INDUCED THERMOLUMINESCENCE PROPERTIES OF FORSTERITE AND IMPLICATIONS FOR THE HISTORY OF PRIMITIVE SOLAR SYSTEM MATERIALS.

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Introduction: As a primary refractory condensate, forsterite represents an important constituent of many primitive solar system materials such as nebular dust, dust associated with galaxies, and cometary dust [1-11]. Preliminary studies on micrometeorites and the fine-grained matrix of Semarkona, a primitive ordinary chondrite, indicate that forsterite is an important component of these materials [12, 13]. We have measured the TL properties of a suite of terrestrial forsterites in order to better understand the TL properties of extraterrestrial materials in which this mineral is thought to be present.

Samples and Experimental Procedures: Seven samples were supplied by the Smithsonian Institution and a commercial source representing both igneous and metamorphic formation environments. Our TL procedures are those used for many years to study extraterrestrial samples. The TL measurements were performed with a modified Daybreak Nuclear and Medical systems apparatus. An EMI 9635QB photomultiplier tube with heat filters and photon-counting electronics produced a signal-to-noise ratio in excess of 10 for the samples in the present study. Two or three separate fragments from each forsterite sample were crushed with mortar and pestle to ~100 µm so the powder would pour and not clump. Each sample was drained of any natural TL by heating briefly to ~500°C, and then the TL signal induced by a five-minute exposure to a 200 mCi ^{90}Sr beta radiation source was measured. The induced TL measurements were repeated three times. As with previous studies, we measured the maximum light produced (which is normalized to 4 mg of the H3.9 ordinary chondrite Dhajala and termed "TL sensitivity"), the temperature at which TL production is a maximum (the "peak temperature"), and the temperature range of the full-width at half-maximum of the TL peak (the "peak width"). Monitoring of black body curves enabled us to ensure the stability of the equipment.

Results: Our TL data are given in Table 1. Three of the forsterites from igneous regions have TL sensitivities similar to those of the metamorphic regions, but the San Carlos forsterite is a factor of two higher. The unknown Arizona sample shows some heterogeneity, but most of the data are in the lower range. Figure 1 shows a plot of TL sensitivity against peak temperatures and peak widths; the data cluster fairly tightly; there is also an indication that both increase with increasing TL sensitivity. Figure 2 shows a comparison of TL peak temperatures with TL peak widths. Not only do we see a

Table 1. TL data for seven forsterite samples†.

Sample source*#	TL sensitivity (Dhajala = 1)	TL Peak temp. (°C)	TL Peak width (°C)
Sunnmore-1*	0.016 ± 0.004	163 ± 29	92 ± 16
Sunnmore-2*	0.009 ± 0.001	162 ± 14	65 ± 8
Sri Lanka-1*	0.017 ± 0.002	166 ± 18	104 ± 21
Sri Lanka-2*	0.007 ± 0.001	126 ± 8	67 ± 2
Daybrook-1*	0.012 ± 0.004	167 ± 26	89 ± 10
Daybrook-2*	0.011 ± 0.002	147 ± 2	65 ± 6
Kilbourne-1*	0.009 ± 0.007	173 ± 21	103 ± 18
Kilbourne-2*	0.009 ± 0.002	185 ± 9	91 ± 5
Kilbourne-3*	0.010 ± 0.001	183 ± 11	100 ± 4
San Carlos-1*	0.025 ± 0.007	178 ± 16	135 ± 20
San Carlos-2*	0.02 ± 0.002	198 ±10	133 ± 10
Unk AZ-1*	0.011 ± 0.010	186 ± 46	136 ± 27
Unk AZ-2*	0.010 ± 0.001	204 ± 12	106 ± 6
Unk AZ-3*	0.010 ± 0.001	193 ± 16	106 ± 8
Unk AZ-4*	0.027 ± 0.002	218 ± 9	159 ± 14
Ethiopia-1#	0.011 ± 0.007	166 ± 27	101 ± 4
Ethiopia-2#	0.010 ± 0.002	160 ± 23	120 ± 21
Ethiopia-3#	0.013 ± 0.001	157 ± 11	114 ± 19

† Uncertainties are 1σ for replicate measurements.
* Smithsonian Institution, # Great South Gems and Minerals

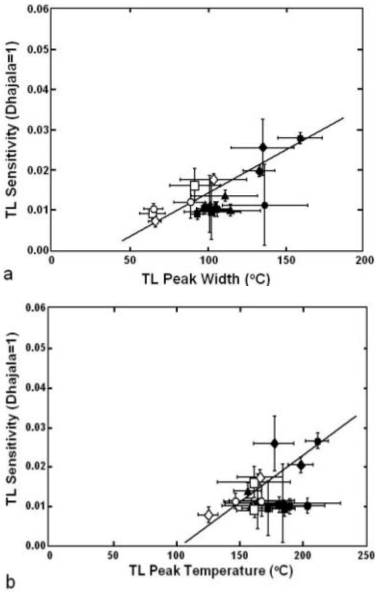

Fig. 1. *TL sensitivity values compared with TL peak width (a) and TL peak temperature (b). In both cases, the forsterites representing the two formation environments (metamorphic-open symbols, volcanic-filled symbols) plot in relatively tight clusters.*

positive correlation between peak temperature and peak width, but the metamorphic samples plot at the lower end of the range and igneous samples plot at the upper end.

