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METAMORPHISM OF CO AND CO-LIKE CHONDRITES AND COMPARISONS WITH TYPE 3 ORDINARY CHONDRITES.

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Introduction CO chondrites differ from type 3 ordinary chondrites in their bulk compositional and isotopic properties [1,2], abundance of refractory-rich inclusions (ameboid olivine inclusions and other CAI similar to those in Allende [3]), and their relatively small chondrule sizes [4]. However, like the ordinary chondrites, CO chondrites are essentially olivine and pyroxene, with minor amounts of plagioclase, metal and sulfide [3]. They may also be sorted into a metamorphic sequence similar to that for the type 3 ordinary chondrites. With increasing levels of metamorphism, CO chondrites show similar variations to those of type 3 ordinary chondrites in silicate heterogeneity, metal composition, TL sensitivity and cathodoluminescence (CL) petrography [3,5,6,7]. On the basis of metamorphism experienced, McSween divided the CO chondrites into petrographic types I, II and III [3], while Scott and Jones divided the group into types 3.0-3.9 [7]. Underlying this is the important issue of the similarity of the thermal histories of the CO and ordinary chondrite classes. In this paper we present new TL data for ten CO and CO-related chondrites (Table 1), and we discuss the thermal histories of the CO and ordinary chondrite classes.

Results Table 1 lists TL data for the new carbonaceous chondrites, and Figs. 1 and 2 compare these data with data for other CO chondrites. Most CO chondrites produce two TL peaks, one at 110-130C whose intensity shows a 100-fold variation which is metamorphism-dependent, and one at 220C which is relatively constant in intensity. Colony and ALHA77307, like the type 3.0-3.1 ordinary chondrites, have broad glow curves, mainly due to an additional peak at 350C. This peak is erratic in its behavior and the curves are reminiscent of those produced by Allende CAI [8]. LEW85332, the three paired MAC samples and Y-82020 produce such glow curves. Allan Hills 85003 and A82101 and Yamato 791717, 81050 and 82094 have curves with dominant peaks at 110-130C with little contribution from a peak at 350C.

Discussion Using the present TL sensitivity data for the 'metamorphic' peak and the petrographic type definitions suggested for type 3 ordinary chondrites [9], Yamato 791717, 81020 and 82050 are petrographic type 3.4 and Yamato 82094 is petrographic type 3.5. These assignments are consistent with the brief descriptions of these samples by Yanai and Kojima [10] and of Y-81020 by Graham and Yanai [11]. ALH85003, ALHA82101, LEW85332 and the MAC87300 group have TL sensitivity based petrographic types of 3.5, 3.6, 3.1 and 3.2, respectively. ALHA82101 was described as type 3.3 by Scott and Jones [7] and LEW85332 was described by Rubin and Kallemeyn [12] as one of the least equilibrated chondrites known; they also regard the meteorite as a unique carbonaceous chondrite.

Table 2 lists TL-based petrographic types for CO chondrites from the Keck and Sears [6] study, along with petrographic type assignments based on petrographic data [3,13,14,7]. We may also use CL petrography to

Table 1. New induced thermoluminescence data for CO and CO-like chondrites.

