LOW TEMPERATURE THERMAL HISTORY OF NON-CHONDRITIC METEORITES AS DEDUCED FROM FE^{2+}-MG ORDERING IN ORTHOPYROXENE.

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Summary: New results on the ordering of Fe^{2+} and Mg between the M1 and M2 sites in two small orthopyroxene crystals of the Acapulcoite ALHA81261 are reported. Closure temperatures (T_C) for Fe^{2+}-Mg ordering calculated from site occupancies and structural parameters according to the procedure of Ganguly et al. [1] yield 528 ± 50 and 474 ± 50 °C for the two crystals. These temperatures are lower than corresponding temperatures for the recently analysed Lodranite FRO90011 [2], but significantly higher than Johnstown orthopyroxene [3] and much higher than closing temperatures in orthopyroxene of Landes silicate inclusion (T_C = 230 °C) determined earlier in the Department at Padova. The quality of the data on ALHA81261 is not sufficient to derive reliable cooling rates. The crystals are very small and show exsolved minerals. The sequence of decreasing closure temperatures from FRO90011 to Landes should, however, in a qualitative sense, reflect decreasing cooling rates. Silicates enclosed in iron meteorites and thus involving core formation processes seem to have cooled more slowly (i.e. deeper in the interior of a parent asteroid) than meteorites that are only affected by partial melting events.

Introduction: Achondritic meteorites, including iron meteorites, have undergone partial or complete melting, perhaps deep in the interior of their parent asteroid. Little is, however, known about the size of these asteroids and therefore the depth inside the parent body at which melting occurred. If melting was induced by internal heating, e.g. ^{26}Al-decay, meteorites should have cooled slowly from melting temperatures down to ambient temperatures, with the rate of cooling depending on the size of the planetesimal, actual burial depth of the sample and the insulating layer covering the parent planet. Local heating by small impacts would primarily affect surface and sub-surface material of the parent planet leading to a different thermal history, i.e. fast cooling. Cooling rates are, for example, recorded in the chemical zoning of minerals. Slow diffusion in pyroxene limits the applicability of this mineral to temperatures of 800 to 1000°C. At lower temperatures metallographic cooling rates are widely used, however, limited to meteorites with FeNi-metal bearing mineral assemblages. Recent work on Ca-zoning in olivine indicated its potential as cooling rate indicator at low temperatures (400 600°C) [4]. The ordering of Fe^{2+} and Mg between the two crystallographic M1 and M2 sites of orthopyroxene is temperature dependent and provides an independent means of determining cooling rates at low temperatures. Additional information from Ar-Ar and Pb-Pb data in combination with fission tracks retained at rather low temperatures should allow to reconstruct the complete cooling history of a meteorite parent body, as cooling rates at different temperatures are compared. It should in particular be possible to detect deviations from simple monotonic cooling histories, for example, ejection of hot material from the interior of a planetesimal by collisional break-up.

Procedure and results: Two orthopyroxene single crystals of about 70x170x200 μm, suitable for X-ray diffraction analysis were selected from a small fragment of the ALHA81261 Acapulcoite. A Philips PW 1100 four-circle automated diffractometer was used for collecting X-ray intensity data. Structure refinements were done in space group Pbca converging to R_{obs}= 2.02 and 2.24 for the two crystals. No violations of Pbca space group extinctions were observed. Chemical analyses were done with a CAMECA-CAMEBAX electron microprobe using synthetic standards. The site populations for both samples were calculated using the results of the two structure refinements and the microprobe analyses following the procedures of Domeneghetti et al. [5]. The two orthopyroxene crystals show very similar structure parameters and site occupancies which agree within one standard deviation. Fe^{2+} and Mg ordering in the M1 and M2 structural sites yields closure temperatures of 528 ± 50 and 474 ± 50 °C respectively, according to Ganguly et al. [1].

Discussion: As shown in the Fig. ($Kd=(Fe^{2+}(M1)Mg(M2)/Fe^{2+}(M2)Mg(M1))$) the closure temperatures for the two ALHA81261 orthopyroxene crystals are somewhat lower than for the Lodranite FRO90011 (T_C = 570 ± 20°C) and higher than for the Johnstown diogenite (T_C = 390 ± 30°C). A single orthopyroxene crystals from a silicate inclusion of the Landes IAB iron meteorite give a much lower closure temperature of 230°C. Similarly low closure temperaturs were obtained by Ganguly et al. [1] from orthopyroxene grains in two mesosiderites, 200°C for Bondoc and 300°C for Estherville, respectively. From metallographic cooling rates these authors estimate a cooling rate of 1°C/my at 250°C or of ~ 2°C/my at 350-500 °C for Estherville. Herpfer et al. [6] determined metallographic cooling rates for Landes silicate inclusions of 30°C ± 10 °C per my which is an order of magnitude above the Estherville value, but probably within the combined error of both cooling rates. The much higher closure temperature for the Johnstown orthopyroxene yields much higher cooling rates, several degrees °C per thousand years according to a recent revison by G.M. Molin. The higher closure temperature for FRO90011 suggests that this Lodranite must have cooled even faster [2]. The range of orthopyroxene closure temperatures from terrestrial volcanic and metamorphic rocks are indicated in the Fig. as reference values ([7,8] and unpublished data).

The meteorite data in the Fig. appear to suggest that meteorites formed during global asteroidal melting such as iron meteorites or mesosiderites cooled significantly slower than meteorites which were only affected by partial melting processes in open (Lodranites) or closed systems (Acapulcoites) [9,10].

Lit.: [1] Ganguly J. et al. (1994) GCA, **58,** 2711; [2] Molin G.M. et al. (1995) EPSL *(in press)*; [3] Molin G.M. et al. (1991) EPSL **105**, 260; [4] Köhler T. et al. (1991) N. Jb. Miner. Mh. **9,** 423; [5] Domeneghetti M.C. et al. (1995) Am. Min. *(in press)*; [6] Herpfer M.A. et al. (1994) GCA, **58,** 1353; [7] Molin G.M. and Stimpfl M. (1994) Min. Mag. **58,** 325; [8] Tribaudino M. and Talarico F. (1992) EJM, **4**, 453; [9] Zipfel J. and Palme H. (1993) LPSC XXIV, 1579; [10] Zipfel J. et al. (1995) GCA (subm.).