MANGANESE-CHROMIUM ISOTOPE SYSTEMATICS OF BASALTIC ACHONDRITE NORTHWEST AFRICA 011. O. Bogdanovski[1] and G. W. Lugmair[1,2], [1]Max-Planck-Institute for Chemistry, Department of Comochemistry, PO Box 3060, 55020 Mainz, Germany; [2]Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093-0212, USA.

Introduction: Northwest Africa (NWA) 011 is an unusual basaltic achondrite with an anomalous Fe/Mn ratio. It was initially classified as a non-cumulate eucrite based on mineralogy, texture and major element composition [1]. Subsequent studies of trace elements, REE and oxygen isotopes suggested that NWA 011 is different from eucrites and probably derived from a unique parent body [2]. It was even proposed that this meteorite might possibly come from Mercury [3]. Already for this reason alone it was deemed important to study the Cr isotope systematics in NWA 011 since it was shown [4] that a gradient exists in the $^{53}Cr/^{52}Cr$ ratio obtained in various solar system bodies with their heliocentric distances. Based on Mn-Cr isotope systematics of a bulk NWA 011 sample we have shown earlier that this meteorite is not related to the HED parent body [5]. We have also demonstrated that NWA 011 is a differentiation product from a relatively large parent body, which is related to CI (or CR?) chondrites [5].

Results: In continuing our studies of NWA 011 we substantially increased our Mn-Cr isotope data base for our first bulk sample (NWA 011-A), that was obtained from Vernadsky Institute of Geochemistry and Analytical Chemistry (Moscow, Russia). In order to extend our investigation we have studied another ~300 mg bulk sample of this meteorite (NWA 011-B), which we received from the Antarctic Meteorite Research Center (Tokyo, Japan). Since ^{54}Cr in NWA 011 is anomalous [5] we cannot use the second-order fractionation correction described in [4]. Thus, to achieve a reasonable precision, obtaining large Cr isotope data sets are very time consuming but necessary. The isotopic composition of Cr was obtained from 102 and 123 individual measurements of 300 ratios each for NWA 011-A and NWA 011-B, respectively.

The Mn and Cr concentrations were measured by significantly improved ICP-OES procedures. We refined our Mn/Cr ratios for NWA 011-A and have measured the Mn and Cr concentrations in NWA 011-B. We have found that the Mn/Cr ratios in the two studied bulk samples are significantly different: 1.98±0.04 ($^{55}Mn/^{52}Cr$ = 2.24±0.05) in NWA 011-A and 1.79±0.03 ($^{55}Mn/^{52}Cr$ = 2.02±0.03) in NWA 011-B. On the other hand, the isotopic composition of Cr in both studied bulk samples is identical. The ^{53}Cr and ^{54}Cr excesses in NWA 011-A are +0.80±0.07ε and +1.35±0.11ε, respectively, and +0.80±0.08ε and +1.38±0.14ε in NWA 011-B, relative to the terrestrial standard (±2σ_{mean}).

Discussion: The observed difference in the Mn/Cr ratios for two relatively large bulk samples of NWA 011 is most likely due to mineralogical heterogeneity of this meteorite. Although this difference is only ~10% it would be large enough to resolve a difference in the $^{53}Cr/^{52}Cr$ ratios if the isotopic equilibration age was very old. Instead, the ^{53}Cr excesses in both bulk samples are the same and yield a horizontal line in an isochron plot. This suggests that isotopic equilibration of this meteorite occurred when ^{53}Mn was very low ($^{53}Mn/^{55}Mn < 1\times10^{-6}$) or had completely decayed.

As was previously discussed [5], the NWA 011 data are inconsistent with its origin from the HED parent body. In addition, if the observed $^{53}Cr/^{52}Cr$ heterogeneity among solar system bodies [4], forming a gradient with decreasing $^{53}Cr/^{52}Cr$ ratios towards the sun, continues inside earth's orbit, then any meteorite derived from Mercury would be expected to show very low $^{53}Cr/^{52}Cr$ ratios. In contrast, +0.8ε is very high and ^{53}Cr excesses of this magnitude have so far only been observed in differentiated meteorites or meteorite components. Thus, based on all currently available Cr data, Mercury can also be excluded as a source of this meteorite.