		TL Sensitivity (Dhajala = 1)			Peak Temperature (C)			Recom-mended
Meteorite	Source	Peak 1	Peak 2	Peak 3	Peak 1	Peak 2	Peak 3	Pet. Type
ALH82101,12	MWG	0.33±0.095	0.07±0.01	---	138±21	268±26	---	3.6
ALH82101,13	MWG	0.2±0.1	0.041±0.009	---	134±18	270±26	---	3.6
ALH85003,2	MWG	0.28±0.08	0.05±0.02	---	118±11	266±25	---	3.5
ALH85003,18	MWG	0.15±0.07	0.031±0.008	---	117±11	267±25	---	3.5
Y82094,95	NIPR	0.188±0.041	---	---	137±1	---	---	3.5
Y791717,93	NIPR	0.072±0.006	0.019±0.004	---	120±3	232±2	---	3.4
Y81020,25	NIPR	0.07±0.02	0.082±0.018	0.055±0.012	125±5	216±1	321±6	3.4
Y82050,73	NIPR	0.054±0.008	0.019±0.004	---	116±8	231±7	---	3.4
LEW85332,13	MWG	0.0098±0.0005	0.017±0.002	0.016±0.001	120±11	258±25	412±40	3.0
LEW85332,2	MWG	0.0010±0.0008	0.019±0.004	0.018±0.005	119±11	240±25	395±36	3.0
MAC88107,3	MWG	0.02±0.01	0.07±0.04	0.07±0.04	125±5	202±3	292±10	3.1
MAC87301,3	MWG	0.03±0.02	0.07±0.03	0.07±0.03	125±5	210±11	300±10	3.1
MAC87300,3	MWG	0.012±0.003	0.031±0.002	0.032±0.005	125±5	212±7	311±7	3.1

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Table 2. Petrographic type for CO chondrites.

Meteorite	McSween	TL sens	CL	Scott/ Jones
Colony	I	3.2	3.0-3.1	3.0
ALHA77307	I	3.3	3.0-3.1	3.0
Ornans	II	3.4	3.2-3.4	3.3
Kainsaz	I	3.5	3.1-3.2	3.1
ALHA77003	II	3.5	3.2-3.4	3.4
Felix	II	3.5	3.2-3.4	3.2
Lance	II	3.6	3.2-3.4	3.4
Warrenton	III	3.6	3.5-3.9	3.6
Isna	III	3.8	3.5-3.9	3.7

assign petrographic types, particularly for the lower types (Table 2). The CL of type 3.0 ordinary chondrites consists of yellow CL from the mesostasis of magnesian chondrules, red CL from low-Fe olivines and pyroxenes in chondrules and matrix, and blue CL from chondrule mesostases with plagioclase-normative compositions. Additionally, a significant number of chondrules contain quartz-normative mesostases which are non-luminescent. With increasing metamorphism, this diversity in color disappears, to be replaced by the ubiquitous blue CL of sodic plagioclase as calcic chondrule mesostases 'equilibrate' toward oligoclase, and magnesian silicates become relatively Fe-rich and therefore non-luminescent [15,16,17]. The CO chondrites of McSween's type III are comparable in their CL properties to ordinary chondrites of type 3.5-3.9. Isna and Warrenton have matrix with little or no CL and a uniform distribution of grains and chondrules with blue CL. Chondrules in Isna have mesostasis which is usually bright blue or bluish/white and only occasionally yellow or orange. The CO chondrites of type II resemble ordinary chondrites of type 3.2-3.4 in their CL properties. Lance, Felix, ALHA77003 and Ornans have matrices which are largely non-luminescent but with scattered isolated grains with red CL (presumably forsterite), somewhat larger matrix 'grains' (probably grain aggregates) with blue CL and which grade into CAI, and chondrules whose mesostases have blue or bluish/white CL and whose grains have either red CL or are non-luminescent. The CO chondrites of McSween's type I have CL properties comparable to type 3.0-3.1 ordinary chondrites. Colony and ALHA77307 have abundant red CL matrices and grains, with inclusions and chondrules which are either non-luminescent or whose mesostasis luminesces white (probably over-exposed blue) or yellow. Kainsaz is also McSween type I, but has CL properties intermediate to those of the other type I and the type II CO chondrites, tending towards the latter.

