THERMAL METAMORPHISM IN CO3 CHONDRITES: APPLICATION OF OLIVINE DIFFUSION MODELLING TO POST-ACCRETIONARY METAMORPHISM. R.H. Jones[1] and D.C. Rubie[2]. 1) Institute of Meteoritics, University of New Mexico, Albuquerque, NM87131, USA; 2) Bayerisches Geoinstitut, Postfach 10 12 51, 8580 Bayreuth, F.R. Germany.

Introduction. The CO3 chondrite group may be subdivided into petrologic types 3.0-3.7, which represent increasing degrees of thermal metamorphism [1]. Petrologic effects observed with increasing petrologic subtype include progressive homogenization of chondrule silicates, equilibration of chondrules and matrix, devitrification of chondrule mesostasis, grain coarsening in the matrix, and changes in TL properties [1-3]. Two different scenarios have been proposed in which chondrule metamorphism may have taken place: 1) after accretion, by equilibration between chondrules and matrix *in situ* [1,2], and 2) in a nebular environment in which chondrule silicates equilibrate with an Fe-rich gas [4]. In order to test whether the former hypothesis is tenable, we have modelled Fe-Mg diffusion between chondrule and matrix olivines in CO3 chondrites using a finite difference approximation. Below we examine whether the times and temperatures necessary for olivine equilibration are reasonable for metamorphism on asteroidal parent bodies, and whether the shapes of zoning profiles in olivines in higher petrologic subtypes (3.4-3.7) may feasibly be derived from subtype 3.0-like material.

Assumptions. Our model examines the changes in zoning profiles in chondrule olivines as they equilibrate with each other and matrix during a metamorphic reheating event. Several important assumptions have been made in order to simplify the calculations. 1) CO3 chondrite olivines are considered to be present in three types of components: Fe-poor (type I) chondrules, Fe-rich (type II) chondrules, and Fe-rich matrix. 2) Pyroxene is assumed not to participate in Fe-Mg equilibration while olivines equilibrate, because diffusion in pyroxene is much slower than in olivine. 3) Fe-poor and Fe-rich olivines have average diameters of 30 and 70 μm respectively, and are assumed to be spherical. Matrix olivines are considerably smaller ($<1\ \mu m$) and are assumed to be homogeneous throughout the calculations. 4) The thermal history of the parent body during which equilibration takes place may be approximated by cooling at a linear cooling rate from the peak metamorphic temperature. 5) Fe-Mg interdiffusion coefficients in olivine are extrapolated from the high temperatures at which they have been determined (>900°C) [5] to significantly lower temperatures pertinent to parent body metamorphism (around 500°C). This is the largest uncertainty in the calculations, and the error associated with this extrapolation is discussed below. We have used the Fe-Mg diffusion data along the olivine c axis determined by [5], combined with a correction for oxygen fugacity dependence determined by [6].

Initial conditions. Parameters obtained from the unaltered CO3 chondrite ALH A77307, subtype 3.0, are used to constrain initial boundary conditions. Zoning profiles for types I and II olivines, which are assumed to be igneous zoning profiles resulting from chondrule formation, have been determined previously [1; unpublished data]. Matrix olivine is assumed to have a similar Fe/(Fe+Mg) ratio to the bulk matrix [1], i.e. Fa=58. The relative proportions of matrix: Fe-poor: Fe-rich olivines have been set as 55:35:10, so that they are consistent with equilibration of chondrule olivines in Isna (3.7), and with the proportions estimated by [2] (46:50:4). Equilibrated olivines have compositions of Fa=36. Initial calculations, carried out assuming that all chondrule olivines are in direct contact with matrix, failed to reproduce the shapes of type I zoning profiles observed in Lancé (3.4), ALH A77003 (3.5) and Isna (3.7) (Fig. 1). Type I chondrules are commonly rimmed by a layer of low-Ca pyroxene [1,2]. We thus introduced a pyroxene layer around type I olivines, which acts as a buffer between chondrule olivines and matrix, limiting the composition of matrix olivine in direct contact with type I olivine. Grain-boundary diffusion of Fe-Mg through cracks in the pyroxene layer is assumed to take place at a rate 10 times that of bulk diffusion in olivine throughout the calculation. Introduction of this layer enables us to reproduce the shapes of zoning profiles observed in type I olivines in petrologic subtypes 3.4-3.7. Metallographic cooling rates for CO3 chondrites determined by [7] are of the order of 0.3-1°C/Ma, through a temperature of approximately 500°C. Willis and Goldstein [8] estimate that these cooling rates should be increased by a factor of two, and also caution that cooling rate estimates are not reliable for chondrites in which peak temperatures are less than approximately 600°C. This may be the case for CO3 chondrites, in which peak temperatures are of the order of 500°C, and should be borne in mind when interpreting the calculations.

