Thermoluminescence sensitivity and thermal history of unequilibrated ordinary chondrites: Review and update. P.H. Benoit[1],K. Ninagawa[2], and D.W.G. Sears[1], [1]Cosmochemistry Group, Dept. Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701, USA. Email: pbenoit@comp.uark.edu. [2]Department of Applied Physics, Okayama University of Science, 1-1, Ridai-Cho, Okayama 700-0005, Japan.

Introduction. The unequilibrated ordinary chondrites (UOC) are some of the least altered meteorites and thus proved a unique opportunity to examine processes, such as chondrule formation and metal silicate fractionation [1], that occurred in the early solar system,. Induced thermoluminescence (TL) has proven to be uniquely successful in evaluating the degree of metamorphism for ordinary chondrites, CM, CV, and CO chondrites and eucrites [2,3]. Sears *et al*. [3] reviewed the database of induced TL data for unequilibrated ordinary chondrites as of 1991. In this paper we review the induced TL data for 102 unequilibrated ordinary chondrites measured since the 1991 report, which double the available data, and briefly discuss the data.

Methods. As in the previous work [3], 150 - 300 mg samples were reduced to 100 mesh powders and the metal removed with a hand magnet. Three 4 mg aliquots were placed in copper pans, their natural TL removed by heating to 500 °C, given a known dose of radiation and their induced TL measured by heating to 500 °C at 7.5 °C/s while the intensity of light emitted was measured using a PMT equipped with IR and red filters. TL sensitivity is the maximum intensity of light emitted normalized to a standard of Dhajala (H3.8) powder. The temperature of maximum intensity ("peak temperature") and full-width-half-maximum ("peak width") of the TL production were also measured. Splits of some samples were subjected to acid washing [4]. Fifty milligram samples were gently swirled in 6 M HCl for 30 to 60 seconds and then filtered and washed in water and acetone. After drying, the TL of the samples was measured using normal procedures.

Results. Most of the new samples are finds from the Sahara [5] or Antarctica, and some of the data for Antarctic meteorites were presented previously [6]. The range of TL sensitivity in the new samples is similar to the range observed in the previous work and the peak temperature and peak width data resemble those reported previously [3]. With the exceptions noted below, there is good agreement between petrographic type assigned from TL sensitivity and types that were reported in discovery announcements derived from petrographic observations.

Discussion. *Pairing.* Pairing among the present samples was examined using petrology, geographic proximity, natural TL data, and induced TL properties [*e.g.*, 5, 6]. Nineteen samples were identified as possibly paired.

Weathering. Weathering results in a decrease in TL sensitivity in ordinary chondrites. In Antarctic equilibrated ordinary chondrites (EOC), modest acid-washing of powders results in an increase in TL sensitivity to values consistent with falls, and thus the effect is probably due to either covering of the surfaces of feldspar (the TL phosphor) with rust or surface weathering of feldspar grains [4,7]. After acid-washing, 15 Antarctic and 18 Saharan UOC exhibited increases in TL sensitivity ranging from factors of two to ten, similar to increases noted in EOC [4,7]. These results suggest that TL sensitivity data for weathered UOC can underestimate petrologic type by as much as 0.3 units, but 0.1-0.2 is more typical [8].

Low petrologic type meteorites. Ten samples are among the least metamorphosed subtypes (3.0-3.1) (Table 1). Two of these samples, MET 96503 and GRO 95502 and the samples paired with them, were estimated from petrographic observation to be type 3.5. Extensive shock processing would lower TL sensitivity but is ruled out by petrographic observation. It is possible that our samples came from unusual lithologies, but further work is needed to resolve this.

Thermal history and parent bodies. About 10% of the meteorites in the new dataset have significantly lower TL sensitivity than expected on the basis of subtype determined petrographically. These are Wells (LL), WIS 95300, GRO 95505 (L), LEW 87284 (L), Acfer 022 (H), Y 790448 (LL), Y 790994 (L), and EET 87726 (H). With the exception of Acfer 022, these samples do not appear extensively weathered in hand specimen and thus it is unlikely that their low values are due to weathering. Either the petrographic assignment overestimated the subtype of these samples or they have been extensively shocked [3]. Petrographic observations suggest that Y 790448 has been intensely shocked.

Sears *et al*. [3] noted that there was a general tendency in the TL sensitivity of UOCs to increase along the series LL,L and H. Although the present samples almost double the database but the trend is unchanged (Fig. 1). The L chondrites exhibit a broad spread in TL sensitivity, with a preferred value of ~0.1. The H chondrites, although having a few members with low TL sensitivities (*e.g.*, RC 075 [9]), exhibit a preferred sensitivity of ~0.5 relative to Dhajala and do not tend to extend <0.1. The LL chondrites cover a broad range and exhibit no preferred value, but a larger proportion have values below 0.1 compared to L and H chondrites.

