EXPLORATION OF EARLY SOLAR SYSTEM HISTORY THROUGH INDUCED THERMOLUMINESCENCE STUDIES. C. Ragland[1,3], J. Yozzo[2,3] and D. W. G. Sears[1,3], [1]Dept. of Chemistry & Biochemistry, Univ. of Arkansas, Fayetteville, AR 72701, [2]Dept. of Geosciences, Univ. of Tulsa, Tulsa, OK 74104, [3]Arkansas Center for Space & Planetary Sciences, Univ. of Arkansas, Fayetteville, AR 72701.

Introduction: The history of early solar system history is recorded in the mineral and structural compositions of ordinary chondrites, compositions that are nearly identical to stars. Studying chondrite compositions uncovers information regarding the processes that shaped them, and it is likely that these processes were active during the formation of the solar system.

Metamorphism is one such process, and a petrographic typing system has been developed based on the degree of metamorphism associated with a chondrite [1]. Type 3 chondrites the make up the lower end of this scale and are relatively unequilibrated. On the opposite end of the scale, type 5 and 6 chondrites are associated with large amounts of metamorphism. The extremes of this typing system have been well-studied, while type 4 ordinary chondrites that have received intermediate amounts of metamorphism have been studied less. Within type 4 chondrites, primary minerals such as olivine and pyroxene homogenize and secondary minerals such as coarse feldspar and chromite form. Our study focuses on the range of metamorphicsm seen in type 4s to develop a better understanding of metamorphic processes on parent bodies.

Experimental: Mineral composition data were measured through electron microprobe analysis by colleagues at UCLA and USGS. Thermoluminescence measurements were done at the University of Arkansas using a modified medical Daybreak Nuclear and Medical Inc. instrument. Samples were prepared for the latter analysis by crushing, removing the magnetic components, and additional crushing to producea powdered sample that flowed but did not clump (~200 μm grains).

Four-miligram aliquots of each sample were heated in the TL rig to 500°C in an intert, nitrogen atmosphere to drain the sample of any natural TL. The sample was then exposed to the 200 mCi ^{90}Sr beta cell for three minutes and allowed to decay for five minutes before being heated, again to 500°C. This heating produced a glow curve, which contributes three parameters for TL analysis: the maximum peak intensity (TL intensity), the temperature at which this peak intensity occurs (peak temperature), and the full-width of the peak measured at half of the maximum peak intensity (peak width). The TL intensity values were standardized using the TL intensity from the Dhajala meteorite, and the TL sensitivity values reported in table 1 are Dhajala-normalized.

Table 1 –Induced TL data for 26 type 3, type 4, and type 4/5 ordinary chondrites*

Meteorite	Class	TL Sensitivity (Dhajala =1)	Peak Width (°C)	Peak Temp. (°C)
Albareto	LL4	1.03 ±0.2	162 ±8	205 ±6
ALH 85033	L4	0.71 ±0.05	168 ±2	202 ±8
Baratta	L4	0.29 ±0.02	159 ±12	181 ±4
Bjurbole	L4	2.41 ±0.08	151 ±8	205 ±6
Bo Xian	LL4	1.25 ±0.09	165 ±4	194 ±6
Bovedy	L4	0.02 ±0.006	155 ±7	184 ±14
Bremervorde	H3.9	1.23 ±0.04	157 ±8	200 ±1
Cali	L4	1.19 ±0.1	144 ±10	184 ±10
Cynthiana	L4	2.04 ±0.1	186 ±5	200 ±5
Dhofar 658	H4/5	0.32 ±0.009	141 ±5	200 ±5
GRA 95215	L4	0.35 ±0.05	153 ±5	214 ±8
GRA 98013	H4	0.30 ±0.01	146 ±5	197 ±9
GRO 95541	H4	0.55 ±0.05	149 ±3	214 ±15
Hamlet	LL4	0.99 ±0.06	151 ±5	145 ±3
Hedjaz	L3.7	0.60 ±0.02	160 ±2	206 ±3
Julesburg	L3.7	0.13 ±0.02	137 ±3	200 ±7
Kalahari 001	H4/5	0.44 ±0.003	147 ±6	247 ±12
LAP 02338	L4	0.47 ±0.01	175 ±6	226 ±9
Matsitama	H4/5	0.42 ±0.05	141 ±5	240 ±14
NWA 1974	LL4/5	0.60 ±0.04	136 ±3	193 ±7
NWA 752	LL4/5	1.16 ±0.07	138 ±2	196 ±5
Thuathe	H4/5	1.94 ±0.07	147 ±3	205 ±4
Tiffa 002	H4/5	1.18 ±0.08	149 ±5	199 ±6
WIS 91618	LL4	0.94 ±0.08	160 ±13	187 ±8
Y-74002, 98	LL4	2.39 ±0.05	157 ±3	210 ±3
Y-81075, 97	L4	1.40 ±0.05	145 ±7	200 ±0

* Uncertainties refer to 1σ determined from triplicate measurement of the same aliquot.

Results: The induced TL sensitivity for the 26 ordinary chondrites tested range from 0.02 ± 0.006 to 2.41 ±0.08 for samples of Bovedy and Bjurbole respectively. With the exception of Bovedy, these values correspond to high type 3 and type 4 chondrites [2]. Peak temperature and peak width data cluster on or above the region representative of high type 3 ordinary chondrites (figure 4).

Discussion: The values measured for induced TL sensitivity listed in table 1 are in agreement with mineral analysis and heterogeneity data with the exception of Bovedy. While analysis of the thin-section clearly places this type 4 chondrite in the proper category, the induced TL sensitivity is uncharacteristically low, corresponding to a type 3.3 chondrite. The anomalous data could be the result of sampling an igneous clast within the chondrites, as the clasts would not be representative of the overall meteorite; therefore Bovedy is excluded from the remaining discussions.

