AN INTEGRATED DIFFUSION AND THERMAL MODELING APPROACH TO DETERMINE THE THERMAL HISTORY OF CHONDRITE PARENT BODIES S. Schwinger[1], R. Dohmen[1] and H.-P. Schertl[1], [1]Institut für Geologie, Mineralogie und Geophysik, Ruhr-Universität Bochum, 44780 Bochum, Germany.

Introduction: Carbonaceous chondrites are a unique archive of the early history of the solar system and are affected to different degrees by thermal and aqueous metamorphism on their parent bodies. In this study we analyzed the chemical zoning of chondrule minerals in the CO3 chondrite Kainsaz, using diffusion modeling to obtain information about the thermal history of the CO parent body. As the metamorphic peak temperatures of CO3 chondrites are supposed to be relatively low, chemical zoning in minerals may be preserved from pre-accretion processes like chondrule formation. It is one of the most important challenges to distinguish if certain element and isotope signatures found in minerals and mineral aggregates were formed before or after accretion into the parent body. We developed a strategy to distinguish between these two cases and found a new method to determine the peak temperatures of parent body metamorphism by combining diffusion modeling with modeling of the thermal evolution of the parent body.

Analytical Methods: We analyzed 17 fayalitic olivines and 5 chromites in 7 type II chondrules of the CO3 chondrite Kainsaz. Chemical analyses and EBSD measurements were performed using a CAMECA SX50 electron microprobe and a LEO (Zeiss) 1530 Gemini FESEM (GMG Institute, Ruhr-University Bochum), respectively.

Chemical zoning and thermometry: We observe concentric but anisotropic zoning of Fe, Mg, Ca and Mn in olivine. The chromite crystals also show concentric zoning in Fe and Mg, but olivine and chromite are rather homogeneous in Al and Cr, which indicates high equilibrium temperatures of 1300-1400 °C [1] that probably reflect their crystallization temperatures during chondrule formation. The Fe-Mg exchange between olivine and spinel is temperature dependent and can be also used as geothermometer [2]. As every analyzed chromite crystal is in direct contact to an olivine crystal, the zoning in chromite was probably controlled by the Fe-Mg exchange between olivine and chromite during the thermal history of these chondrules. The olivine crystals on the other hand are typically surrounded by mesostasis, so that we interpret the concentric zoning in olivine to be dominated by the chemical exchange with the mesostasis. We applied various calibrations for the Fe-Mg exchange thermometer, e.g. [2], using the rim composition of the olivine and the variable composition across the chromite. We obtained for the core of the chromite temperatures approaching the crystallization temperature as obtained from the Al thermometer [1]. Towards the rim the apparent temperature decreases continuously and reaches a minimum at the chromite rim of around 500-800 °C, depending on which calibration is used for the geothermometer. Therefore the observed Fe-Mg zoning reflects resetting of this thermometer at lower temperatures, consistent with an earlier interpretation, where the Fe-Mg exchange between spinel and olivine was used as an indicator for the extent of thermal metamorphism on the parent body [3].

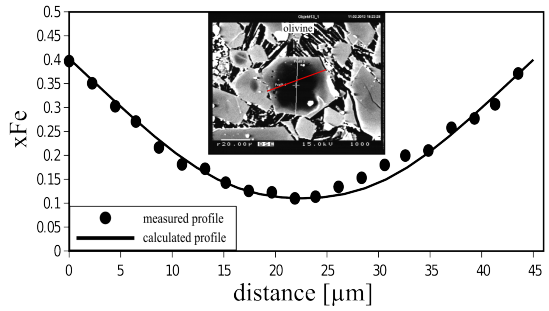

Fig. 1: *Diffusion profile of Fe in olivine.*

Diffusion modeling: We simulated the zoning in olivine and spinel with a one-dimensional diffusion model introducing $\Gamma=\int D dt$ as a fitting parameter, where D is the respective diffusion coefficient, e.g., D_{FeMg} for olivine. The value of Γ quantifies the total extent of compositional change of the initial profiles by diffusion processes, which is directly related to the thermal history of the mineral. The measured diffusion profiles were modeled using compositionally dependent diffusion coefficients according to [4], [5], [6] and [7] and the crystallographic orientations of the profiles determined by EBSD measurements.

