced TL as a window to comet particle history:**

The temperature of the peak, the width of the peak at half maximum peak, and the intensity of the peak can be measured from the glow curve induced by a given standard test dose of radiation after removal of the natural TL signal. Experience shows that the intensity of TL is related to the amount of crystalline phosphor present and its composition. For instance, the crystallization of chondrule glasses causes a $10^5$-fold increase in the TL sensitivity of ordinary chondrites [4] while Fe diffusing out of the feldspar causes a factor of 10 increase in the TL of HED meteorites [7]. Like feldspar, forsterite produces TL but has distinctive TL peak temperatures and widths [10,11]. In fact, different temperature-dependent ordering of feldspar can be detected using peak shape [6]. Since modern equipment is highly sensitive and can in principal detect a few tens of photons these phases can be detected when immersed in amorphous substrates.

**Conclusion:** TL studies provide a wide variety of data on tiny samples not obtainable by other methods.

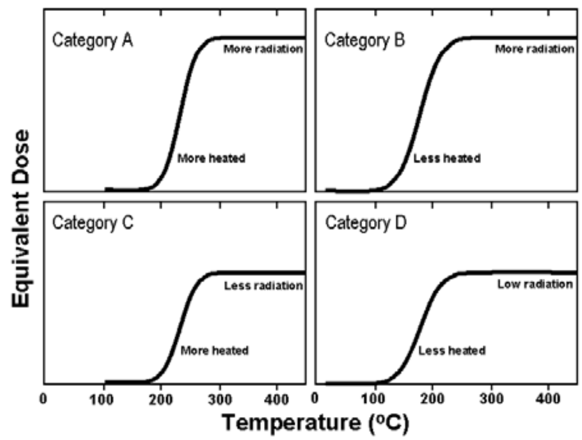


*Fig. 2. Plateau curves for the thermoluminescence of comet dust particles. High radiation exposure causes high plateau levels, heating causes the onset of the plateau to be off-set to higher temperatures. Thus we have four situations corresponding to the four categories of particles discussed in the text.*

**References:** [1] Levasseur-Regourd *et al.* (2008). *Planet. Space Sci.* 56, 1719-1724. [2] Sears (1988). *Nucl. Tracks Radiat. Meas.* 14, 5-17. [3] Hasan *et al.* (1987). *J. Geophys. Res.* 92, E703-E709. [4] Sears *et al.* (1980). *Nature* 287, 791-795. [5] Keck and Sears (1987) *Geochim. Cosmochim. Acta* 51, 3013-3022. [6] Sears *et al.* (1995). *Meteoritics* 30, 707-714. [7] Batchelor and Sears (1991). *Geochim. Cosmochim. Acta* 55, 3831-3844. [8] Sears *et al.* (1995). *Meteoritics* 30, 169-181. [9] Batchelor *et al.* (1997). *J. Geophys. Res. (Planets)* 102, 19,321- 19,334. [10] Sedaghatpour and Sears (2009). *Meteor. and Planet. Sci.* 44, 653-664. [11] Craig and Sears (2009). *Meteor. Planet. Sci.* 44,643-652. [12] Keller and Thomas (1997). *Adv. Space Res.* 19, 187-194. [13] Nelson *et al.* (2004). *Icarus* 167, 1-3. [14] Tozzi *et al.* (2007). *Astron. Astrophys.* 476, 979-988. [15] Fernández et al. (2007) *Icarus* 191, 11-21. [16] Sears *et al.* (1998). *Meteor. Planet. Sci.* 44, 653-664. [17] McKeever (1980). *Mod. Geol.* 7. 105-114.