The scarcity of low petrologic type H chondrites is possibly because the approximate region of the H chondrite parent body has not been sampled within the last few tens of millions of years [*e.g.*, 10]. However, it is possible that thermal or electrical conductivity are responsible since the H chondrites contain more metal than L and LL chondrites [3]. A third possibility is that formational processes precluded the formation of litte-metamorphosed H chondrites. Akridge and Sears [11] argue that H chondrites were produced near the surface of the parent body, since there are a greater abundance of regolith breccias among H compared to L and LL chondrites [12]. Numeric models indicate that the thermal history of asteroid bodies is strongly dependent on the degree of insulation provided by the regolith [13] and thus the differences between H and L, LL may reflect differences in parent body regolith rather than differences in heat source or parent body size.

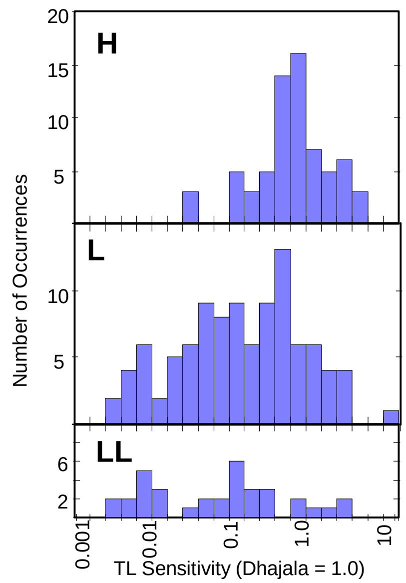

Fig. 1. Induced TL sensitivity of type 3 ordinary chondrites. Data from Sears *et al*. [3] and present work.

Summary. We have located 10 potential new type 3.0-3.1 UOC (Table 1). We have also identified some highly shocked UOC and confirmed previous trends suggesting a different thermal history for H chondrites compared to L and LL chondrites.

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References. [1] Grossman *et al.* (1988) In *Meteorites and the Early Solar System*, Univ. Arizona Press, p. 619; Scott *et al.* (1996) In *Chondrules and the Protoplanetary Disk*, Cambridge Press, p. 87; Brearley A.J. (1996) In *Chondrules and the Protoplanetary Disk*, Cambridge Press, p. 137; Huang *et al.* (1996) *Icarus* **122**, 316. [2] Batchelor J.D. and Sears D.W.G. (1991) *Nature* **349**, 516; Sears *et al.* (1991) *Proc. NIPR Symp. Antarctic Meteor*. **4**, 319; Guimon *et al*. (1995) *Meteoritics* **30**, 704; Sears *et al.* (1995) *Meteoritics* **30**, 169. [3] Sears *et al.* (1991) *Proc. Lunar Planet. Sci.* **21**, 493. [4] Benoit *et al.* (1991) *Meteoritics* **26**, 157. [5] Bischoff *et al.* (1992) *LPSC* **23**, 107. [6] Ninagawa *et al.* (1997) *Antarctic Meteor. Res.* **11**, 1. [7] Benoit P.H. and Sears D.W.G. (1999) *JGR* **104**, 14,159. [8] Sears *et al.* (1982) *GCA* **46**, 2471. [9] McCoy *et al.* (1993) *Meteoritics* **28**, 681. [10] Marti K. and Graf T. (1992) *Ann. Rev. Earth Planet. Sci.* **20**, 221; Hartmann *et al.* (1999) *Meteor. Planet. Sci.* **34**, A161. [11] Akridge D.G. and Sears D.W.G. (1999) *JGR* **104**, 11853. [12] Wasson J.T. (1974) *Meteorites: Classification and Properties*. [13] Akridge *et al.* (1998) *Icarus* **132**, 185.

Table 1. Candidates for petrologic subtypes 3.0-3.1.

Meteorite	Class[+]	Mass (g)	TL Sensitivity, Dhajala = 1.0	Suggested TL type
EET 90066	L3	9.8	0.003 ± 0.001	3.0
EET 90161	L3	9.7	0.004 ± 0.001	3.0-3.1
GRO 95502 group*	L3.5	10491.2	0.002 ± 0.001	3.0
LEW 88477	LL3	12.3	0.005 ± 0.001	3.1
MET 96503 group[†]	L3.6	308.7	0.001 ± 0.001	3.0
Y 790787	L3	46.1	0.003 ± 0.003	3.0-3.1
Y 791324	LL3	20.7	0.005 ± 0.003	3.0-3.1
Y 791558	LL3	101.6	0.0065 ± 0.0006	3.1
Y 793565	LL3	16.2	0.0028 ± 0.0006	3.0
Y 793596	LL3	62.9	0.0025 ± 0.0006	3.0

+Inferred classification from petrographic observation and mineral chemistry, from the *Catalog of Yamato Meteorites* and the *Antarctic Meteorite Newsletter*.

*Pairing group members: GRO 95502, GRO 95504, GRO 95512, GRO 95539, GRO 95544.

†Pairing group members: MET 96503 and MET 96515.