Mn-Cr dating of enstatite chondrites

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Introduction: The ^{53}Mn-^{53}Cr system (half-life 3.7 Ma) is a short-lived decay system that can be used as a relative chronometer of early solar system processes. Ideally, if ^{53}Cr/^{52}Cr-ratios in a sample are linearly correlated with the associated ratio of (stable) ^{55}Mn/^{52}Cr the excess ^{53}Cr can be interpreted to be the result of in situ decay of ^{53}Mn. The respective slope of this isochron corresponds to the initial ^{53}Mn/^{55}Mn of the sample. This initial ^{53}Mn/^{55}Mn ratio can be translated into an absolute age by comparing it with the initial ^{53}Mn/^{55}Mn ratio of a standard meteorite of known absolute age. Commonly used is the LEW 86010 angrite Mn-Cr age standard with an absolute U-Pb age of 4557.8±0.5 Ma and an initial ^{53}Mn/^{55}Mn ratio of $(1.25\pm0.07)\cdot10^{-6}$ (errors are 1σ-uncertainties) [1].

Mn and Cr are both rather abundant elements and assumed to have a relatively low diffusivity. Application of the Mn-Cr dating method is limited to few carrier phases with a low partitioning behavior of Cr and high Mn/Cr ratios and hence, besides other problematic issues, is still rarely applied in early solar system chronology. Enstatite chondrites contain a large variety of exotic mineral phases formed at low $f(O_2)$, in particular Mn-bearing sulfides, which might be suited for Mn-Cr dating. The aim of our project is to add more cosmochronological constraints on the early evolution of the enstatite chondrite parent bodies.

Methods: In this study we screened several distinct mineral phases for potential ^{53}Cr-excesses in enstatite chondrites at the new Cameca 1280 HR ion probe facility in Heidelberg, Germany. We used a focussed beam mode and the primary beam current commonly was in the range of 2 to 3 nA (equivalent to a spot diameter of about 3-5 µm). The field aperture was adjusted to values down to about 500 in order to avoid potentially nearby Cr-bearing phases. Element ratios were obtained by electron microprobe analyses with a Cameca SX51 device.

Samples and results: We analyzed the enstatite chondrites Sahara 97072 (EH 3), Indarch (EH 4), EET 96135 (EH 4/5), LAP 02225 (EH impact melt), MAC 88136 (EL 3) and Neuschwanstein (EL 6). For some of these chondrites age data from different chronometers already exist (e.g., Mn-Cr [1], [2], [3] I-Xe [4], [5], [6], Ar-Ar [7]). The major Mn-bearing phases in EH and EL chondrites are niningerite and alabandite, respectively. However, Mn/Cr ratios in both phases always were below 400, i.e., far below required ratios to detect ^{53}Cr-excesses. Hence, ^{53}Cr/^{52}Cr-ratios are indistinguishable from the ^{53}Cr/^{52}Cr-ratio determined by analyses of Cr-rich phases troilite and daubréelite (Mn/Cr<1). Results of troilite and daubréelite analyses were intended for determination of the relative sensitivity factor (rsf) for Mn/Cr (= ratio of Mn/Cr compositions determined by electron microprobe versus ion probe signals). However, the fine-grained nature of daubréelite in most meteorites and the relatively low amount of Mn in troilite made a consistent determination of rsf-values challenging. In case of LAP 02225 a reproducible rsf-value of 1.43±0.01 (two analyses of daubréelite) could be obtained. Only in sphalerite we found significant excess ^{53}Cr associated with high ^{55}Mn/^{52}Cr-ratios (up to 10^7). However, commonly data do not define a distinct isochron but rather show some scatter. Most sphalerite data were obtained for the impact melt LAP 02225 for which a range in initial ^{53}Mn/^{55}Mn of $(1.5\text{-}3.5)\cdot10^{-7}$ could be derived, corresponding to an absolute age range of 4546.5-4551.0 Ma (rsf=1.43) which agrees with I-Xe and Ar-Ar ages. This is consistent with fast cooling associated with simultaneous closure of all isotope chronometers, as expected for an impact melt rock. The initial ^{53}Mn/^{55}Mn derived for a single sphalerite datum of MAC 88136 is $(2.55\pm0.30)\cdot10^{-7}$, equivalent to an absolute age of 4549.3±0.6 Ma (for rsf=1). This is relatively young and may point to a weak disturbance of the Mn-Cr system by a thermal event. For Indarch we obtained an initial ^{53}Mn/^{55}Mn = $(4.2\pm1.1)\cdot10^{-6}$ (rsf=1), which corresponds to an absolute age of 4564.1±1.5 Ma, in broad agreement with previous results [1], [2], [3]. Application of a rsf=1.43 as for LAP 02225 would result in 1.9 Ma younger sphalerite ages for both meteorites. A better determination of the Mn/Cr rsf-value for sphalerite is an important aspect of future work. In addition, more Mn-Cr analyses of EL chondrites are planned.

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