Results. Figure 2 shows results of calculations performed for a cooling rate of 1°C/Ma from peak temperatures of 470-530°C. Comparison with Fig. 1 shows that shapes of zoning profiles are in good agreement with those measured in CO3 chondrites, for both type I and type II olivines. The model is consistent with the observation that type II olivines in ALH A77003 are more Fe-rich than those in Isna, because type II olivines equilibrate with matrix faster than type I olivines. There is good agreement between peak temperatures indicated for each chondrite for the two olivine types, viz. Lancé 490-500°C, ALH A77003 510-515°C, Isna 520-530°C. For a peak temperature of 530°C both types of olivines are essentially equilibrated. Variations in peak metamorphic temperatures of only 5°C appear to be responsible for differences between subtypes. Calculations have also been performed for a cooling rate of 10°C/Ma and 0.1°C/Ma. Ranges in peak metamorphic temperatures calculated between type 3.0 and equilibrated olivines are 510-570°C for 10°C/Ma, and 450-500°C for 0.1°C/Ma. Thus a very narrow range of peak metamorphic temperatures is suggested, in the range of cooling rates examined. The error associated with uncertainties in D(Fe-Mg) has been calculated: variation of D by a factor of 100 places uncertainties in peak metamorphic temperatures of ±50°C.

Conclusions. The model is successful in reproducing zoning profiles observed in CO3 chondrites of petrologic subtype 3.4-3.7, both in type I and type II olivines. Chondrites of these subtypes may feasibly be derived from material similar to that of subtype 3.0. Calculations are consistent with simultaneous equilibration of type I and type II olivines *in situ*, and matrix material is a plausible source of Fe with which chondrules equilibrate. Modelling shows that, subject to the validity of certain important assumptions, thermal metamorphism of CO3 chondrites may feasibly take place after accretion, on a parent body. Using cooling rates determined from metallographic studies it appears that only a very narrow range of peak metamorphic temperatures is necessary to account for the entire range of petrologic subtypes observed. We plan to carry out similar calculations for a nebular equilibration model, which will enable us to evaluate the relative merits of the two proposed models.

References. [1] Scott ERD and Jones RH (1990) GCA: in review. [2] McSween HYJr (1977) GCA, 41, 477-491. [3] Keck BD and Sears DWG (1987) GCA, 51, 3013-3021. [4] Kurat G (1988) Phil Trans R Soc London, A325, 459-482. [5] Misener DJ (1974) Carnegie Inst Washington, Publ. 634, 117-129. [6] Buening DK and Buseck PR (1973) J Geophys Res, 78, 6852-6862. [7] Wood JA (1964) Icarus, 6, 1-49. [7] Willis J and Goldstein JI (1981) Proc Lunar Planet Sci, 12B, 1135-1143.

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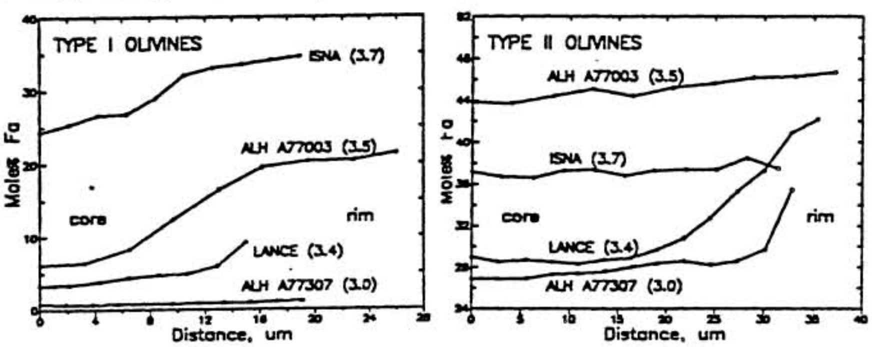

Fig. 1. Fa zoning profiles in olivine measured in types I [1] and II [unpublished data] chondrules for four CO3 chondrites, subtypes 3.0-3.7.

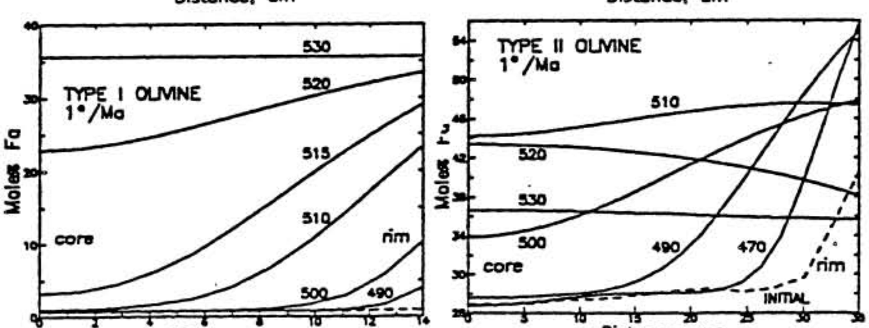

Fig. 2. Calculated Fa zoning profiles for olivines in CO3 chondrites. Linear cooling rate of 1°/Ma; peak metamorphic temperatures (°C) indicated on each profile. Dashed curves are initial profiles from ALH A77307 (Fig. 1). Equilibrated olivine composition is Fa=36.