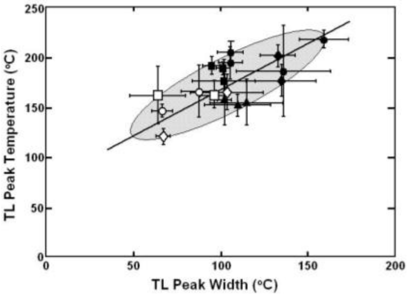

Fig. 2. *There is a positive correlation between peak temperature and peak width. Metamorphic samples plot at the lower end of the range and volcanic samples plot at the upper end of the range.*

Discussion: The forsterites we have examined, while from a wide variety of geological contexts, have relatively uniform TL properties, plotting in tight clusters in Fig. 1-2. However, forsterites from igneous localities have comparable to higher TL sensitivities, higher TL peak temperatures and broader TL peak widths than forsterites from metamorphic environments. The fact that the data plot in tight clusters means that they can be used to some extent for mineral identification.

Figure 3 shows TL data obtained for micrometeorites recovered from Cap Prudhomme, Antarctica and for six micrometer fragments of Semarkona matrix; also shown are the forsterite field and the fields occupied by the type 3 ordinary chondrites where the luminescent phase is feldspar [12-15]. The forsterites plot along a similar diagonal to the ordinary chondrite fields but are displaced to the upper left with minimal overlap between the fields clearly distinquishing the two minerals. The process for moving along the diagonals however, is very different for the two minerals. While the meteorites represent a metamorphic series from ordered to disordered forms of feldspar, the forsterite situation is quite different in that material starting in the upper half of the field may move to the lower half through metamorphic processes [12,14]. We note that not only do the micrometeorites and Semarkona matrix plot in the forsterite field, but that the data plot in the portion of the forsterite field we identify with igneous forsterites; consistent with forsterite being a major component of these primitive materials. In CL imagery forsterite is known for its characteristic red color [16]. CL images by Akridge *et al.* [17] also show forsterite is a ubiquitous component of Semarkona matrix.

Conclusions: Forsterite appears to be common in many primitive extraterrestrial materials. Our studies indicate that forsterite is an important component of micrometeorites and of Semarkona. Further, we find that the TL properties of the micrometeorites and Semarkona matrix are most closely matched by that of the forsterites having an igneous origin. A thorough understanding of this mineral in its terrestrial context should provide more complete insight into deciphering not only early solar system formation history but also the occurrence of forsterite in more widespread astronomical environments.

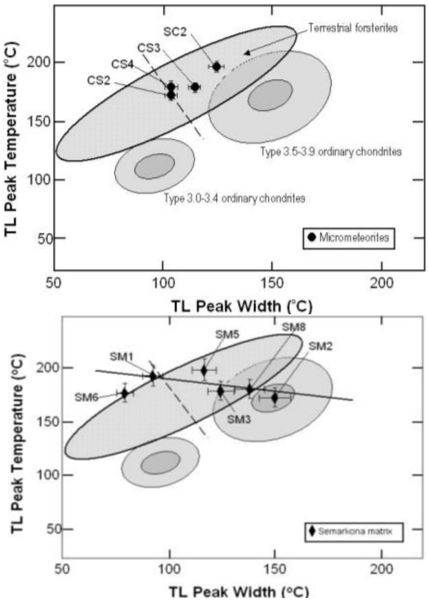

Fig. 3. *Thermoluminescence data reported by Sedaghatpour and Sears (2008) for a suite of micrometeorites and six micrometer fragments of Semarkona matrix reported by Craig and Sears (2008); both plot inside the forsterite field.*

References: [1] McSween (1977) *GCA* **41**, 411. [2] Beckerling *et al*. (1993) *Meteoritics* **28**, 3:320. [3] Hanner (1999) *Space Sci. Rev.* **90**, 1/2:99. [4] Weibruch *et al*. (2000) *MAPS* **35**:161. [5] Mothé-Diniz *et al.* (2008) *Icarus*, **195**, 1:277. [6] Koike *et al*. (2002) *MAPS* **37**:1591. [7] Molster *et al*. (2002) *XXXIII LPS* Abstract # 1471. [8] Markwick-Kemper and Dijkstra *et al*. (2006) *Bul. of the AAS* **38**:1121. [9] Bringa *et al*. (2007) *Astrophys. J.* **662**, 1:372. [10] Zhang and Jiang (2008) *Science in China Series G* **51**, 9:1187. [11] Zolensky *et al*. (2006) *Science* **314**:1735. [12] Craig and Sears (2008) *MAPS* (submitted). [13] Sedaghatpour and Sears (2008) *MAPS* (submitted). [14] Sears *et al*. (1980) *Nature* **287**:791. [15] Engrand and Maurette (1998) *MAPS* **33**:565. [16] Benstock *et al.* (1997) *American Mineralogist* **82**:310. [17] Akridge *et al*. (2004) *JGR* **109**:E07S03.