With the exception of Kainsaz, for which CL and petrologic data suggest a much lower value than TL sensitivity, the types assigned by TL, CL and mineral chemistry are in reasonable agreement. However, there are two points to stress. (1) CO chondrites differed significantly in thermal history from the ordinary chondrites. Unlike CO chondrites, ordinary chondrites contain a single metamorphism-dependent TL peak which shifts from 100 to 200C with increasing metamorphism, the change in peak temperature occurs at metamorphic intensities equivalent to type 3.5. Since the change is thought to be associated with disordering of feldspar [18], type 3.5 ordinary chondrites probably experienced temperatures of 500-600C. Apparently while some CO chondrites suffered devitrification of their chondrule glasses to the extents observed for ordinary chondrites of type 3.5-3.8, they did not experience the same relatively high temperatures. Presumably either the CO chondrites suffered metamorphism for much longer periods than the ordinary chondrites [6] or their higher water content facilitated devitrification and other metamorphic reactions. The recent calculations of Jones and Rubie [20] also indicate that the metamorphism of the CO chondrites was the result of various times at a modest range of temperatures below 600C. (2) While CL data (and the mineral and matrix compositions) suggest that metamorphic intensities for Colony and ALHA77307 were comparable to those of type 3.0-3.1 ordinary chondrites, their TL sensitivities are higher. This most probably reflects interference of the metamorphic peak by the higher temperature TL peaks, and we prefer the 3.0 assignment for Colony and ALHA77307. We also suspect the TL assignments for LEW85332 and the MAC87300 group are high by about 0.1, and this is reflected in our recommended petrographic type assignments in Table 1.

<u>Conclusions</u> TL sensitivity, CL petrography and mineral and matrix composition data suggest that the CO chondrites form a metamorphic sequence analogous to that of type 3 ordinary chondrites and subdivision in an analogous manner is appropriate. However, while these observations suggest that the degree of metamorphic alteration for some CO chondrites may approach that observed for type 3.6-3.8 ordinary chondrites, induced TL data make it clear that they did not experience temperatures as high. CO chondrites did not experience temperatures greater than those experienced by type 3.5 ordinary chondrites (presumed to be 500-600C). LEW-85332, MAC87300/87301/88107 and Y-81020 have glow curves similar to those of Colony and ALHA77307; these may be either particularly primitive CO chondrites, members of a new primitive carbonaceous chondrite class, or intermediate between existing carbonaceous chondrite classes. Our recommended petrographic types for the present samples are listed in Table 1.

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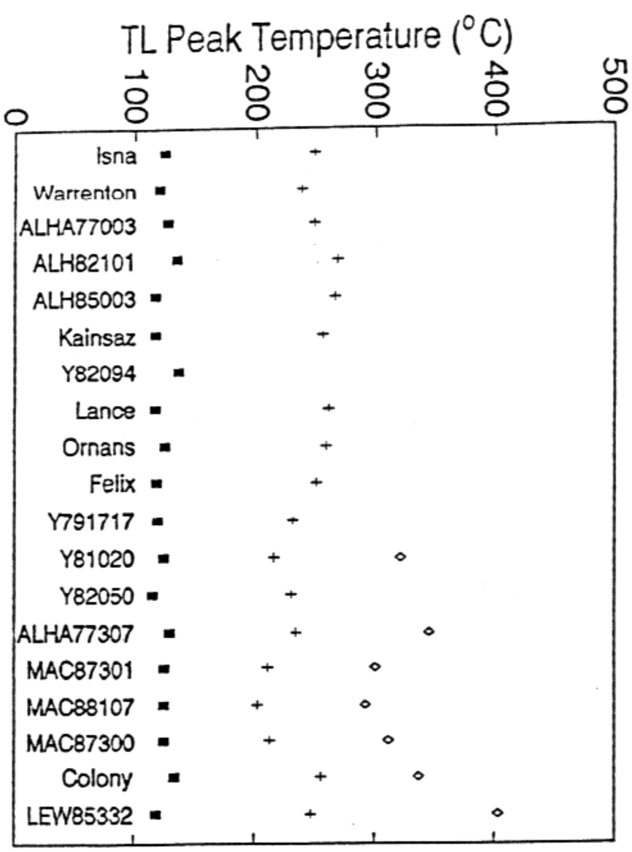

Fig. 1. TL peak temperatures for CO and CO-like chondrites. The 100-120C peak is metamorphism-related, the others are not.