One important property of NWA 011 is its ^{54}Cr excess. This excess of ~ 1.4ε, identical in both bulk samples, is intermediate between those found in the bulk CI carbonaceous chondrites Ivuna and Orgueil and the CM chondrite Murray [5]. Thus, this would strengthen our earlier suggestion that the NWA 011 parent body may be related to CI meteorites but a parent body of intermediate type between CI and CM cannot be excluded. However, the oxygen isotopic composition of NWA 011 has been measured to be close to that in CR chondrites [2]. We do not yet know the Cr isotopic composition of this meteorite class. But from petrographic and chemical considerations we would expect the Cr isotopic signature to fall closer to the CO or CV chondrites [see 6], rather than having high values similar to CI or CM. At any rate, to resolve this question, Cr isotopes in CR meteorites have to be measured and work has already been started.

NWA 011 clearly is the result of planetary differentiation [2]. With the available data, can we derive further information on its evolutionary history? The isotopic relationship of NWA 011 with carbonaceous chondrites was already discussed. Shukolyukov et al. [6] have presented evidence for a good correlation between ^{53}Cr and ^{54}Cr excesses in bulk samples of carbonaceous chondrites (Fig. 1).

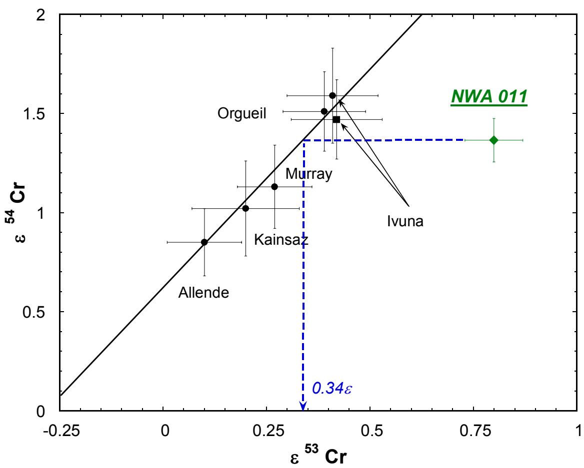

Fig. 1. ^{53}Cr–^{54}Cr excesses in bulk CC [6] and NWA 011. The dashed lines indicate an estimate of ε^{53}Cr for the NWA 011parent body.

The data point for NWA 011 is also plotted in Fig. 1 and falls far to the right of the CC correlation line at a much higher ^{53}Cr excess. Thus, it can be safely assumed that the source for this basaltic meteorite was fractionated to obtain its relatively high Mn/Cr ratio at a time when ^{53}Mn was still extant. Since ^{54}Cr/^{52}Cr does not change during differentiation we can project the ^{54}Cr excess measured in NWA 011 onto the ^{53}Cr – ^{54}Cr correlation line for bulk carbonaceous chondrites. In doing so, we can estimate the ^{53}Cr excess in the NWA 011 parent body (PB), which turns out to be ~ 0.34ε. This ^{53}Cr excess in the NWA 011 PB along with the parameters obtained from the bulk carbonaceous chondrite Mn-Cr evolution diagram of [6] allow us to calculate the ^{55}Mn/^{52}Cr ratio in the NWA 011 PB using the following equation:

$$(^{53}\mathrm{Cr}/^{52}\mathrm{Cr})^{\mathrm{NWA\text{-}PB}} = (^{53}\mathrm{Cr}/^{52}\mathrm{Cr})^{\mathrm{cc}}_{\mathrm{T0}} + (^{55}\mathrm{Mn}/^{52}\mathrm{Cr})^{\mathrm{NWA\text{-}PB}} \times (^{53}\mathrm{Mn}/^{55}\mathrm{Mn})^{\mathrm{cc}}_{\mathrm{T0}}$$