Olivine. The quality of the fits and the consistency between the zoning profiles measured for different crystallographic orientations and different elements in olivine strongly indicate that the zoning in type II chondrule olivines was formed by solid-state diffusion (Fig. 1). The total variation for the obtained values of Γ is within a factor of 10: $1.6*10^{-12}$ m² and $2.1*10^{-11}$ m² but the abundance of the Γ values form a Gaussian distribution as could be explained by the accumulation of various errors,

e.g., produced by cutting effects and the fitting procedure (Fig. 2). Therefore our results strongly indicate that the chemical zoning in these different olivine crystals were produced by the same thermal history consistent with a value of log (Γ [10^{-12} m^2]) = 0.91 ± 0.29.

Chromite. We fitted the Fe and Mg zoning in chromite with log (Γ [10^{-12} m^2]) values of 0.67 ± 0.1 and additionally simulated the profiles employing the olivine spinel thermometer [2] as a temperature dependent boundary condition. By this procedure we can directly couple the simulation to the thermal history as the form of the profile depends on the cooling rate. The measured profiles cannot be reproduced assuming a simple cooling history starting from the crystallization temperature but are consistent with slow cooling from low temperatures as expected during parent body metamorphism.

Parent body modeling: We calculated the thermal histories of parent bodies internally heated by ^{26}Al decay in different depths of parent bodies of different sizes and with different properties using a one-dimensional numerical model. To test the range of possible thermal histories for the observed diffusion profiles, the integrated diffusion coefficient over time (Γ) was calculated for every thermal history. Plotting the Γ values against the peak temperatures of the calculated thermal histories reveals that there is a unique relation between Γ value and peak temperature. This relation is valid for all thermal histories and almost independent from burial depths, parent body sizes and material properties of the parent body.

However, as the relation between Γ value and peak temperature strongly depends on the used diffusion coefficient, it needs to be defined individually for each respective diffusing process.

Discussion: The combination of a geothermometer and diffusion modeling for the chromite crystals indicates formation during slow cooling on the parent body, but this result is dependent on the assumption that the olivine rim composition is roughly constant and buffered by the Fe-Mg exchange with the mesostasis, which may also depend on temperature. The profile shapes are consistent with this assumption and the quality of the fits and the reproducibility of the fitting parameter Γ for different crystals in different Type II chondrules strongly indicate that the zoning developed mainly in the same environment, hence after accretion in situ within the parent body.

As there is a unique relation between Γ and the peak temperature for parent body metamorphism, Γ obtained from the diffusion profiles can be now used

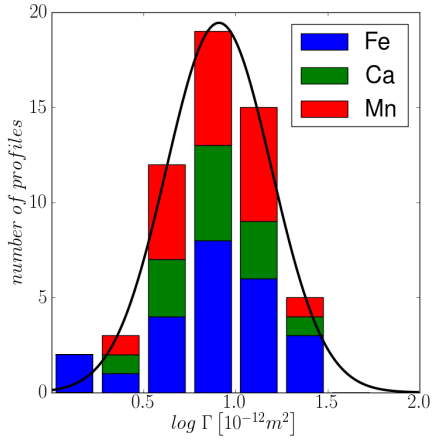

Fig 2: *log(Γ) values for olivine diffusion profiles.*

to estimate the metamorphic peak temperature of Kainsaz, which is 765±34K. The Γ values of the chromite diffusion profiles indicate a peak temperature of 646±11K, but this temperature estimate might be incorrect, since we used the Fe-Mg interdiffusion coefficient for aluminous spinel. Replacing Al to a large extent by Cr within the spinel structure should have some effect on the diffusion properties, but which is not determined yet. Thus the peak temperature determined by zoning in olivine is more accurate and is in very good agreement with the peak temperature estimate of 726±29K obtained by Raman spectroscopy of carbonaceous matter [8].

Conclusions: The combination of diffusion modeling with numerical modeling of the thermal evolution of the parent body provides an independent estimate of the peak temperature of parent body metamorphism with high accuracy depending on the accuracy of the diffusion coefficients. Once the peak temperature is calibrated in this way, any chemical zoning observed in other objects can be now evaluated based on the known thermal history of the parent body and pre-accretion features can be identified.

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