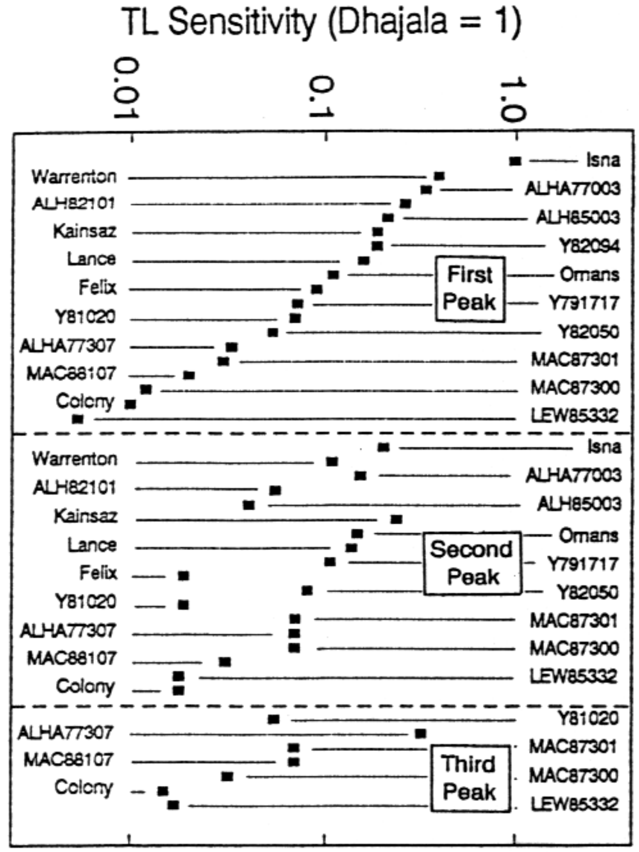

Fig. 2. TL sensitivity data for the present samples compared with those of the CO chondrites of Keck and Sears [6].

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References 1. Kallemeyn G.W. and Wasson J.T. (1981) GCA 45, 1217-1230. 2. Clayton R.N. and Mayeda T.K. (1984) EPSL 67, 151-161. 3. McSween H.Y .(1977) GCA 41, 477-491. 4. Rubin A.E. (1989) Meteoritics 24, 179-189. 5. Keck B.D. and Sears D.W.G. (1986) Meteoritics 21, 411-412. 6. Keck B.D. and Sears D.W.G. (1987) GCA 51, 3013-3021. 7. Scott E.R.D. and Jones R.H. (1990) GCA (submitted). 8. Guimon R.K. and Sears D.W.G. (1986) Meteoritics 21, 381-383. 9. Sears D.W., Grossman J.N., Melcher C.L., Ross L.M. and Mills A.A. (1980) Nature 287, 791-795. 10. Yanai K. and Kojima H. (1987) Photographic Catalog of the Antarctic Meteorites NIPR, Tokyo. 11. Graham A.L. and Yanai K. (1986) Proc. 10th Symp. Antarct. Meteor., 1985, 167-180. 12. Rubin A.E. and Kallemeyn G.W. (1990) LPS XXI, 1045-1046. 13. Scott E.R.D., Taylor G.J., McSween H.Y., Okada A., Maggiore P., Keil K. and McKinley S.G. (1981) Meteoritics 16, 385. 14. Rubin A.E., James J.A., Keck B.D., Weeks K.S., Sears D.W.G. and Jarosewich E. (1985) Meteoritics 20, 175-195. 15. Sears D.W.G., DeHart J.M., Hasan F.A. and Lofgren G.E. (1989) In Spectroscopic Characterization of Minerals and Their Surfaces (L.M. Coyne, S.W.S. McKeever and D.F. Blake, eds.), 190-222. 16. DeHart J.M. and Sears D.W.G. (1986) LPS XVII, 160-161. 17. DeHart J.M., Lofgren G.E. and Sears D.W.G. (1990) GCA (submitted). 18. Sears D.W.G. (1988) Nucl. Tracks Radiat. Meas. 14, 5-17. 19. Guimon R.K., Keck B.D. and Sears D.W.G. (1985) GCA 49, 1515-1524. 20. Jones R.H. and Rubie D.C. (1990) LPS XXI, 583-584.