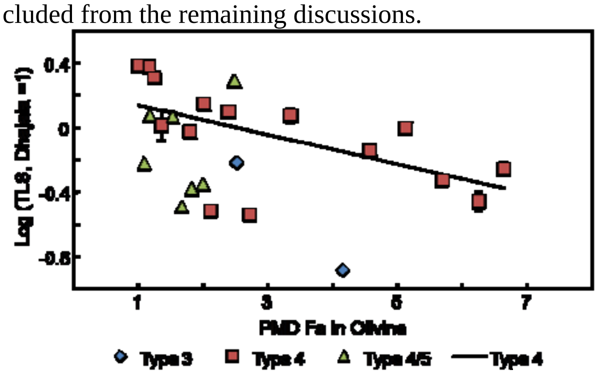

Figure 1 – TL Sensitivity is compared with the heterogeneity seen in olivine.

Although there is a slight negative correlation between olivine heterogeneity and induced TL sensitivity, there is not sufficient variation in the heterogeneity of the olivine to enable the trend to be a relevant measure of metamorphism in type 4s.

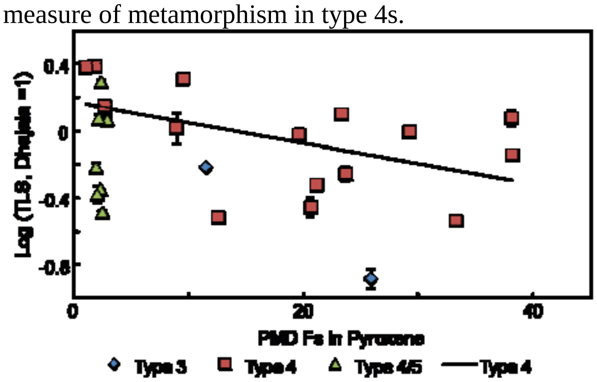

Figure 2 – TL Sensitivity is compared with the heterogeneity seen in pyroxene.

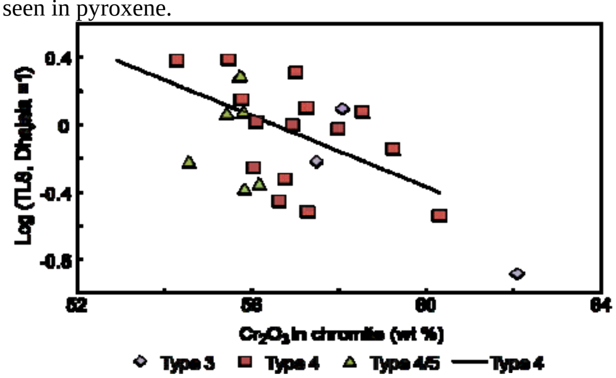

Figure 3 – TL Sensitivity is compared with the changing Cr_2O_3 content in chromite.

A similar negative correlation is seen in the comparision of pyroxene heterogenetity in the pyroxene (figure 2). Pyroxene homogenizes throughout the type 4s, and because it encompasses a larger range than olivine heterogeneity, this relationship better models progressive metamorphism in type 4 chondrites.

TL sensitivity also relates to changes in chromite across the range of type 4s (figure 3). Thus further analysis of chromite chemistry may provide another parameter for quantifying metamorphism in type 4s.

The temperature-width plot (figure 4) provides evidence of thermal history and indicates the presence of both ordered and disordered feldspar in type 4 samples. The position of data on and above the upper bulls-eye suggests that disordered feldspar, formed at higher temperatures than ordered feldspar, is present in larger quantities in type 4s than in type 3s. Due to higher degrees of metamorphism, type 4 chondrites would be expected to have more disordered feldspar than type 3s. The clustering of type 4 data also indicates that these chondrites cooled in a way that allowed a small amount of ordered feldspar to form amidst the disordered feldspar.

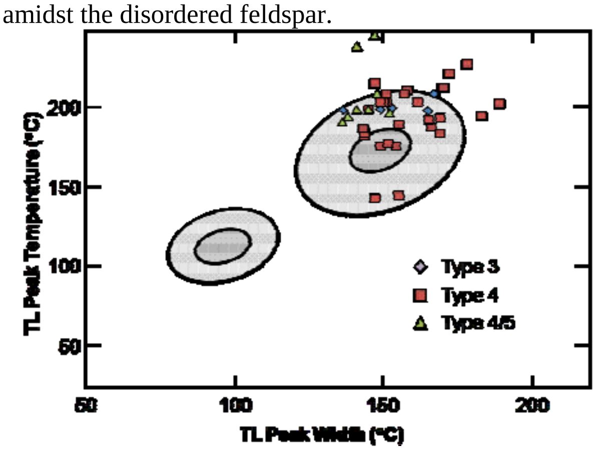

Figure 4 – Temperature-width data for the samples compared with the fields occupied by type 3.0-3.5 (lower field) and type 3.5-3.9 (upper field) ordinary chondrites [3]. The bulls-eyes refer to 1 sigma and 2 sigma fits to the data.

Conclusion: Olivine and pyroxene yield slight, negative correlations with induced TL sensitivities, and the relationship between changes in chromite and induced TL sensitivities suggests that metamorphism in type 4 chondrites may be better studied through further analysis of chromite chemistry. The position and clustering of temperature-width data provides evidence of higher metamorphic temperatures in type 4s than in type 3s and of cooling rates that allowed small amounts of ordered feldspar to form.

References: [1] Dodd et al. (1967) *Geochim. Cosmochim. Acta* **31**, 921. [2] Sears et al. (1980) *Nature* **287**, 791. [3] Benoit et al. (2001) *American Mineralogist* **86**, 780.