where $(^{53}\mathrm{Cr}/^{52}\mathrm{Cr})^{\mathrm{NWA\text{-}PB}}$ and $(^{55}\mathrm{Mn}/^{52}\mathrm{Cr})^{\mathrm{NWA\text{-}PB}}$ are the ^{53}Cr/^{52}Cr and ^{55}Mn/^{52}Cr ratios in NWA 011 PB, respectively; $(^{53}\mathrm{Cr}/^{52}\mathrm{Cr})^{\mathrm{cc}}_{\mathrm{T0}}$ is the initial value (-0.21ε) and $(^{53}\mathrm{Mn}/^{55}\mathrm{Mn})^{\mathrm{cc}}_{\mathrm{T0}}$ the relative ^{53}Mn abundance (8.5 × 10^{-6}) in carbonaceous chondrites at the time T_0, when the fractionation of carbonaceous chondrites (and NWA-PB) occurred. From this equation we obtain a ^{55}Mn/^{52}Cr ratio of 0.73 for the NWA 011 PB. If these are indeed the parameters for NWA 011 PB then, using the equation of ^{53}Mn decay, we can calculate the ^{53}Mn/^{55}Mn ratio in this hypothetical NWA 011 PB at the time T_1, when the NWA 011 magma source fractionated (Fig. 2). The ^{53}Mn/^{55}Mn ratio in the NWA 011 PB and in the NWA 011 magma source at the time of its fractionation is calculated to be ~ 3.5 × 10^{-6}. If we compare this ^{53}Mn/^{55}Mn ratio to that at the time inferred for carbonaceous chondrite fractionation [6] we can calculate the time difference between T_1 and T_0. This time interval is found to be approximately 4.7Ma. Using the angrite LEW86010 as an absolute time marker [4] we obtain a time of fractionation of the NWA 011 magma source of ~ 4563Ma (using $T_{1/2}$(^{53}Mn) = 3.7 Ma).

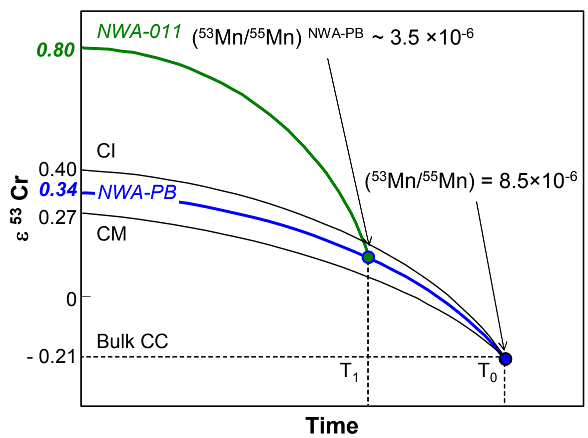

Fig. 2. The ^{53}Mn-^{53}Cr isotopic evolution of NWA 011. Data for carbonaceous chondrites from [6].

Conclusions: The Mn-Cr isotope data obtained for NWA 011 allow us to conclude that this meteorite does not relate to the HED parent body; it is also unlikely that it comes from Mercury. NWA 011 is a differentiation product from a parent body similar to CI or CM (or CR?) meteorites. The source reservoir of NWA 011 differentiated from its parent body at ~ 4563Ma, approximately 4.7Ma after fractionation of the NWA 011 parent body and the other carbonaceous chondrites.

References: [1] Afanasiev S.V. et al. (2000) *MAPS 35*, A19. [2] Yamaguchi A. et al. (2002) *Science, 296,* 334-336. [3] Palme H. (2002) *Science, 296,* 271-273. [4] Lugmair G.W. and Shukolyukov A. (1998) *GCA, 62,* 2863-2886. [5] Bogdanovski O. and Lugmair G.W. (2003) *MAPS 38*, A54. [6] Shukolyukov A. et al. (2003) *LPSC XXXIV,* Abstract #1279.